1980

VOLTAGE REGULATOR HANDBOOK

National Semiconductor

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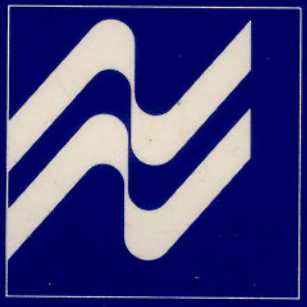
NATIONAL SEMICONDUCTOR



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# VOLTAGE REGULATOR HANDBOOK

NATIONAL SEMICONDUCTOR

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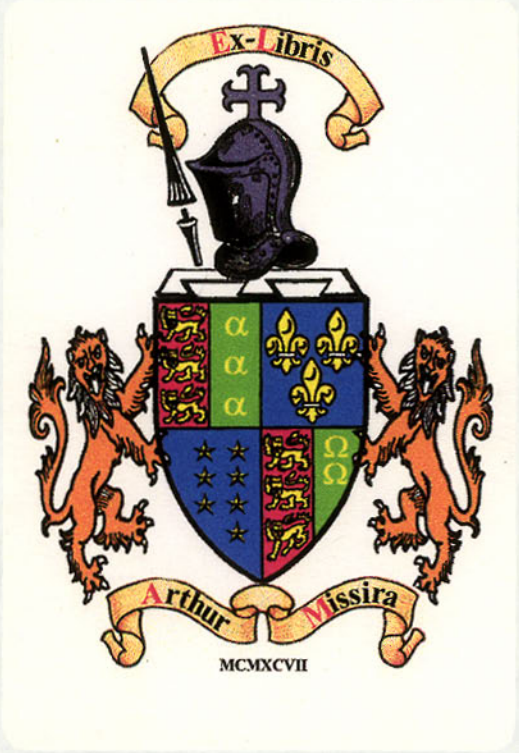


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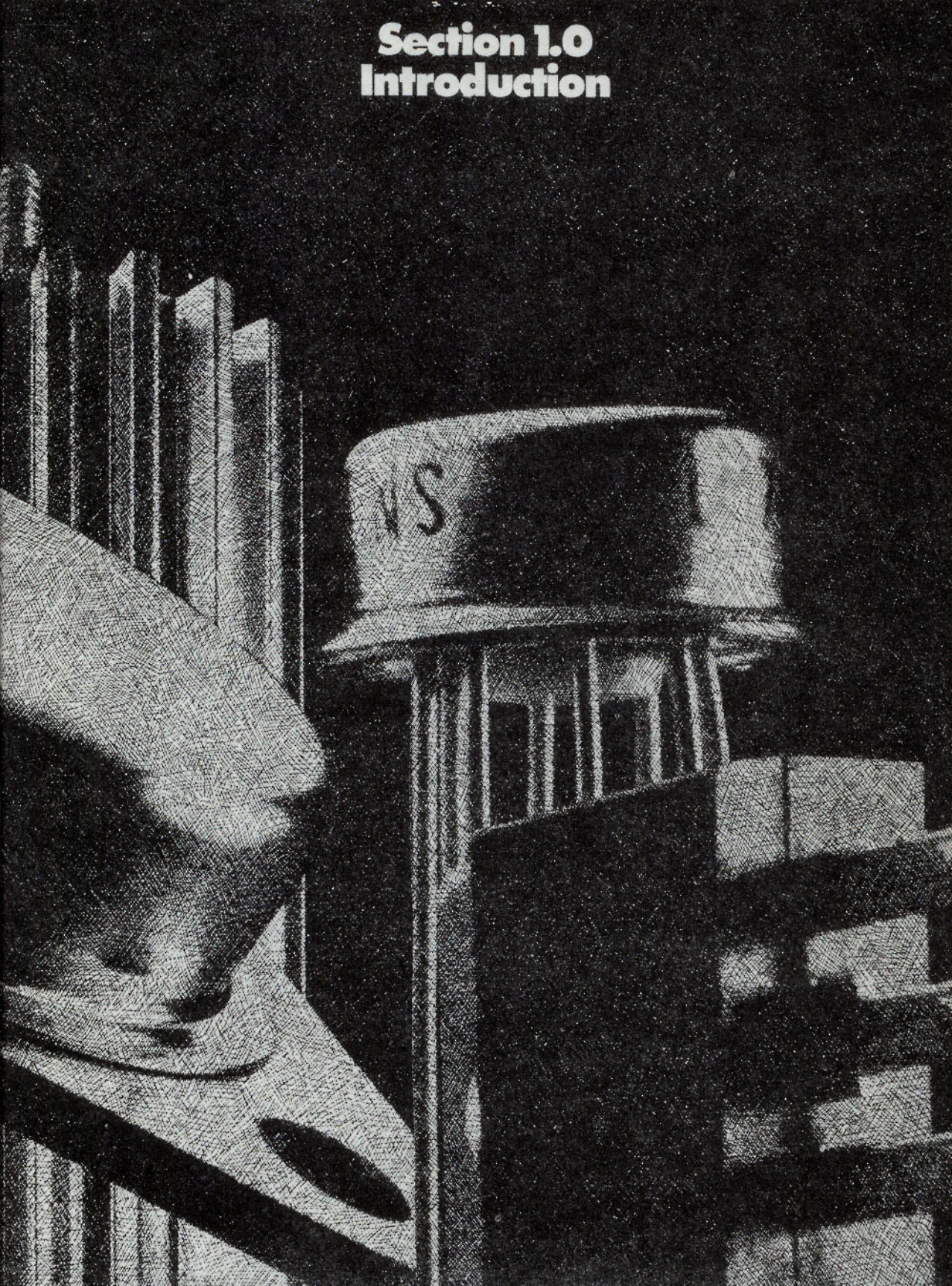
# Section 1.0
# Introduction



# 1.0 INTRODUCTION

## 1.1 HOW TO USE THIS BOOK

This manual has been created and arranged to simplify the task of selecting an appropriate three-terminal regulator according to your specific system needs. Information is also supplied on heat sink selection and design, power transformer and filter specification, and on various extended use applications for the basic three-terminal and dual tracking regulators.

**If a system supply already exists** and regulation is required at a current range or voltage listed in Figure 1.2, selection is relatively easy. Make initial selection from Figure 1.2 and the data sheet summary in Section 2, then go directly to the product selection procedures of Section 3.

**If a higher current is required**, refer also to Section 7, Applications, for current booster circuits.

**Where a heat sink is required** (possible with K, T & P suffix devices), refer to Sections 5 and 6 on heat sink selection and design.

**For small systems using only one regulator** or **if a system supply does not yet exist**, Section 8, Power Supply Design, provides the information necessary to specify transformer output voltage and current, diode characteristics, and filter capacitance.

**For applications other than simple three-terminal regulation** (listed in Section 1.3), refer to Section 7, Applications.

**For voltage regulation at other than the voltages listed** in Figure 1.2, refer to the applications section, or consider an adjustable regulator such as the LM105, LM723, LM117, etc. Refer to the data sheets on these parts and to the National Semiconductor Linear Applications Handbook. Section 1.4 compares the features and applications of three-terminal and adjustable regulators.

**Ordering information** is covered in Appendix 2.

**Test methods and circuits** are covered in Appendix 4.

**A cross-reference** listing the National Semiconductor part number most closely matching other manufacturers' part numbers is in Appendix 6.

## 1.2 FEATURES OF ON-CARD REGULATION

The trend in voltage regulation is toward localized regulation with smaller, low-cost, low-current, fixed-voltage IC regulators which require minimal or no heat sinking and few or no external components. In the past, one used bulky, high power regulators or regulators made up of many discrete components to regulate a line which supplied all areas of an electronic system. Unfortunately, the impedance of this line and associated connectors caused voltage drops which varied throughout the system. Also, any common impedance in the line between chasses or cards could allow unwanted coupling between critical parts of the system. These older systems often required considerable bypassing or decoupling which caused degraded local regulation. More recently, simple three-terminal regulators supplying one to three amps have been placed on individual cards within a system. These, however, are often larger in capacity and price than is necessary for one-per-card use. If used to supply several cards and fully loaded, some of the same old problems recur. The newest regulator designs emphasize low-current ranges and small, low-power, three-lead packages. These regulators are available in a variety of positive and negative voltages at current ranges of 100 mA to 5 A, some in packages as small as the TO-92 plastic small-signal transistor. There are also dual tracking ±100 mA regulators in TO-100 or plastic power DIP packages. With this variety to choose from, it is now possible to select the regulator for each application, and reduce cost significantly over competing approaches.

H
TO-39

H
TO-100

K,KC, K STEEL
TO-3

N
DIP

P
TO-202

T
TO-220

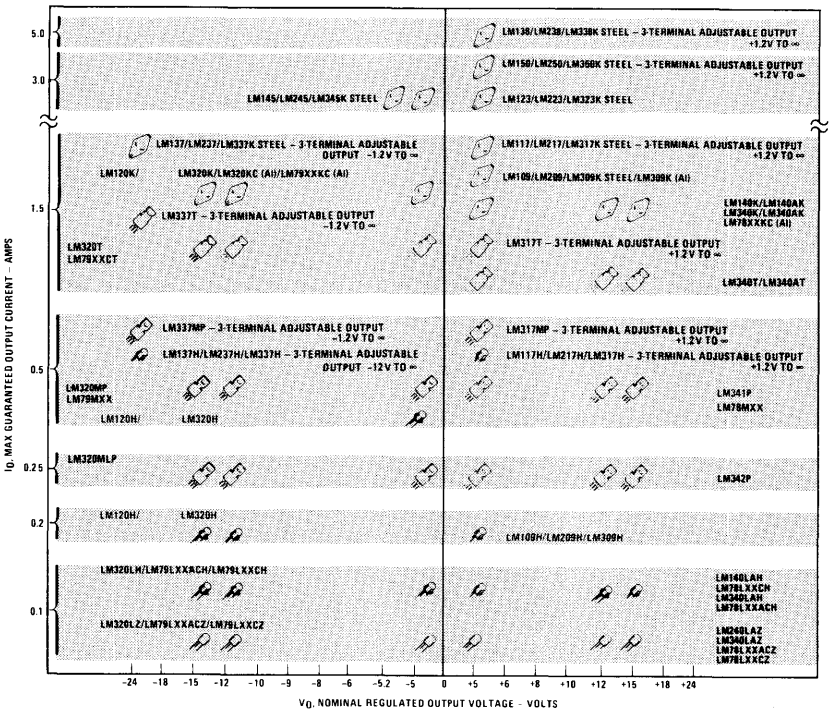
Z
TO-92

**FIGURE 1.2. Available Regulator Packages**

| ± 15 V | ± 12 V |
|---|---|
| LM125H | LM126H |
| LM225H | LM226H |
| LM325H | LM326H |

**FIGURE 1.2a. Dual Tracking Regulator Package Selection Guide**

# National's Voltage Regulator Guide




**Note:** All devices with TO-3 package designation (K and K STEEL) are supplied in steel TO-3 packages unless otherwise designated as (Al) aluminum TO-3 package. All devices with KC package designation are supplied in aluminum TO-3.

## THREE-TERMINAL VOLTAGE REGULATORS

| Output Current | | Positive Output Voltage | | Negative Output Voltage | |
|---|---|---|---|---|---|
| | | Fixed Output Voltage | Adjustable[2] Output Voltage | Fixed Output Voltage | Adjustable[2] Output Voltage |
| 5 Amp | Device<br>Output Voltage<br>Package | | LM338<br>+1.2V to +33V<br>TO-3 | | |
| 3 Amp | Device<br>Output Voltage<br>Package | LM323<br>+5.0V<br>TO-3 | LM350<br>+1.2V to +33V<br>TO-3 | LM345<br>–5.0V, –5.2V<br>TO-3 | |
| 1.5 Amp | Device<br>Output Voltage<br><br>Package | LM340-XX, LM78XX<br>+5V, +12V, +15V<br><br>TO-3, TO-220 | LM317<br>+1.2V to +37V<br>High Voltage (HV)<br>+1.2V to +57V<br>TO-3, TO-220 | LM320-XX, LM79XX<br>–5.0V, –12V, –15V<br><br>TO-3, TO-220 | LM337<br>–1.2V to –37V<br>High Voltage (HV)<br>–1.2V to –47V<br>TO-3, TO-220 |
| 0.5 Amp | Device<br>Output Voltage<br><br>Package | LM341-XX, LM78MXX<br>+5V, +12V, +15V<br><br>TO-202 | LM317M<br>+1.2V to +37V<br><br>TO-202, TO-39 | LM320M, LM79MXX<br>–5.0V, –12V, –15V<br><br>TO-202, TO-39[1] | LM337M<br>–1.2V to –37V<br><br>TO-202, TO-39 |
| 0.25 Amp | Device<br>Output Voltage<br><br>Package | LM342-XX<br>+5V, +12V, +15V<br><br>TO-202 | | LM320ML<br>–5.0V, –12V, –15V<br><br>TO-202 | |
| 0.10 Amp | Device<br>Output Voltage<br><br>Package | LM340LA-XX, LM78L-XX<br>+5V, +12V, +15V<br><br>TO-39, TO-92 | | LM320L-XX, LM79L-XX<br>–5V, –12V, –15V<br><br>TO-92, TO-39 | |

**Note 1:** *Some voltage options are rated only to 200 mA.*
**Note 2:** Adjustable voltage regulators can regulate voltages to infinity.

## 1.3 FIXED VOLTAGE THREE-TERMINAL REGULATOR DESCRIPTION

A graphic comparison of the available regulators and packages is made in Figure 1.2. All include short-circuit protection, automatic thermal shutdown, on-chip pass transistors, and internal references. The LM125-126 series are dual tracking regulators with provision for external boost while using the internal circuitry for current limiting in the boosted mode (Figure 1.1b). The LM125-126 series are essentially a pair of three-terminal regulators, one positive and one negative, while the others are single three-terminal positive or negative regulators.

With the exceptions to be noted, all listed regulators operate simply without the need for external components. Normal connections are as indicated in Figure 1.1. If the regulator is located more than two inches from the supply filter capacitor, a supply bypass capacitor is required to maintain stability (much as is the case with op-amps). This should be an 0.22 $\mu$F ceramic disc, 2 $\mu$F or larger solid tantalum, or 25 $\mu$F or larger aluminum electrolytic capacitor (the LM120 and LM123 series require the solid tantalum or aluminum electrolytics). The LM120 series alone of all the group requires an output capacitor to insure stable operation. This should be a 1 $\mu$F solid tantalum or 25 $\mu$F or larger aluminum electrolytic capacitor. With this exception, no output capacitor is required for stability; however, transient response and noise rejection can be improved by adding an output capacitor. An 0.1 $\mu$F output capacitor is recommended for the LM78LXX and LM340L series to minimize high-frequency noise.

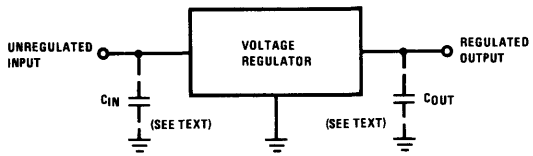



**FIGURE 1.1a. Normal Three-Terminal Regulator Connection**

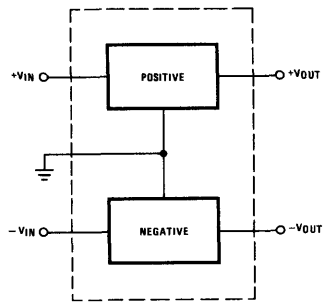



**FIGURE 1.1b. Basic Fixed Voltage Dual Tracking Regulator**

In addition to their normal fixed-voltage application, the three-terminal regulators may be used in the following circuits (discussed in Section 7):

- Current regulator
- Adjustable voltage regulator
- High current boosted regulator
- High current switching regulator
- Regulator with electronic shutdown
- High voltage regulator
- Combined + and - regulators for dual balanced supplies
- Tracking dual regulators

The LM125-126 series dual tracking regulators are unique in that they are the only available tracking regulators which incorporate thermal shutdown, require *no external components in normal operation*, and allow addition of external boost using few additional components. Special applications for the tracking regulators are discussed in Section 7, as follows:

- High current boosted operation
- Foldback current limiting
- Electronic shutdown
- Positive current dependent simultaneous current limiting

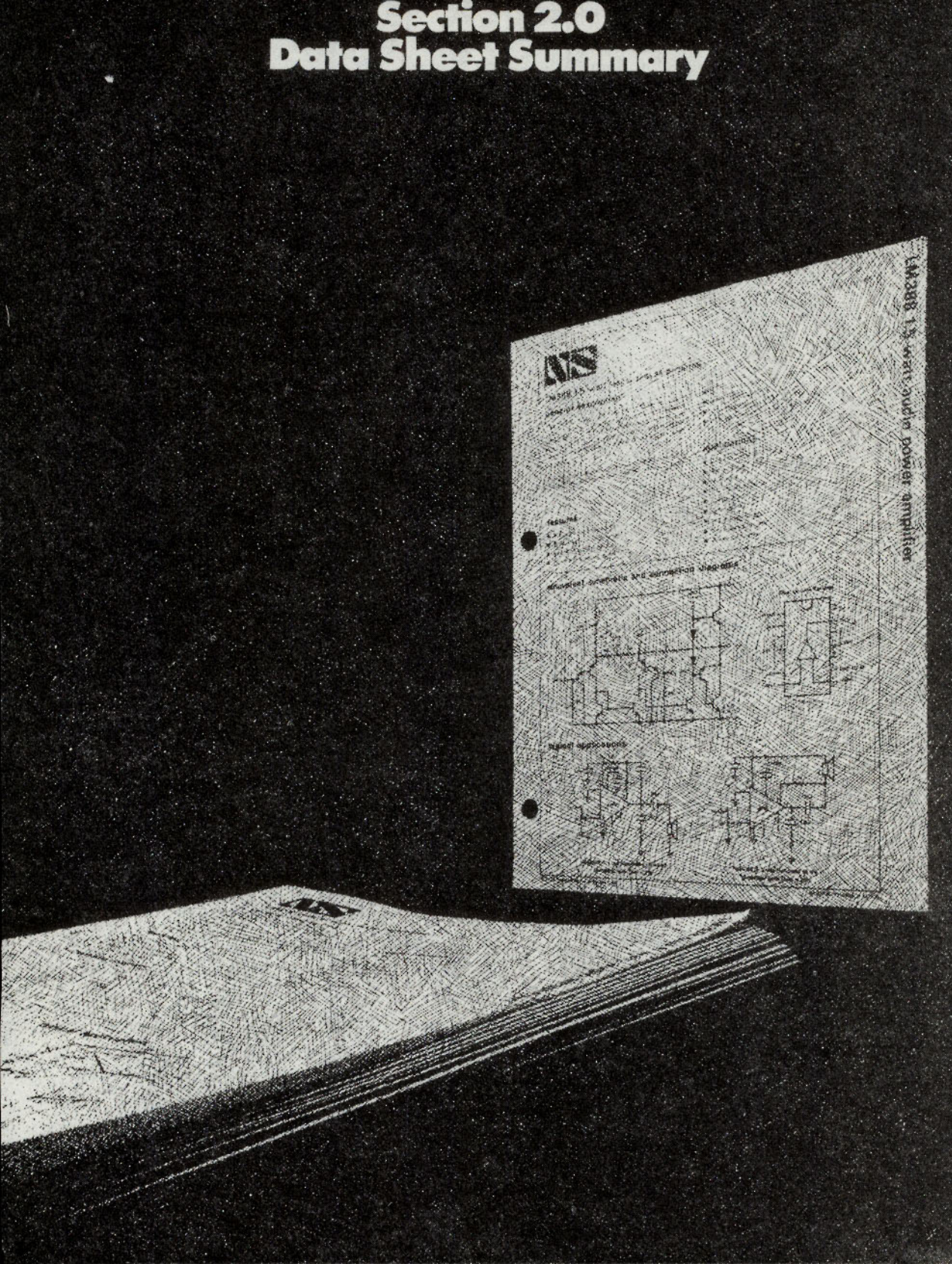
## 1.4 COMPARISON, FIXED VOLTAGE THREE-TERMINAL vs VARIABLE VOLTAGE REGULATORS BY APPLICATION

A simple comparison between three-terminal regulators and variable regulators (e.g., LM105, LM723, etc.) appears in Table 1.1. The variable regulators are most useful for providing non-standard voltages, switching regulators, or in programmable-voltage high current supplies with foldback current-limiting.

**Table 1.1 Comparison of Fixed Voltage Three-Terminal Regulators and Variable Regulators by Use or Feature**

| USE/FEATURE | FIXED OUTPUT VOLTAGE | VARIABLE OUTPUT VOLTAGE |
|---|---|---|
| **Features:** | | |
| - Current limit | Internal | Practical with external circuit |
| - Thermal shutdown | Internal | Complex external circuit |
| - Voltage reference noise bypass | Not possible, but noise is comparable to unbypassed variable reg. | Single capacitor |
| - Electronic shutdown | Fairly complex external circuit | Simple external circuit |
| - Programmable output voltage | Practical with some performance loss | Simple and effective with two resistors |
| **Uses:** | | |
| - High output voltage | Fairly complex circuitry | Simple external circuit |
| - Current regulator | Practical | Practical |
| - Switching regulator | Self-oscillating mode. No short circuit protection on switching transistor | Self-oscillating or driven modes. Short circuit protection, but must be added for external pass transistor |
| - Current boost | Possible (easy with LM125-126) | Practical |
| - Foldback current limiting | Internal (not programmable) for all three-terminal regulators. Programmable for LM125-126 | Requires 2 resistors (pos. only), more complex for negative |

# Section 2.0
# Data Sheet Summary



# 2.0 DATA SHEET SUMMARY

Table 2.1 lists the various regulators and the most useful specifications for each. Note that accuracy specifications are over the full temperature range, including drift. Room temperature accuracy specifications are about 1% better than the figures given.

**TABLE 2.1 Data Sheet Summary**

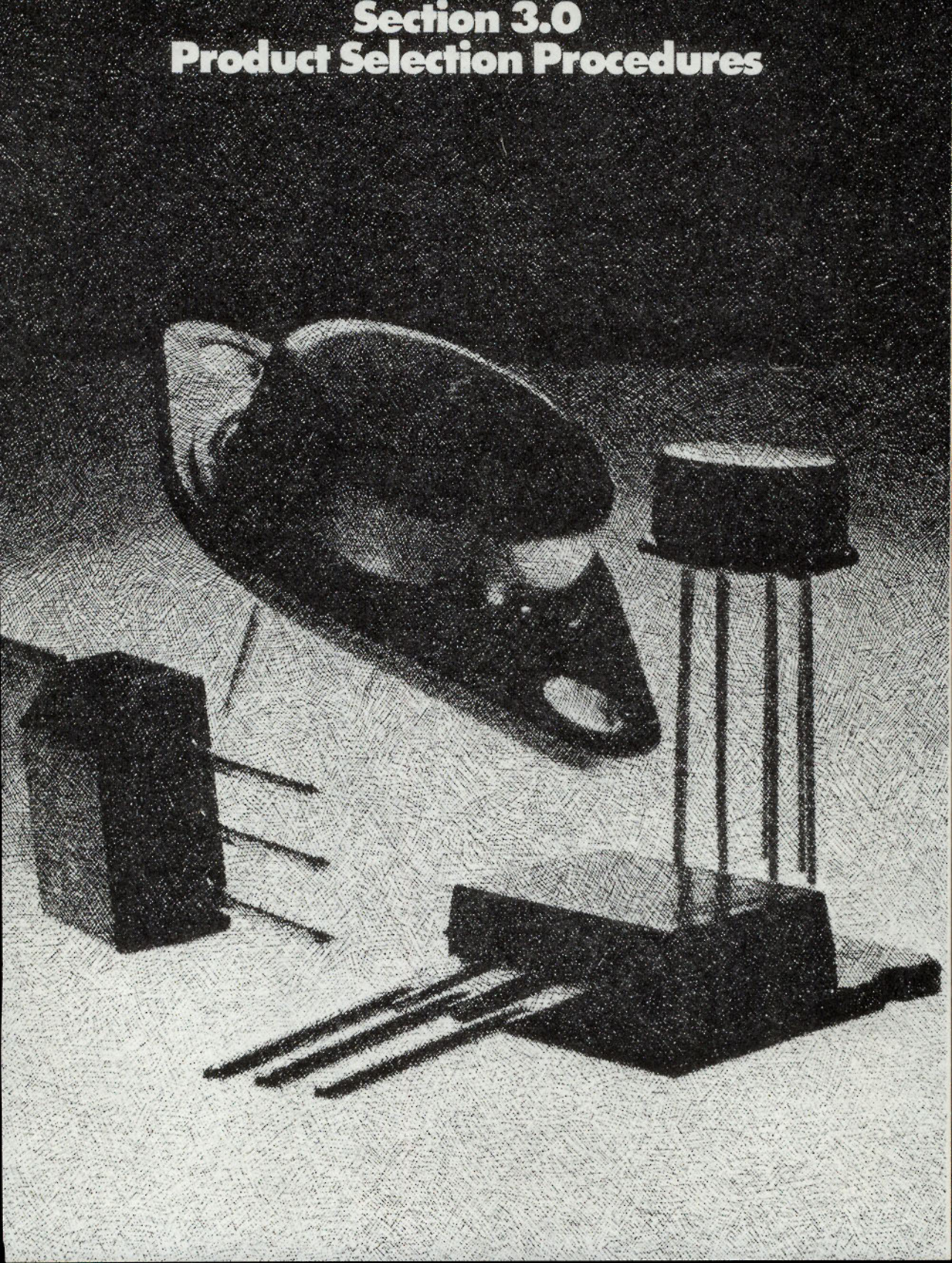
| Output Current | Device[1,2] | $V_{OUT}$ (V) | $T_A$ = 25°C (± %) | Max Regulation Line[3] (%$V_{OUT}$/V) | Load[4] | Max $V_{IN}$ (V) | Ripple (dB)[6] | Typ Dropout Voltage (V) | Device | Pkg Style | Typ $\theta_{JC}$ (°C/W) | Typ $\theta_{JA}$ (°C/W) | Max $P_D$ (W) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.0 | LM138, LM238 | 1.2-32 (adj) | N/A | 0.005 | 0.1 | 35 | 86 | 2 | LM138K STEEL | TO-3 | 2 | 35 | 30 |
| | LM338 | 1.2-32 (adj) | N/A | 0.005 | 0.1 | 35 | 86 | 2 | series | | | | |
| 3.0 | LM150, LM250 | 1.2-32 (adj) | N/A | 0.005 | 0.1 | 35 | 86 | 2 | LM150K STEEL | TO-3 | 2 | 35 | 30 |
| | LM350 | 1.2-32 (adj) | N/A | 0.005 | 0.1 | 35 | 86 | 2 | (series) | | | | |
| | LM123K, LM223K | 5 | 6 | 0.01 | 0.5 | 20 | 75 | 1.7-2 | LM123K series | TO-3 | 2 | 35 | 30 |
| | LM323K | 5 | 4 | 0.01 | 0.5 | 20 | 75 | 1.7-2 | | | | | |
| 1.5 | LM117, LM217 | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 2 | LM117, LM317K STEEL | TO-3 | 2.3 | 35 | 20 |
| | LM317 | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 2 | LM317K STEEL | TO-3 | 2.3 | 35 | 20 |
| | LM117HV, LM217HV | 1.2-57 (adj) | N/A | 0.01 | 0.1 | 60 | 80 | 2 | LM117HV, LM217HVK STEEL | TO-3 | 2.3 | 35 | 20 |
| | LM317HV | 1.2-57 (adj) | N/A | 0.01 | 0.1 | 60 | 80 | 2 | LM317HVK STEEL | TO-3 | 2.3 | 35 | 20 |
| | | | | | | | | | LM317T | TO-220 | 4 | 50 | 20 |
| | LM109K, LM209K | 5 | 6 | 0.004 | 1.0 | 35 | 80 | 1-2 | LM109K series | TO-3 | 3 | 35 | 20 |
| | LM309K | 5 | 4 | 0.004 | 1.0 | 35 | 80 | 1-2 | — | — | — | — | — |
| | LM140K | 5, 12, 15 | 4 | 0.02 | 0.5 | 35, 40 (24V) | 66-80 | 1.6-2 | LM140K | TO-3 | 4 | 35 | 20 |
| | LM140AK | 5, 12, 15 | 2 | 0.002 | 0.1 | 35, 40 (24V) | 66-80 | 1.6-2 | LM140AK | TO-3 | 4 | 35 | 20 |
| | LM340 | 5, 12, 15 | 4 | 0.02 | 0.5 | 35, 40 (24V) | 66-80 | 1.6-2 | LM340K, LM340AK | TO-3 | 4 | 35 | 20 |
| | LM340A | 5, 12, 15 | 2 | 0.002 | 0.1 | 35, 40 (24V) | 66-80 | 1.6-2 | LM340AK | TO-3 | 4 | 35 | 20 |
| | | | | | | | | | LM340AT | TO-220 | 4 | 50 | 20 |
| | LM78XXC | 5, 12, 15 | 4 | 0.03 | 0.5 | 35, 40 (24V) | 66-80 | 1.6-2 | LM340K, LM78XXKC | TO-3 | 4 | 35 | 20 |
| | | | | | | | | 1.6-2 | LM340CT, LM340T LM78XXCT | TO-220 | 4 | 50 | 18 |
| 0.5 | LM117H, LM217H | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 1.5 | LM117H, LM217H | TO-39 | 15 | 150 | 2 |
| | LM317H | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 2.0 | LM317H | TO-39 | 15 | 150 | 2 |
| | LM117HVH, LM217HVH | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 1.5 | LM117HVH, LM217HVH | TO-39 | 15 | 150 | 2 |
| | LM317HVH | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 1.5 | LM317HVH | TO-39 | 15 | 150 | 2 |
| | LM317M | 1.2-37 (adj) | N/A | 0.01 | 0.1 | 40 | 80 | 2.0 | LM317MP | TO-202 | 12 | 85 | 12 |
| | LM341 | 5, 12, 15 | 4 | 0.02 | 0.5 | 35, 40 (24V) | | 1.2-1.7 | LM341P | TO-202 | 12 | 80 | 12 |
| | LM78MXX | 5, 12, 15 | 4 | 0.03 | 0.5 | 35, 40 (24V) | | 1.2-1.7 | LM78MXXCP | TO-202 | 12 | 80 | 12 |
| 0.25 | LM342 | 5, 12, 15 | 4 | 0.03 | 0.5 | 35, 40 (24V) | 53-64 | 1.5-2 | LM342P | TO-202 | 12 | 80 | 10 |
| 0.20 | LM109H, LM209H | 5 | 6 | 0.004 | 0.4 | 35 | 80 | 1-2 | LM109H, LM209H | TO-39 | 15 | 150 | 2 |
| | LM309H | 5 | 4 | 0.004 | 0.4 | 35 | 80 | 1-2 | LM309H | TO-39 | 15 | 150 | 2 |
| 0.10 | LM140L | 5, 12, 15 | 2 | 0.02 | 0.25 | 35, 40 (24V) | 48-62 | 1.5-2 | LM140LAH | TO-39 | 40 | 140 | 3 |
| | LM340L | 5, 12, 15 | 2 | 0.02 | 0.25 | 35, 40 (24V) | 48-62 | 1.5-2 | LM340LAH | TO-39 | 40 | 140 | 3 |
| | LM78LXXA | 5, 12, 15 | 4 | 0.03 | 0.25 | 35, 40 (24V) | 45-60 | 1.5-2 | LM78LXXACH | TO-39 | 40 | 140 | 3 |
| | | | | | | | | | LM78LXXACZ | TO-92 | 40 | 180 | 1 |

1. Operating temp range:
   LM100 series −55°C to +125°C
   LM200 series −25°C to +85°C
   LM300 series 0°C to +70°C
2. Max $T_J$ = 150°C except 125°C for LM309, 320, 323, 345
3. Typ at 50-100% of rated $I_{OUT}$, 25°C, max $V_{IN}$ change
4. Near zero to max rated $I_{OUT}$, 25°C pulse test
5. Max mV per volt of out voltage rating
6. Subtract (20 log $V_{OUT}$) for ripple rejection factor
7. ±4% available for LM140A and LM340A
8. ±10% available as LM78L CH and LM78L CZ
9. DIP = 14-pin dual-in-line plastic pkg
   SGS = special DIP with heat sink
10. $V_{IN}$ = 40V for LM120H15 & LM120K15 series

**TABLE 2.1 Data Sheet Summary (Continued)**

| Output Current | Device[1,2] | $V_{OUT}$ (V) | $T_A$ = 25°C (± %) | Max Regulation Line[3] (%$V_{OUT}$/V) | Max Regulation Load[4] (%$V_{OUT}$/V) | Max $V_{IN}$ (V) | Ripple (dB)[5] | Typ Dropout Voltage (V) | Device | Pkg Style | Typ $\theta_{JC}$ (°C/W) | Typ $\theta_{JA}$ (°C/W) | Max $P_D$ (W) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | LM145K, LM245K | −5.0, −5.2 | 2 | 0.008 | 0.6 | 20 | 68 | 2 | LM145K, LM245K | TO-3 | 2 | 35 | 25 |
| | LM345K | −5.0, −5.2 | 4 | 0.008 | 0.6 | 20 | 68 | 2 | LM345K | TO-3 | 2 | 35 | 25 |
| 1.5 | LM137, LM237 | −1.2− −37 (adj) | N/A | 0.006 | 0.3 | 40 | 77 | 2 | LM137, LM237K STEEL | TO-3 | 2 | 35 | 20 |
| | LM337 | −1.2− −37 (adj) | N/A | 0.007 | 0.3 | 40 | 77 | 2 | LM337K STEEL<br>LM337T | TO-3<br>TO-220 | 2<br>3 | 35<br>50 | 20 |
| | LM137HV, LM237HV | −1.2− −47 (adj) | N/A | 0.006 | 0.3 | 50 | 77 | 2 | LM137HV, LM137HVK STEEL | TO-3 | 2 | 35 | 20 |
| | LM337HV | −1.2− −47 (adj) | N/A | 0.007 | 0.3 | 50 | 77 | 2 | LM337HVK STEEL | TO-3 | 2 | 35 | 20 |
| | LM120K | -5, -12, -15 | 2 | 0.02 | 0.3 | 25<br>35 (9V, 12V)<br>40 (15V, 18V)<br>42 (24V) | 64<br>80<br>75<br>70 | 2<br>2<br>2<br>2 | LM120K series | TO-3 | 3 | 35 | 20 |
| | LM320K | -5, -12, -15 | 4 | 0.02 | 0.3 | 25<br>35 (9V, 12V)<br>40 (15V, 18V)<br>42 (24V) | 64<br>80<br>75<br>70 | 2 | LM120K series | TO-3 | 3 | 35 | 20 |
| | LM320T | -5, -12, -15 | 4 | 0.02 | 0.3 | 25<br>35 (9V, 12V, 15V, 18V)<br>40 (24V) | 64<br>75-80<br>70 | 2<br>4<br>4 | LM320T | TO-220 | 3 | 50 | 20 |
| | LM79XXC | -5, -12, -15 | 4 | 0.03 | 0.4 | 35, 40 (24V) | 66-70 | 2-4 | LM79XXCT | TO-220 | 3 | 50 | 20 |
| 0.5 | LM137H, LM237H | −1.2− −37 (adj) | N/A | 0.006 | 0.3 | 40 | 77 | 2 | LM137H, LM237H | TO-39 | 15 | 150 | 2 |
| | LM337H | −1.2− −37 (adj) | N/A | 0.007 | 0.3 | 40 | 77 | 2 | LM337H | TO-39 | 15 | 150 | 2 |
| | LM137HVH, LM237HVH | −1.2− −47 (adj) | N/A | 0.006 | 0.3 | 50 | 77 | 2 | LM137HVH, LM237HVH | TO-39 | 15 | 150 | 2 |
| | LM337HVH | −1.2− −47 (adj) | N/A | 0.007 | 0.3 | 50 | 77 | 2 | LM337HVH | TO-39 | 15 | 150 | 2 |
| | LM337M | −1.2− −37 (adj) | N/A | 0.007 | 0.3 | 40 | 77 | | | | | | |
| | LM120H | -5, -12, -15 | 2 | 0.02 | 0.6 | 25 | 64 | 2 | LM120H | TO-39 | 15 | 150 | 2 |
| | LM320H | -5, -12, -15 | 4 | 0.02 | 0.6 | 25 | 64 | 2 | LM320H | TO-39 | 15 | 150 | 2 |
| | LM320M | -5, -12, -15 | 4<br>4 | 0.02 | 0.6 | 25<br>35 (9V, 12V, 15V, 18V)<br>40 (24V) | 60-64<br>70-80 | 2<br>2 | LM320MP | TO-202 | 12 | 80 | 12 |
| | LM79MXX | -5, -12, -15 | 4 | 0.03 | 0.7 | 35, 40 (24V) | 58-60 | 2 | LM79MXXCP | TO-202 | 12 | 80 | 12 |
| 0.25 | LM320ML | -5, -12, -15 | 4 | 0.01 | 0.5 | 35, 40 (24V) | 50-60 | 2 | LM320MLP | TO-202 | 12 | 80 | 12 |
| 0.20 | LM120H | −9, −12, | 2 | 0.02 | 0.1 | 35 (9V, 12V) | 70-80 | 2 | LM120H | TO-39 | 15 | 150 | 2 |
| | LM320H | −15 | 4 | 0.02 | 0.1 | 40 (15V, 18V)<br>42 (24V) | | 2 | LM320H | TO-39 | 15 | 150 | 2 |
| 0.10 | LM320L | -5, -12, -15 | 4 | 0.01 | 0.5 | 35, 40 (24V) | 60-65 | 2 | LM320LZ | TO-92 | 40 | 180 | 1 |
| | LM79LXXA | -5, -12, -15 | 4 | 0.02 | 0.6 | 35, 40 (24V) | 50-55 | | LM79LXXACZ<br>LM79LXXACH | TO-92<br>TO-39 | 40<br>40 | 180<br>140 | 1<br>2 |

# Section 3.0
# Product Selection Procedures



# 3.0 PRODUCT SELECTION PROCEDURES: FIXED VOLTAGE THREE-TERMINAL REGULATORS

### 3.1 DETERMINE:

a) $V_{OUT}$, required output voltage

b) $I_{OUT}$, maximum output current

c) $V_{IN}$, mean unregulated input voltage

d) $T_A$, ambient temperature

### 3.2 SPECIFY:

$T_J$, maximum operating junction temperature. For highest reliability, $T_J$ should be 25°C or more below $T_{J(MAX)}$ as specified on the data sheet.

### 3.3 SELECT A REGULATOR

a) Make preliminary selection based on step 1a and 1b above, from Figure 1.2, or the data sheet summary of Section 2.

b) Verify this selection with Figure 3.1 or 3.2 to insure that the selected regulator will provide a peak current greater than $I_{OUT}$ under the $V_{IN}$ - $V_{OUT}$ operating conditions (peak current is limited by internal circuitry).

c) Note also in Figure 3.1 or 3.2, the power dissipation curves, but choose packages from Figure 2.1 with $P_D$ greater than dissipated power.

d) Determine heat sink requirements from Section 5.

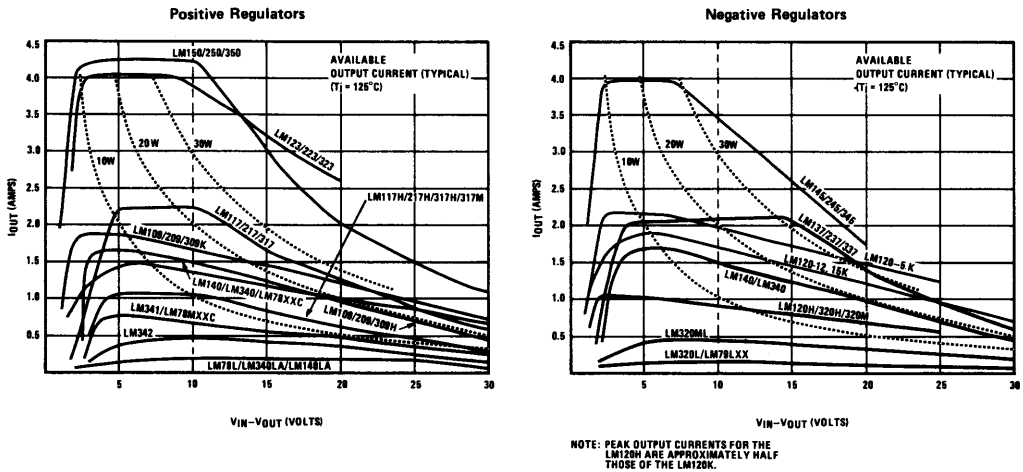
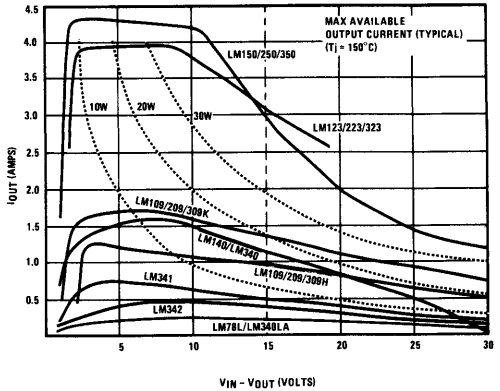


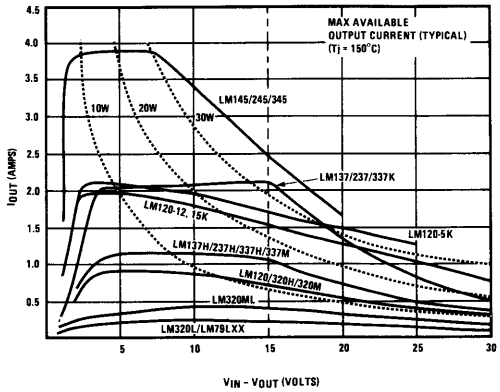

**FIGURE 3.1. Max Available Output Current at $T_j$ = 125°C**

**Positive Regulators**




NOTE: PEAK OUTPUT CURRENTS FOR THE LM120H ARE APPROXIMATELY HALF THOSE OF THE LM120K.

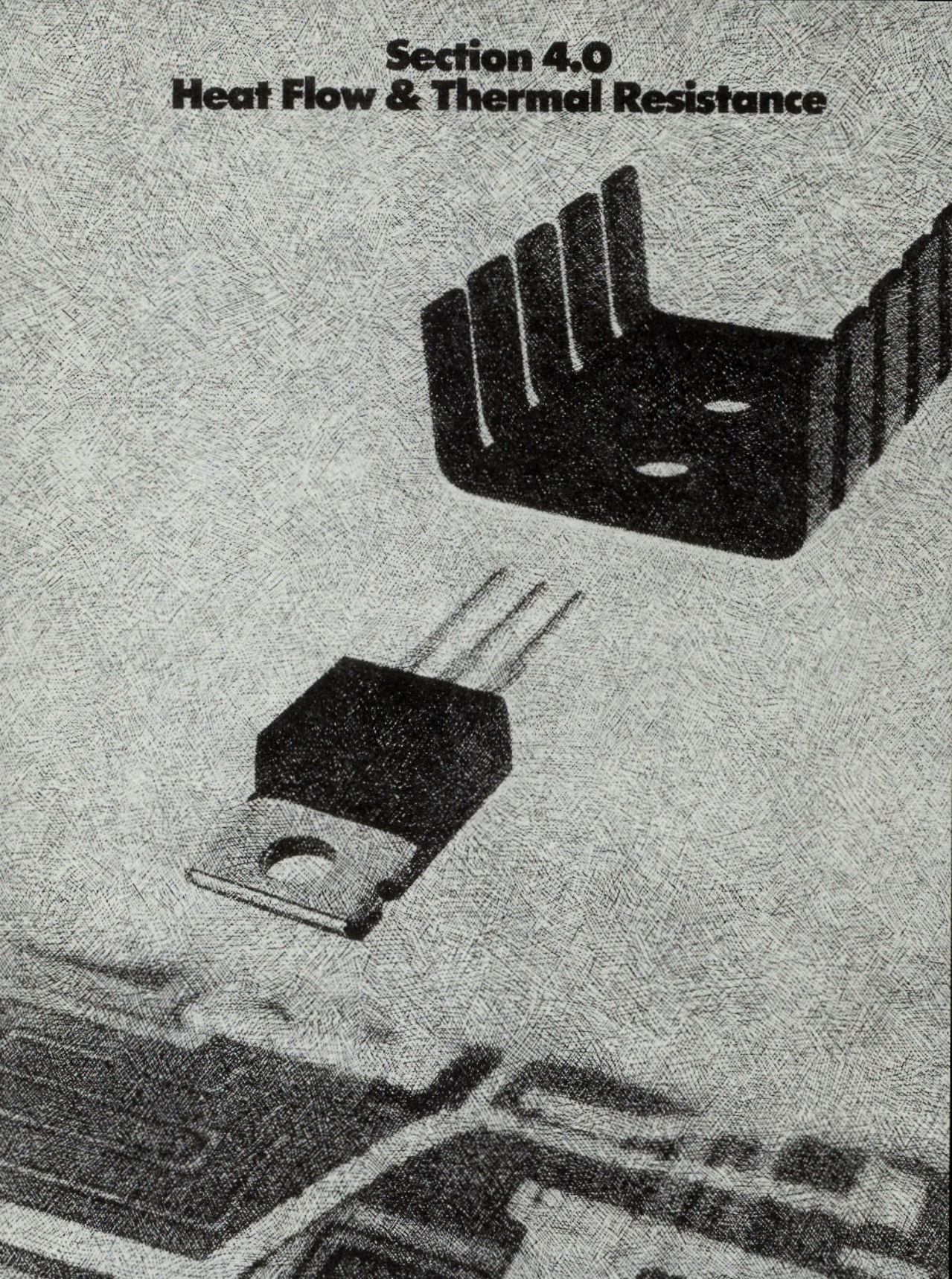
**Negative Regulators**




NOTE: PEAK OUTPUT CURRENTS FOR THE LM120H ARE APPROXIMATELY HALF THOSE OF THE LM120K.

**FIGURE 3.2. Max Available Output Current at $T_j = 150°C$**

# Section 4.0
# Heat Flow & Thermal Resistance



# 4.0 HEAT FLOW & THERMAL RESISTANCE

## 4.1 HEAT FLOW

Heat can be transferred from the regulator package by three methods, as described and characterized in Table 4.1.

**TABLE 4.1. Methods of Heat Flow**

| METHOD | DESCRIBING PARAMETERS |
|---|---|
| **Conduction** is the heat transfer method most effective in moving heat from junction to case and case to heat sink. | Thermal resistance $\theta_{JC}$ & $\theta_{CS}$. Cross section, length and temperature difference across the conducting medium. |
| **Convection** is the effective method of heat transfer from case to ambient and heat sink to ambient. | Thermal resistance $\theta_{SA}$ and $\theta_{CA}$. Surface condition, type of convecting fluid, velocity and character of the fluid flow (e.g., turbulent or laminar), and temperature difference between surface and fluid. |
| **Radiation** is important in transferring heat from cooling fins. | Surface emissivity and area. Temperature difference between radiating and adjacent objects or space. See Table 4.2 for values of emissivity. |

## 4.2 THERMAL RESISTANCE

The thermal resistance between two points of a conductive system is expressed as

$$\theta_{12} = \frac{T_1 - T_2}{P_D} °C/W \qquad (4.1)$$

where subscript order indicates the direction of heat flow. A simplified heat transfer circuit for a cased semiconductor and heat sink system is shown in Figure 4.1. The circuit is valid only if the system is in thermal equilibrium (constant heat flow) and there are, indeed, single specific temperatures $T_J$, $T_C$, and $T_X$ (no temperature distribution in junction, case, or heat sink). Nevertheless, this is a reasonable approximation of actual performance.

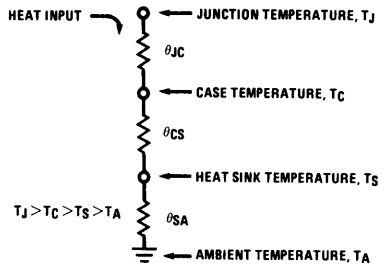



**FIGURE 4.1. Semiconductor-Heat Sink Thermal Circuit**

The junction-to-case thermal resistance $\theta_{JC}$ specified in the regulator data sheets depends upon the material and size of the package, die size and thickness, and quality of the die bond to the case or lead frame. The case-to-heat sink thermal resistance $\theta_{CS}$ depends on the mounting of the regulator to the heat sink and upon the area and quality of the contact surface. Typical $\theta_{CS}$ for several packages and mounting conditions are as shown in Table 4.2.

The heat sink to ambient thermal resistance $\theta_{SA}$ depends on the quality of the heat sink and the ambient conditions. A listing of approximate $\theta_{SA}$ for a number of commercially available heat sinks appears in Section 5. $\theta_{SA}$ includes effects of both convection and radiation.

## 4.3 BASIC THERMAL CALCULATIONS

Cooling is normally required to maintain the worst case operating junction temperature $T_J$ of the regulator below the specified maximum value $T_{J(MAX)}$. $T_J$ can be calculated from known operating conditions. Rewriting Eqn 4.1, we find

$$\theta_{JA} = \frac{T_J - T_A}{P_D} °C/W \qquad (4.2)$$

$$T_J = T_A + P_D\theta_{JA} °C \qquad (4.3)$$

Where: $P_D = (V_{IN} - V_{OUT})I_{OUT} + V_{IN}I_Q$

$$\approx (V_{IN} - V_{OUT})I_{OUT}$$

except for TO-92 package where $V_{IN}I_Q$ must be considered important.

$I_Q$ = Regulator quiescent current

$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$.

Data sheets usually provide a plot of Eqn 4.3 for several heat sinks. An example for the LM340T with $T_J = T_{J(MAX)} = 150°C$ appears in Figure 4.2. Note that for the lower curve $\theta_{JA} = \theta_{CS} + \theta_{SA}$ while the upper curve is for $\theta_{JA} = \theta_{JC}$. Where the upper curve slope is zero, the limit is the arbitrary power dissipation rating instead of Eqn 4.1.

Table 4.2 Approximate Thermal Resistance, Case to Heat Sink $\theta_{CS}$ in °C/W

| Package | Direct contact | Contact with silicone grease | Contact with grease and mica washer |
|---|---|---|---|
| TO-3 | 0.5 - 0.7 | 0.3 - 0.5 | 0.4 - 0.6 |
| TO-202 | 1.5 - 2.0 | 0.9 - 1.2 | 1.2 - 1.7 |
| TO-220 | 1.0 - 1.3 | 0.6 - 0.8 | 0.8 - 1.1 |

Normally, we impose a full load operating junction temperature $T_J$ at 25°C (or more) below specified $T_{J(MAX)}$ at maximum expected $T_A$, and we need to find the required $\theta_{JA}$ from Eqn 4.2.

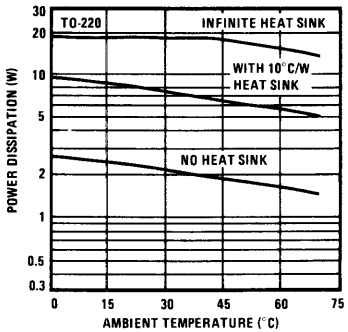



**FIGURE 4.2. Power De-Rating Curves for LM340T**

# Section 5.0
# Selection of Commercial Heat Sink

# 5.0 STANDARD HEAT SINK SELECTION PROCEDURES

## 5.1 COMPUTE TOTAL THERMAL RESISTANCE

Determine the total thermal resistance, junction to ambient $\theta_{JA(TOT)}$ necessary to maintain steady state $T_J$ below the maximum value specified in Section 3.2.

$$\theta_{JA(TOT)} = \frac{T_J - T_A}{P_D} \,^\circ C/W \qquad (5.1)$$

Under short circuit conditions, the internal thermal shutdown will limit $T_J$ to about 175 ± 15°C. Although this protects the device, prolonged operation at such temperatures can adversely effect device reliability (see Appendix 5, Reliability). If short circuit operation totaling more than 10-100 hours (For plastic package limit short circuit time to less than 1 hour) over system lifetime is expected, it is wise to use heat sinks which will limit short circuit $T_J$ to $T_{J(MAX)}$. Accordingly, check operation with $V_{OUT} = 0$. The $\theta'_{JA(TOT)}$ necessary to maintain $T_J < T_{J(MAX)}$ under short circuit conditions is

$$\theta'_{JA(TOT)} = \frac{T_{J(MAX)} - T_A}{V_{IN} I_{SC}} \,^\circ C/W \qquad (5.2)$$

where $I_{SC}$ is read from Figure 3.2. .

## 5.2 DETERMINE IF HEAT SINK IS REQUIRED

Refer to the thermal resistance, $\theta_{JC}$ and $\theta_{JA}$, columns of the data sheet summary of Section 2.

a) $\theta_{JA(TOT)} > \theta_{JC}$ must be met, otherwise a higher wattage device must be used or a boost circuit employed. (See Section 7, Applications, for boost circuits.)

b) If $\theta_{JA(TOT)} > \theta_{JA}$, a heat sink is not required.

c) If $\theta_{JC} < \theta_{JA(TOT)} < \theta_{JA}$, a heat sink is required.

## 5.3 SELECT A HEAT SINK

Choose a suitable heat sink from the selection guide, Table 5.1, or from manufacturers' specification data. The necessary conditions are that $\theta_{JA(TOT)}$ and $\theta'_{JA(TOT)}$ be less than $\theta_{JA}$, as read from Table 2.1. The total thermal resistance is that from junction to case plus that from case to ambient or sink to ambient (neglecting that from case to sink, which is small).

$$\theta_{JA(TOT)} \approx \theta_{JC} + \theta_{SA} \,^\circ C \qquad (5.3)$$

## 5.4 CHECK INPUT RIPPLE AND INPUT VARIATIONS

Insure that full-load $V_{IN(MIN)}$ does not allow $V_{IN} - V_{OUT}$ to fall below the dropout voltage of about 2 V. See individual data sheets if operation with $V_{IN} - V_{OUT} <$ 2 V is required. Insure that no-load $V_{IN(MAX)}$ does not exceed the value listed on the data sheets or in the table of Section 2.

## 5.5 EXAMPLE CALCULATION

Given: $V_{OUT} = 5\ V \pm 5\%$ $V_{IN} = 15\ V$

$I_{OUT(MAX)} = 0.7\ A$ Short circuit protected

$T_A = 60°C$ $T_J = 125°C$

Select a suitable regulator and heat sink

a) From Figure 1.2, initial selection is LM340T-5.0, LM340K-5.0, or LM309K.

b) From Figure 3.1, at $V_{IN} - V_{OUT} = 10$ V, it is clear that either the LM340 or LM309 will meet the maximum current required. The LM341P is also a possibility as seen from this figure, although a marginal one on the basis of $I_{OUT(MAX)}$, and should not be considered.

c) Calculate necessary thermal resistance from Eqn 5.1

$$\theta_{JA(TOT)} = \frac{125 - 60}{10 \times 0.7} = \frac{65}{7} = 9.3^\circ C/W$$

Since $\theta_{JA(TOT)}$ must be greater than $\theta_{JC}$ as read from Table 2.1, the LM341P is now clearly eliminated as a possibility. If not already eliminated in step (a) above, the LM309H would also drop out at this time. The selection is still limited to the LM340T, LM340K, or LM309K.

d) Since $\theta_{JA(TOT)}$ is less than $\theta_{JA}$ for any of these parts, a heat sink is required.

e) From Figure 3.2, $I_{OUT(MAX)}$ is 0.75 A or 1.4 A for the LM340 or LM309K respectively, under short circuit conditions. If extended periods of short circuit operation are expected, calculate $\theta'_{JA(TOT)}$ from Eqn 5.2.

$$\theta'_{JA(TOT)} = \frac{150 - 60}{15 \times 1.4} = \frac{90}{21} = 4.3^\circ C/W \text{ for LM309}$$

$$\theta'_{JA(TOT)} = \frac{150 - 60}{15 \times 0.75} = \frac{90}{11.25} = 8^\circ C/W \text{ for LM340}$$

The worst case heat sink requirement is then for short circuit conditions, and the LM340 has a lesser heat sink requirement. Further selection will depend upon hermeticity and mounting requirements. The T package is TO-220 plastic and the K package is TO-3 hermetic.

f) Choosing the LM340T, calculate heat sink thermal resistance from Eqn 5.4 where $\theta_{JC}$ is found from Table 2.1.

$$\theta_{SA} = \theta'_{JA(TOT)} - \theta_{JC} = 8 - 4 = 4^\circ C/W \qquad (5.4)$$

If we were to accept a $T_J > 150°C$ for short circuit conditions, calculations based on $\theta_{JA(TOT)}$ would yield a $\theta_{SA} = 5.3°C/W$. If an LM309K had been selected, a $\theta_{SA} = 6.3°C/W$ would be all that is required.

g) Referring to the heat sink selection guide, Table 5.1, for the TO-220 package we see that only the IERC HP3 series will come close to the 4°C/W figure. A 4°C/W heat sink is widely available for the TO-3 or K package.

h) For detailed information on heat sink design, see Section 6.

**TABLE 5.1 Heat Sink Selection Guide**

No attempt has been made to provide a complete list of all heat sink manufacturers. This list is only representative.

| $\theta_{SA}$ Approx[1] (°C/W) | Manufacturer & Type |
|---|---|
| **For TO-202 Packages** | |
| 12.5 - 14.2 | Staver V4-3-192 |
| 13 | Staver V5-1 |
| 15.1 - 17.2 | Staver V4-3-128 |
| 19 | Thermalloy 6106 Series |
| 20 | Staver V6-2 |
| 25 | Thermalloy 6107 Series |
| 37 | IERC PA1-7CB with PVC-1B Clip |
| 40 - 42 | Staver F7-3 |
| 40 - 43 | Staver F7-2 |
| 42 | IERC PA2-7CB with PVC-1B Clip |
| 42 - 44 | Staver F7-1 |
| **For TO-220 Packages** | |
| 4.2 | IERC HP3 Series |
| 5 - 6 | IERC HP1 Series |
| 6.4 | Staver V3-7-225 |
| 6.5 - 7.5 | IERC VP Series |
| 8.1 | Staver V3-5 |
| 8.8 | Staver V3-7-96 |
| 9.5 | Staver V3-3 |
| 10 | Thermalloy 6032, 6034 Series |
| 12.5 - 14.2 | Staver V4-3-192 |
| 13 | Staver V5-1 |
| 15 | Thermalloy 6030 Series |
| 15.1 - 17.2 | Staver V4-3-128 |
| 16 | Thermalloy 6106 Series |
| 18 | Thermalloy 6107 Series |
| 19 | IERC PB Series |
| 20 | Staver V6-2 |
| 25 | IERC PA Series |
| 26 | Thermalloy 6025 Series |
| **For TO-92 Packages** | |
| 30 | Staver F2-7 |
| 46 | Staver F5-7A, F5-8-1 |
| 50 | IERC RUR Series |
| 57 | Staver F5-7D |
| 65 | IERC RU Series |
| 72 | Staver F1-7 |
| 85 | Thermalloy 2224 Series |

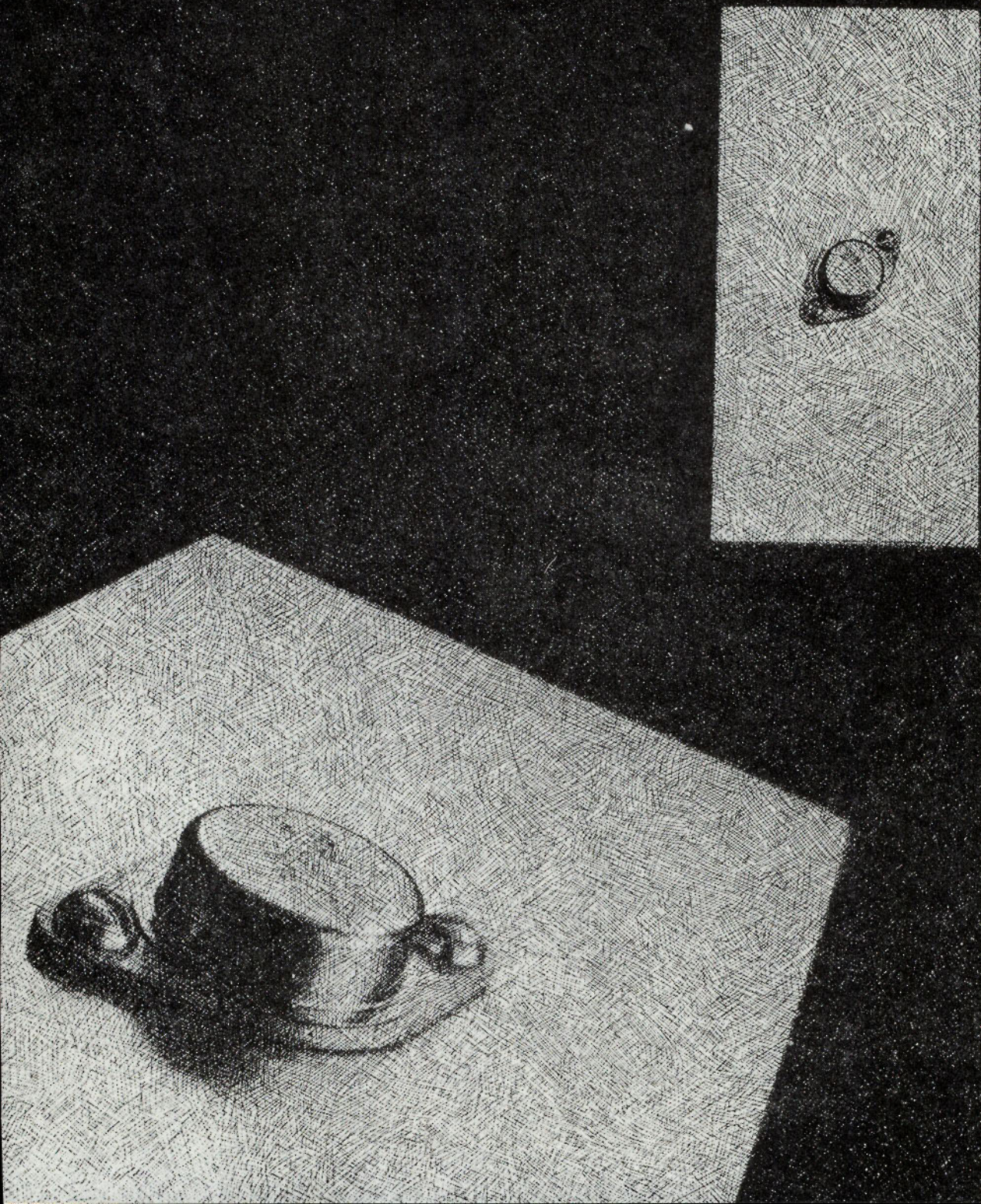
| $\theta_{SA}$ Approx[1] (°C/W) | Manufacturer & Type |
|---|---|
| **For TO-5 Packages** | |
| 12 | Thermalloy 1101, 1103 Series |
| 12 - 16 | Wakefield 260-5 Series |
| 15 | Staver V3A-5 |
| 22 | Thermalloy 1116, 1121, 1123 Series |
| 22 | Thermalloy 1130, 1131, 1132 Series |
| 24 | Staver F5-5C |
| 26 - 30 | IERC Thermal Links |
| 27 - 83 | Wakefield 200 Series |
| 28 | Staver F5-5B |
| 30 | Thermalloy 2227 Series |
| 34 | Thermalloy 2228 Series |
| 35 | IERC Clip Mount Thermal Link |
| 39 | Thermalloy 2215 Series |
| 42 | Staver F5-5A |
| 45 - 65 | Wakefield 296 Series |
| 46 | Staver F6-5, F6-5L |
| 50 | Thermalloy 2225 Series |
| 50 - 55 | IERC Fan Tops |
| 51 | Thermalloy 2205 Series |
| 53 | Thermalloy 2211 Series |
| 55 | Thermalloy 2210 Series |
| 56 | Thermalloy 1129 Series |
| 58 | Thermalloy 2230, 2235 Series |
| 60 | Thermalloy 2226 Series |
| 68 | Staver F1-5 |
| 72 | Thermalloy 1115 Series |

| $\theta_{SA}$ Approx[1] (°C/W) | Manufacturer & Type |
|---|---|
| **For TO-3 Packages** | |
| 0.4 (9" length) | Thermalloy (Extruded) 6590 Series |
| 0.4 - 0.5 (6" length) | Thermalloy (Extruded) 6660, 6560 Series |
| 0.56 - 3.0 | Wakefield 400 Series |
| 0.6 (7.5" length) | Thermalloy (Extruded) 6470 Series |
| 0.7 - 1.2 (5 - 5.5" length) | Thermalloy (Extruded) 6423, 6443, 6441, 6450 Series |
| 1.0 - 5.4 (3" length) | Thermalloy (Extruded) 6427, 6500, 6123, 6401, 6403, 6421, 6463, 6176, 6129, 6141, 6169, 6135, 6442 Series |
| 1.9 | IERC E2 Series (Extruded) |
| 2.1 | IERC E1, E3 Series (Extruded) |
| 2.3 - 4.7 | Wakefield 600 Series |
| 4.2 | IERC HP3 Series |
| 4.5 | Staver V3-5-2 |
| 5 - 6 | IERC HP3 Series |
| 5.2 - 6.2 | Thermalloy 6103 Series |
| 5.6 | Staver V3-3-2 |
| 5.8 - 7.9 | Thermalloy 6001 Series |
| 5.9 - 10 | Wakefield 680 Series |
| 6 | Wakefield 390 Series |
| 6.4 | Staver V3-7-224 |
| 6.5 - 7.5 | IERC UP Series |
| 8 | Staver V1-5 |
| 8.1 | Staver V3-5 |
| 8.8 | Staver V3-7-96 |
| 8.8 - 14.4 | Thermalloy 6013 Series |
| 9.5 | Staver V3-3 |
| 9.5 - 10.5 | IERC LA Series |
| 9.8 - 13.9 | Wakefield 630 Series |
| 10 | Staver V1-3 |
| 13 | Thermalloy 6117 |

Staver Co, Inc: 41-51 N. Saxon Ave, Bay Shore, NY 11706
IERC: 135 W. Magnolia Blvd, Burbank, CA 91502
Thermalloy: PO Box 34829, 2021 W. Valley View Ln, Dallas TX
Wakefield Engin Ind: Wakefield MA 01880

[1] All values are typical as given by mfgr. or as determined from characteristic curves supplied by mfgr.

# Section 6.0
# Custom Heat Sink Design



# 6.0 CUSTOM HEAT SINK DESIGN

## 6.1 IS A CUSTOM DESIGN NECESSARY?

The required $\theta_{SA}$ was determined in Section 5. Even though many heat sinks are commercially available, it is sometimes more practical, more convenient, or more economical to mount the regulator to chassis, to an aluminum or copper fin, to an aluminum extrusion, or to a custom heat sink. In such cases, design a simple heat sink.

## 6.2 SIMPLE RULES

a) Mount cooling fin vertically where practical for best convective heat flow.

b) Anodize, oxidize, or paint the fin surface for better radiation heat flow; see Table 6.1 for emissivity data.

c) Use 1/16" or thicker fins to provide low thermal resistance at the regulator mounting where total fin cross-section is least.

## 6.3 FIN THERMAL RESISTANCE

The heat sink-to-ambient thermal resistance of a vertically mounted symmetrical square or round fin (see Figure 6.1) in still air is:

$$\theta_{SA} = \frac{1}{2H^2\eta(h_c + h_r)} \ ^\circ C/W \qquad (6.1)$$

Where: H = height of vertical plate in inches

$\eta$ = fin effectiveness factor

$h_c$ = convection heat transfer coefficient

$h_r$ = radiation heat transfer coefficient

$$h_c = 2.21 \times 10^{-3}\left(\frac{T_S - T_A}{H}\right)^{1/4} W/in^2{}^\circ C \qquad (6.2)$$

$$h_r = 1.47 \times 10^{-10} E\left(\frac{T_S + T_A}{2} + 273\right)^3 W/in^2{}^\circ C \qquad (6.3)$$

Where: $T_S$ = temperature of heat sink at regulator mounting, in °C

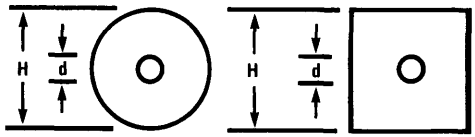
$T_A$ = ambient temperature in °C

E = surface emissivity (see Table 6.1)

Fin effectiveness factor $\eta$ includes the effects of fin thickness, shape, thermal conduction, et. al. It may be determined from the nomogram of Figure 6.2.

**TABLE 6.1. Emissivity Values for Various Surface Treatments**

| SURFACE | EMISSIVITY, E |
|---|---|
| Polished Aluminum | 0.05 |
| Polished Copper | 0.07 |
| Rolled Sheet Steel | 0.66 |
| Oxidized Copper | 0.70 |
| Black Anodized Aluminum | 0.7–0.9 |
| Black Air Drying Enamel | 0.85–0.91 |
| Dark Varnish | 0.89–0.93 |
| Black Oil Paint | 0.92–0.96 |




$B = \frac{H - d}{2}$ $\qquad$ $B = 0.564H - \frac{d}{2}$

**Note:** For H >> d, using B = H/2 is a satisfactory approximation for either square or round fins.

**FIGURE 6.1. Symmetrical Fin Shapes**

The procedure for use of the nomogram of Figure 6.2 is as follows:

a) Specify fin height H as first approximation.

b) Calculate $h = h_r + h_c$ from Eqns 6.2 and 6.3.

c) Determine $\alpha$ from values of h and fin thickness x (line a).

d) Determine $\eta$ from values of B (from Figure 6.1) and $\alpha$ (line b).

The value of $\eta$ thus determined is valid for vertically mounted symmetrical square or round fins (with H >> d) in still air. For other conditions, $\eta$ must be modified as follows:

**Horizontal mounting** - multiply $h_c$ by 0.7.

**Horizontal mounting where only one side is effective** – multiply $\eta$ by 0.5 and $h_c$ by 0.94

**For 2:1 rectangular fins** – multiply h by 0.8.

**For non-symmetrical fins** where the regulator is mounted at the bottom of a vertical fin – multiply $\eta$ by 0.7.

## 6.4 FIN DESIGN

a) Establish initial conditions $T_A$ and desired $\theta_{SA}$ as determined in Section 5.3.

b) Determine $T_S$ at contact point with the regulator by rewriting Eqn 4.1.

$$\theta_{JC} + \theta_{CS} = \frac{T_J - T_S}{P_D} \qquad (6.4)$$

$$T_S = T_J - (\theta_{JC} + \theta_{CS})(V_{IN} - V_{OUT})I_{OUT}$$
$$\approx T_J - \theta_{JC}(V_{IN} - V_{OUT})I_{OUT} \qquad (6.5)$$

c) Select fin thickness, x > 0.0625" and fin height, H.

d) Determine $h_c$ and $h_r$ from Eqns 6.2 and 6.3.

e) Find fin effectiveness factor $\eta$ from Figure 6.2.

f) Calculate $\theta_{SA}$ from Eqn 6.1.

g) If $\theta_{SA}$ is too large or unnecessarily small, choose a different height and repeat steps (c) through (f).

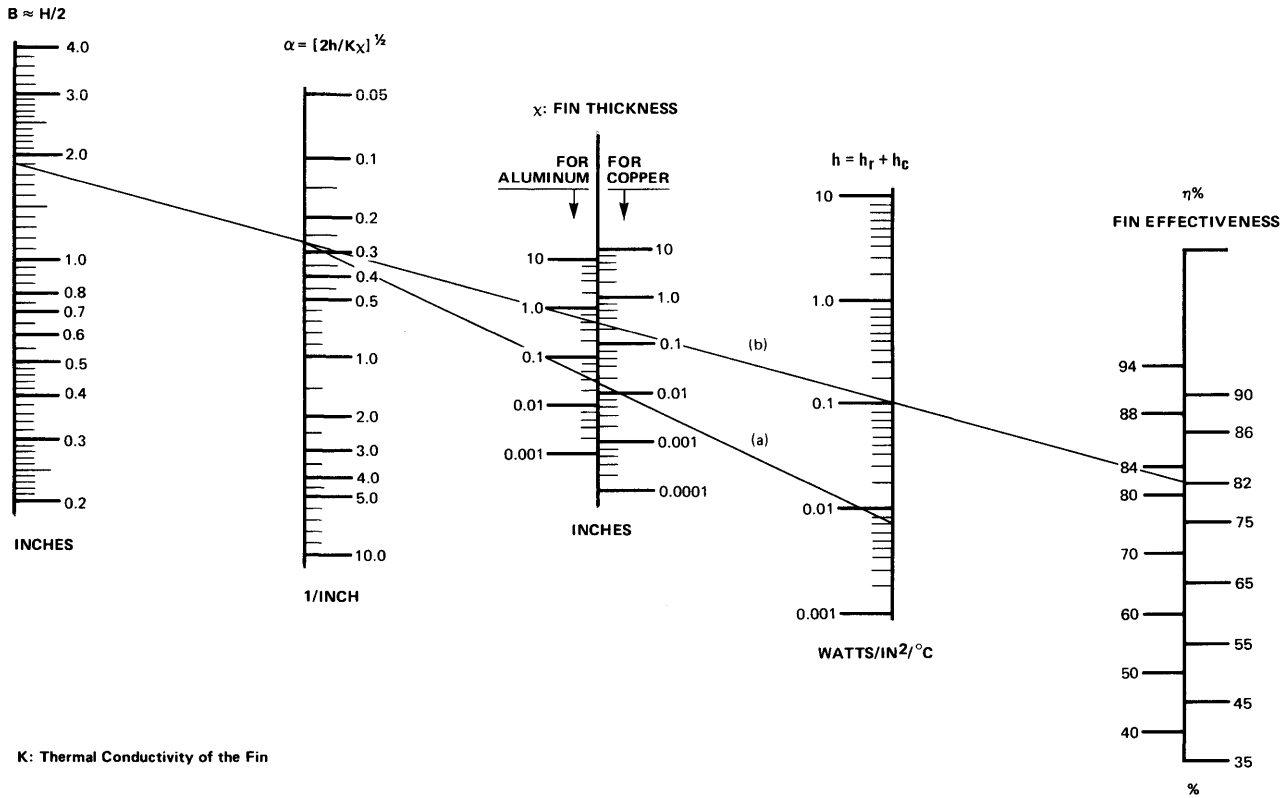



FIGURE 6.2. Fin Effectiveness Nomogram for Symmetrical, Flat, Uniformly-Thick, Vertically Mounted Fins

## 6.5 DESIGN EXAMPLE

Design a symmetrical square vertical fin of black anodized 1/16" thick aluminum to have a thermal resistance of 4°C/W. LM340T-05 operating conditions are:

a) $T_J = 125°C$ $T_A = 60°C$
$V_{IN} = 15\ V$ $V_{OUT} = 5\ V$
$I_{OUT} = 0.8\ A$ Neglect $\theta_{CS}$

b) $T_S = 125°C - 4°C/W(15\ V - 5\ V)0.8\ A = 93°C$

c) $x = 0.0625''$ from initial conditions. $E = 0.9$ from Table 6.1.

Select $H = 3.5''$ for first trial (experience will simplify this step).

d) $$h_c = 2.21 \times 10^{-3}\left(\frac{93 - 60}{3.5}\right)^{1/4}$$

$$= 3.86 \times 10^{-3}\ W/°C\text{-}in^2$$

$$h_r = 1.47 \times 10^{-10} \times 0.9\left(\frac{93 + 60}{2} + 273\right)^3$$

$$= 5.6 \times 10^{-3}\ W/°C\text{-}in^2$$

$$h = h_c + h_r = 9.46 \times 10^{-3}\ W/°C\text{-}in^2$$

e) $\eta = 0.85$ from Figure 6.2.

f) $$\theta_{SA} = \frac{10^3}{2 \times 12.3 \times 0.85 \times 9.46} = 5.1°C/W,$$

which is too large.

g) A larger fin is required, probably by about 40% in area. Accordingly, using a fin of 4.25" square, a new calculation is made.

d') $$h_c = 2.21 \times 10^{-3}\left(\frac{0.33}{4.2}\right)^{1/4} = 3.7 \times 10^{-3}$$

$h_r = 5.6 \times 10^{-3}$ as before

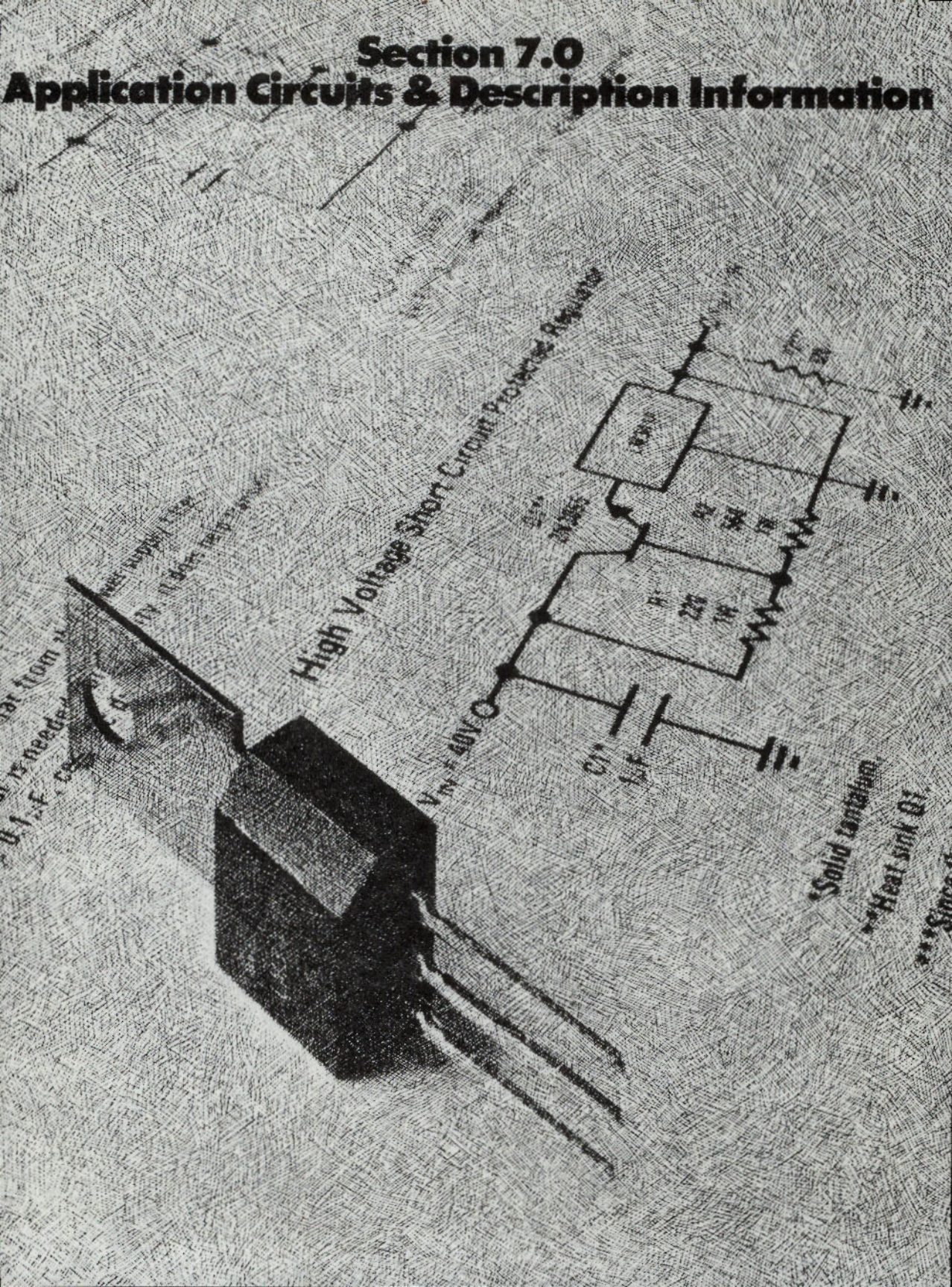
$h = 9.3 \times 10^{-3}$

e') $\eta = 0.75$ from Figure 6.2

f') $$\theta_{SA} = \frac{10^3}{2 \times 18 \times 0.75 \times 9.3} = 3.98°C/W,$$

which is satisfactory.

# Section 7.0
# Application Circuits & Description Information



# 7.0 APPLICATIONS

Voltage regulator use can be expanded beyond that of the simple three-terminal fixed voltage regulator. Some of the circuits which are practical and useful are described in this section. Pertinent equations are included rather than providing fixed component values as the circuits are equally applicable to all regulators within a family.

## 7.1 POSITIVE REGULATORS

### 7.1.1 Basic Regulator

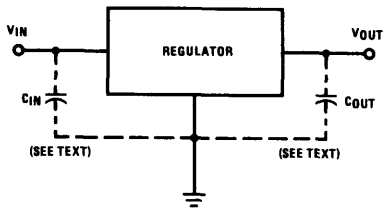



**FIGURE 7.1. Basic Regulator Connection**

Normal connections are indicated in Figure 7.1. If the regulator is located more than two inches from the supply filter capacitor, a supply bypass capacitor is required to maintain stability (much as is the case with op-amps). This should be an 0.22 $\mu$F or larger disc ceramic, 2 $\mu$F or larger solid tantalum, or 25 $\mu$F or larger aluminum electrolytic capacitor (the LM120 and LM123 series require the solid tantalum or aluminum electrolytics). Progressively larger values are required of ceramic, solid tantalum and aluminum electrolytic capacitors because the effective series resistance ESR increases respectively in each type capacitor. The LM120 series alone of all the group requires an output capacitor to insure stable operation. The others are stable when operating into a resistive load. The LM120 output capacitor should be a 1 $\mu$F or larger solid tantalum or 25 $\mu$F or larger aluminum electrolytic. Transient response of all the regulators is improved when output capacitors are added. To minimize high-frequency noise, an 0.01 $\mu$F output capacitor is recommended on the LM78LXX and LM140L series.

### 7.1.2 Current Source

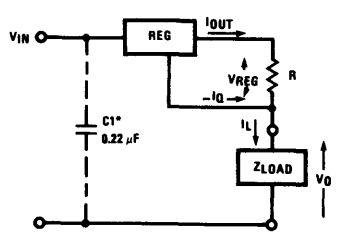



**FIGURE 7.2. Current Source**

A constant output current $I_L$ is delivered to a variable load impedance $Z_L$.

$$I_L = \frac{V_{REG}}{R} + I_Q \qquad (7.1)$$

$$\text{for } 0 \leqslant Z_L \leqslant \frac{V_{IN} - (V_{REG} + V_{dropout})}{I_L}$$

The output impedance is:

$$Z_O = \frac{\Delta V_O}{\Delta I_L} = \frac{1}{\frac{\Delta I_Q}{\Delta V_{IN}} + \frac{L'_r}{R}} \qquad (7.2)$$

where: $\frac{\Delta I_Q}{\Delta V_{IN}}$ = quiescent current change per volt of input voltage change of the regulator

$L'_r = \frac{\Delta V_O}{\Delta V_{IN}}$ = line regulation, the change in regulator output per volt of input voltage change at a given $I_O$

### 7.1.3 High Current Regulator

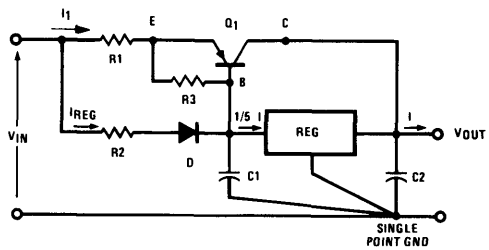



**FIGURE 7.3. High Current Regulator with Short Circuit Limit During Output Shorts**

This current boost circuit takes advantage of the internal current limiting characteristics of the regulator to provide short-circuit current protection for the booster as well. The regulator and $Q_1$ share load current in the ratio set between $R_2$ and $R_1$ if $V_D = V_{BE(Q1)}$.

$$I_1 = \frac{R_2}{R_1} I_{REG} \qquad (7.3)$$

During output shorts

$$I_{1(SC)} = \frac{R_2}{R_1} I_{REG(SC)} \qquad (7.4)$$

If the regulator and $Q_1$ have the same thermal resistance $\theta_{JC}$ and the pass transistor heat sink has $R_2/R_1$ times the capacity of the regulator heat sink, the thermal protection (shutdown) of the regulator will also be extended to $Q_1$. Some suggested transistors are listed below.

| $Q_1$ | D | $I_1$ | $I_{REG}$ | $R_2/R_1$ | $R_3$ |
|---|---|---|---|---|---|
| 2N4398 | IN4719 | $\geqslant$ 3 A | 1 A | $\geqslant$ 3 | 5 - 10 $\Omega$ |
| NSD32 | IN4719 | 2 A | 1 A | 2 | 5 - 10 $\Omega$ |
| NSDU51A | IN4003 | 1 A | 0.5 A | 2 | 5 - 10 $\Omega$ |

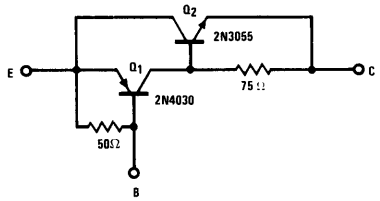



**FIGURE 7.4. Equivalent of Power PNP Transistor**

The minimum input-to-output voltage differential of the regulator circuit is increased by a diode drop plus the $V_{R1}$ drop. For high current applications a low priced PNP/NPN combination may be used to replace the expensive single PNP 2N4398 as illustrated in Figure 7.4.

### 7.1.4 Adjustable Output Voltage

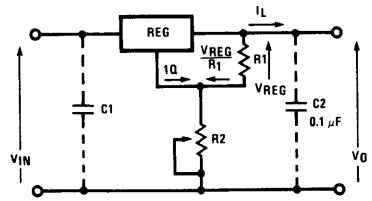



**FIGURE 7.5. Adjustable $V_{OUT}$**

A fraction of the regulator current $V_{REG}/R_1$ is used to raise the ground pin of the regulator and provide, through voltage drop across $R_2$, an adjustable output voltage.

$$V_O = V_{REG} + R_2(I_Q + \frac{V_{REG}}{R_1}) \qquad (7.5)$$

Line regulation is

$$\frac{\Delta V_O}{\Delta V_{IN}} = (L'_r)(\frac{R_1 + R_2}{R_1}) + (\frac{\Delta I_Q}{\Delta V_{IN}})R_2 \qquad (7.6)$$

Load regulation is

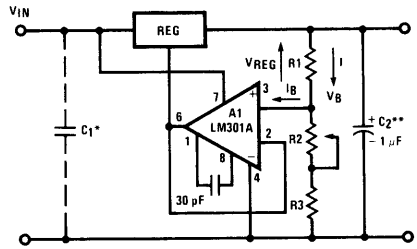
$$\frac{\Delta V_O}{\Delta I_L} = (L_r)(\frac{R_1 + R_2}{R_1}) + (\frac{\Delta I_Q}{\Delta I_O})R_2 \qquad (7.7)$$

where: $L_r = \frac{\Delta V_O}{\Delta I_O}$, the regulator load regulation per amp of load change

$\frac{\Delta I_Q}{\Delta I_O}$ = quiescent current change per amp of load current change

$\frac{\Delta I_Q}{\Delta V_{IN}}$ = quiescent current change per volt of input voltage change

### 7.1.5. Variable Output Voltage




* Required if the regulator far from power supply filter
** Solid tantalum

**FIGURE 7.6. Variable Output Regulator**

The ground terminal of the regulator is raised above common by an amount equal to the voltage applied at the non-inverting input of the op-amp. For $I >> I_B$, the output voltage is:

$$V_O = (\frac{R_1 + R_2 + R_3}{R_1})V_{REG} \qquad (7.8)$$

The minimum output voltage will be determined by the $V_{REG}$ and $V_{B(MIN)}$, where $V_{B(MIN)}$ is the op-amp common-mode voltage lower limit ($\approx$ 2 V for LM301A used with single supply).

$$V_{O(MIN)} = V_{REG} + V_{B(MIN)} \qquad (7.9)$$

when $R_2 = 0$, $\frac{R_3}{R_1} = \frac{V_{B(MIN)}}{V_{REG}}$ (7.10a)

$$V_{O(MAX)} = (\frac{R_1 + R_{2(MAX)} + R_3}{R_1})V_{REG} = V_{IN} - V_{dropout} \qquad (7.10b)$$

To choose $R_1$, $R_2$, $R_3$ for a specified $V_{IN}$, start with an arbitrary value for $R_1$. Determine $R_2$ and $R_3$ from Eqn 7.10 and finally check to insure that

$$\frac{V_{O(MIN)}}{R_1 + R_3} >>> I_B, \quad \frac{V_{O(MAX)}}{R_1 + R_2 + R_3} >> I_B$$

**Example:** $V_{IN}$ = 25 V, $V_O$ = 7-23 V, LM341P-5.0, $R_1$ = 3K, $R_2$ = 10K, $R_3$ = 1.2K

The load and line regulation can be determined by:

$$\frac{\Delta V_O}{\Delta V_{IN}} = (L'_r)(\frac{R_1 + R_2 + R_3}{R_1}) \qquad (7.11)$$

$$\frac{\Delta V_O}{\Delta I_L} = (L_r)(\frac{R_1 + R_2 + R_3}{R_1}) \qquad (7.12)$$

The $\Delta I_Q$ factor (see previous paragraph) is neglected because the op-amp output impedance is very low.

### 7.1.6 Variable Output Voltage with $V_{O(MIN)} \approx 0$

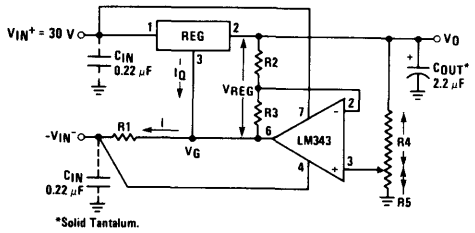



**FIGURE 7.7. Variable Output Voltage of 0.5 - 28 V**

A wide range of output voltages can be obtained with the circuit of Figure 7.7. A 0- to 20-volt supply can be built using a -7-volt supply and a conventional op-amp. For higher output voltages, a high-voltage op-amp, such as LM143, is required. If

$$R_2 + R_3 = R_4 + R_5 = R, \quad \text{and} \quad R_2/R_3 = 1/10,$$

then $$V_O = V_{REG}\left(\frac{R_2}{R_4}\right) = V_{REG}\left(\frac{1}{11}\right)\left(\frac{R_4 + R_5}{R_4}\right) \qquad (7.13)$$

Since $V_O$ is inversely proportional to $R_4$, low output voltages can be very accurately set. The required $R_1$ is

$$R_1 = \frac{V_{IN}^-}{I_Q}$$

The $V_{O(MAX)}$ is dependent on $V_{IN}$ and $V_{dropout}$, provided that the amplifier can source the current required to raise $V_G$ to $V_O - V_{REG}$.

**Example:** $V^-_{IN} = -15$ V, $V^+_{IN} = +30$ V, $V_O = 0.5$-28 V, LM340K-5.0, $R_1 = 2.1$K, $R_2 = 910\ \Omega$, $R_3 = 9.1$K, $R_4 + R_5 = 10$K

### 7.1.7 High Input Voltage

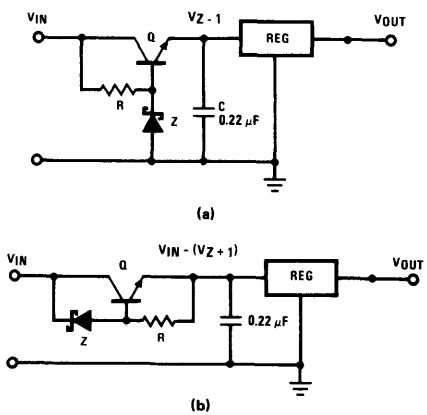



**FIGURE 7.8. High Input Voltage**

For input voltages higher than $V_{IN(MAX)}$ as specified for the regulator, a transistor/low-power zener combination can be used (instead of an expensive power zener) to reduce the input voltage seen by the regulator. Transistor Q conducts full load current, and therefore requires a power device with adequate heat sink.

**Example:** In Figure 7.8b

$V_{IN} = 48$ V, LM341P-15

$I_L = 400$ mA, Z = 1N4745 (16 V)

Q would dissipate 7 W, therefore use an NSD31 power transistor. For higher dissipation, use a 2N3055.

### 7.1.8 High Output Voltage

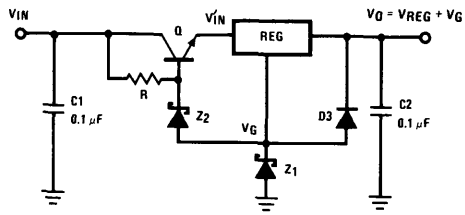



**FIGURE 7.9. High-Voltage Regulator**

With the circuit of Figure 7.6, one can obtain high output voltages if a high-voltage op-amp is used (LM343). Another approach is to raise the ground terminal with a zener diode as illustrated in Figure 7.9. Transistor Q and $Z_2$ set $V'_{IN} \approx V_{Z2} + V_{Z1} - 1$ V. $D_3$ aids full load start-up and also holds $V_G$ to a diode drop above ground during short circuits, thus protecting the regulator from high input-to-output voltage differentials.

**Example:** LM340T-15, $V_{IN} = 80$ V, $V_O = 39$ V, $R = 600\ \Omega$, $Z_1$ = 1N5359 (24 V), $Z_2$ = 1N5365 (36 V), Q = 2N3055

Under short-circuit conditions, $V'_{IN}$ reduces to 35 V.

Figure 7.10 illustrates another circuit for a high-voltage regulator with better input voltage limiting under short circuit conditions. In normal operation, $Q_2$ is OFF and $Q_1$ conducts full load current. $Q_2$ saturates when the output is shorted, thus dropping the voltage at $Q_1$ base and limiting regulator $V'_{IN}$ to a low value. $D_1$ (1N914) protects $Q_2$ from base-emitter breakdown. If an output capacitor is used, $D_2$ protects the regulator from $V_{IN}$

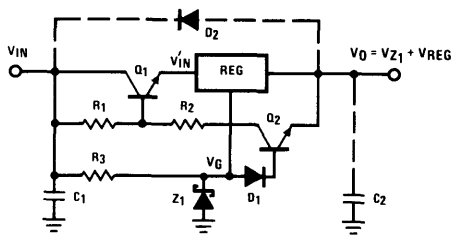



**FIGURE 7.10. High-Voltage Regulator**

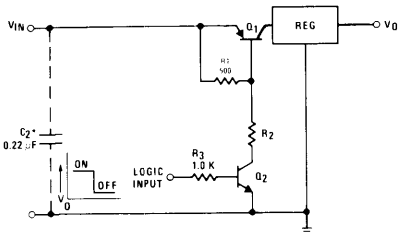
shorts which would temporarily reverse $V_{IN}$ - $V_O$ polarity. A large input capacitor $C_1$ should be included in the circuit to insure that $V_G$ will rise along with $V_{IN}$ at turn-on. Since $Q_1$ does not switch OFF under short-circuit load, it must be a power device with heat sink adequate to handle the short circuit dissipation.

**Example:** LM340T-15

| | | |
|---|---|---|
| | $Z_1$ = 1N5359 (24 V) | $R_1$ = 300 Ω, 10 W |
| $V_{IN}$ = 60 V | $Q_1$ = 2N3055 | $R_2$ = 60 Ω, 4 W |
| $V_O$ = 39 V | $Q_2$ = 2N3643 | $R_3$ = 1500 Ω, 4 W |

Under short circuit conditions $V'_{IN}$ reduces to 9 V.

### 7.1.9 Electronic Shutdown




* Required if regulator far from power supply filter

**FIGURE 7.11. Electronic Shutdown Circuit**

Electronic shutdown in three-terminal regulators is done by simply opening the input circuit using a transistor switch. $Q_1$ operates as the switch which is driven by $Q_2$. The control voltage $V_C$ can be TTL compatible with the use of $R_3$ = 1K. $R_1$ is a biasing resistor, and $R_2$ can be calculated as

$$R_2 = \frac{V_{IN} - 1\,V}{I_O} \beta_{SAT(Q1)} \qquad (7.14)$$

Figure 7.12 illustrates a short-circuit dependent power shutdown circuit with reduced heat sink requirements under short-circuit conditions.

When the power is first applied, $Q_2$ turns ON and saturates $Q_1$. The regulator output ramps up to turn $Q_3$ ON, which turns $Q_2$ OFF ($V_C$ should be > $V_A$), thus maintaining $Q_1$ in the ON state.

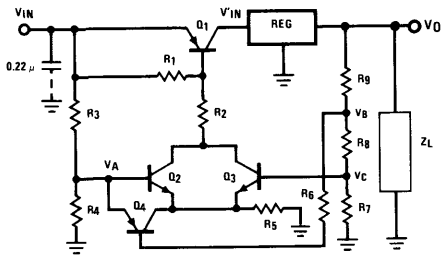


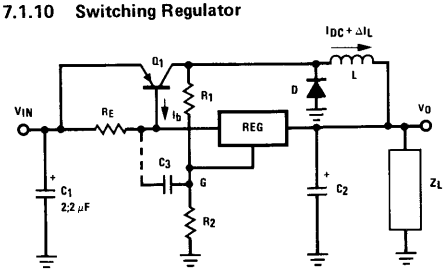

**FIGURE 7.12. Output Dependant Electronic Shutdown**

When the output is shorted, $Q_3$ turns OFF, $Q_4$ turns ON to clamp $Q_2$ OFF. $Q_1$ loses base drive and so opens to isolate the regulator from $V_{IN}$. When the short circuit is removed, $Q_4$ loses some base drive and enables $Q_2$ to re-start the regulator. $Q_1$ always operates as a switch and needs no heat sinking. $Q_2$ and $Q_3$ need not be matched. $Q_4$ may be any small signal PNP transistor. The entire circuit (less regulator) fits easily on a one-inch square PC board.

**Example:** LM340K-15

| | | |
|---|---|---|
| $V_{IN}$ = 25 V | $Q_1$ = TIP32 | $R_1$ = 500 Ω |
| $V_O$ = 15 V | $Q_2$ = 2N4141 | $R_2$ = 250 Ω, 2 W |
| $I_O$ = 1 A | $Q_3$ = 2N4141 | $R_3$ = 3000 Ω |
| $V_A$ = 2.5 V | $Q_4$ = 2N2906 | $R_4$ = 330 Ω |
| $V_B \cong$ 8 V | | $R_5$ = 62 Ω |
| $V_C \cong$ 4.6 V | | $R_6$ = 2K |
| | | $R_7$ = 1K |
| | | $R_8$ = 680 Ω |
| | | $R_9$ = 1.5K |

### 7.1.10 Switching Regulator




$$\text{Ripple} \approx V_{IN} \frac{R_2}{R_1 + R_2}$$

**FIGURE 7.13. Switching Regulator**

A switching power supply may be constructed with a three-terminal regulator, as shown in Figure 7.13. Since no reference pin is available, the positive feedback loop ($R_1$, $R_2$) will be connected to the ground terminal. With the supply ON, the load draws current through the regulator, which turns ON $Q_1$ and applies power to the inductor. As the current through L increases, the regulator supplies less and less current to the load and finally turns $Q_1$ OFF. See National Semiconductor Application Note AN-2 for further design information on switching regulator design. To optimize the efficiency of the regulator, any DC current through $R_E$ should be minimized. This is done by appropriate choice of $R_E$, that is:

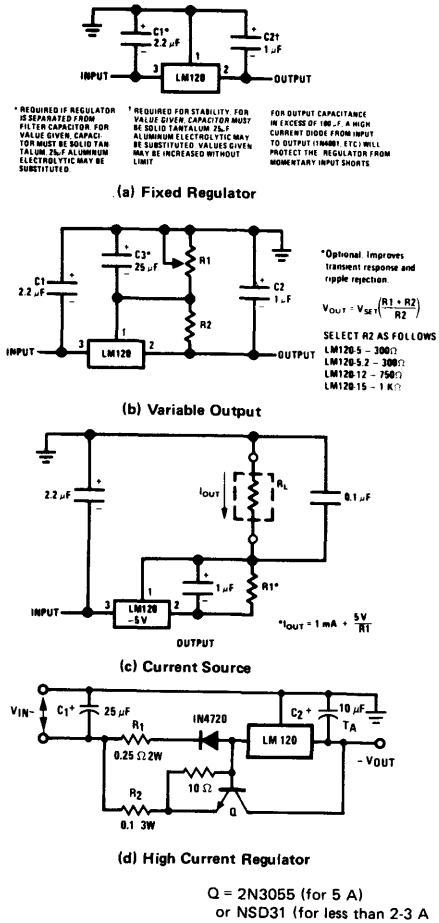
$$I_{RE} + I_b = \frac{V_{BE(SAT)}}{R_E} + I_b \approx \frac{V_{IN} - V_O}{2L} t_{on} \qquad (7.15)$$

Capacitor $C_3$ improves the waveform at node G to minimize ripple.

**Example:** LM341P-5.0 (less heat sink)

| | | |
|---|---|---|
| $V_O$ = 5 V | f = 37 kHz | $R_2$ = 1 Ω |
| $V_{IN}$ = 10 V | L = 500 μH | $R_E$ = 10 Ω |
| $I_O$ = 300 mA | $t_{on} = t_{off}$ | $C_2$ = 100 μF |
| | n = 80% | $C_3$ = 0.1 μF |
| | Q = 2N2905A | $R_1$ = 500 Ω |
| | D = 1N5807 | |

## 7.2 NEGATIVE REGULATORS




Q = 2N3055 (for 5 A)
or NSD31 (for less than 2-3 A

**FIGURE 7.14. Negative Regulator Circuits**

All the applications circuits for positive regulators can be used with the polarities inversed for the negative regulator LM320/345 series (e.g., reverse the sense of the diodes, replace PNP's with NPN's etc., etc.), as shown in Figure 7.14.

### 7.2.1 Basic Dual Power Supply

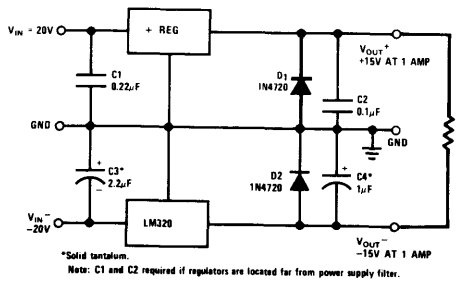



**FIGURE 7.15. Dual Power Supply**

A positive regulator can be connected with an LM320 to form a non-tracking dual power supply. Each regulator exhibits line and load regulation consistent with their specifications as individual devices. Protective diodes $D_1$, $D_2$ allow the regulators to start under common load. They should be rated at the regulator short circuit current.

**Examples:**

1. ±15 V supply, 1 A common load:
   LM340T-15, LM320T-15, $D_1$, $D_2$: IN4720.
2. ±12 V supply, 1 A common load:
   LM340T-12, LM320T-12, $D_1$, $D_2$: IN4720.
3. ±15 V supply, 200 mA common load:
   LM342P-15, LM320MP-15, $D_1$, $D_2$: IN4001.

### 7.2.2 Trimmed Dual Supply

Figure 7.15 may be modified to obtain a dual supply trimmed to a closer output tolerance. The trimming potentiometers are connected across the outputs so positive or negative trimming currents are available to set the voltage across the $R_1$($R_2$) resistors. $R_3$, $R_5$ are included to linearize the adjustment and to prevent shorting the regulator ground pin to opposite polarity output voltages.

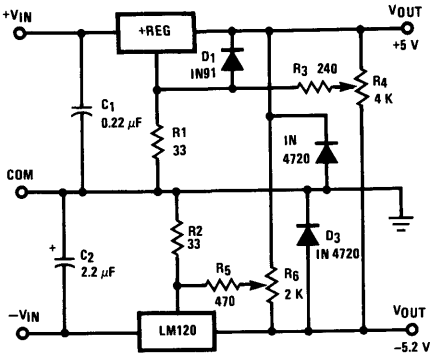
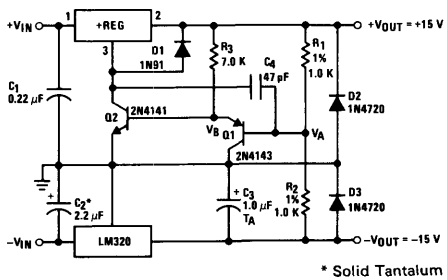



FIGURE 7.16. Trimmed Dual Supply

### 7.2.3 Tracking Dual Supply




* Solid Tantalum

FIGURE 7.17. Tracking Dual Supply

A tracking dual supply can be built as in Figure 7.17 where the positive regulator tracks the negative regulator. $V_A$ is a virtual ground under steady state conditions. $Q_2$ conducts the quiescent current of the positive regulator.

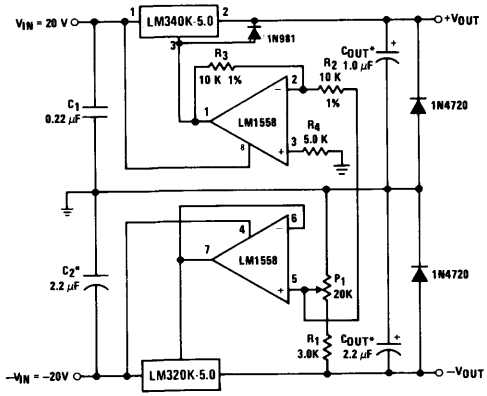
If $-V_{OUT}$ falls, $V_A$ follows forward biasing collector-base junction of $Q_1$. $V_B$ falls, thus raising the collector voltage of $Q_2$ and $+V_{OUT}$ to restore $V_A$ to desired voltage. Germanium diode $D_1$ may be needed to start the positive regulator with a high differential load.

**Example:** ±15 V, 1 A tracking dual supply:

LM340T-5.0, LM320T-15.

The LM340 will track the LM320 within 100 mV. $D_2$, $D_3$: IN4720.

### 7.2.4 Variable Tracking Dual Supply ±5.0 to ±18 V @ 1 A

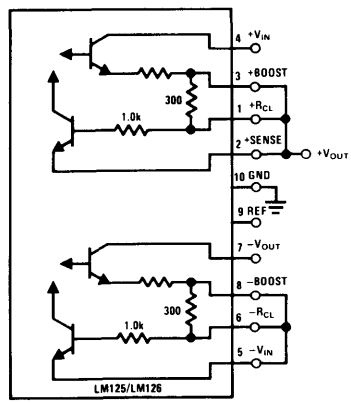



* Solid Tantalum

FIGURE 7.18. Variable Tracking Dual Supply ±5.0 V - ±18 V

The ground pins of the negative regulator and the positive regulators are controlled by means of a voltage follower and an inverter, respectively. (The same approach is used for the LM340 as in Figure 7.18.) The positive regulator tracks the negative to within 100 mV over the entire output range if $R_2$ is matched to $R_3$ within one percent.

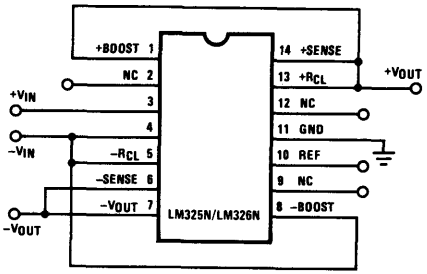
## 7.3 DUAL TRACKING REGULATORS




NOTE: PIN NUMBERS FOR METAL CAN PACKAGE ONLY.

(a)

FIGURE 7.19 (a). Basic Dual Regulator




(b)

**FIGURE 7.19b. Basic Dual Regulator for the 14-Pin Package***

### 7.3.1 High Current Regulator

The basic dual regulator is shown connected in Figure 7.19. The only connections required other than plus and minus inputs, outputs, and ground are the completion of the output current paths from $+R_{CL}$ to $+V_{OUT}$ and from $-R_{CL}$ to $-V_{IN}$. These may be direct shorts if the internal preset current limit is desired, or resistors may be used to set the maximum current at some level less than the internal current limit. The internal 300 Ω resistors from pins 3 to 1 and pins 8 to 6 should be shorted as shown when no external pass transistors are used. To improve line ripple rejection and transient response, filter capacitors may be added to the inputs, outputs, or both, depending on the unregulated input available. If a very low noise output voltage is desired, a capacitor may be connected from the reference voltage pin to ground, thus shunting noise generated by the reference zener. Figure 7.20 shows the internal current-limiting characteristics for the basic regulator circuit of Figure 7.19.

### 7.3.1 High Current Regulator

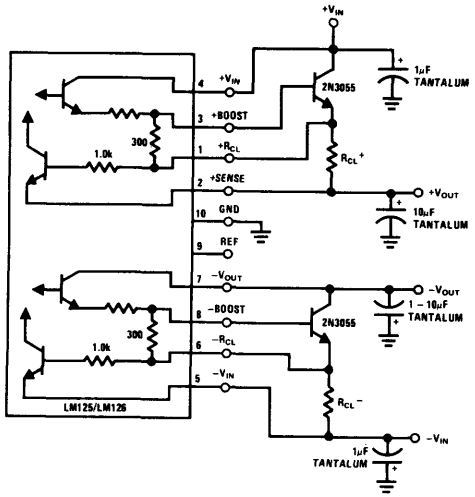
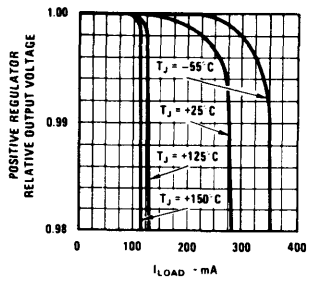


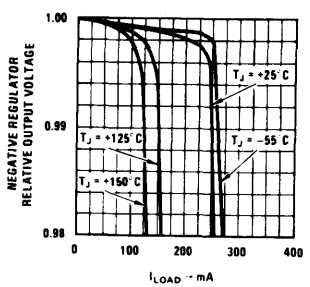

**FIGURE 7.21. Boosted High Current Regulator**

For applications requiring more output current than can be delivered by the basic regulator, an external NPN pass transistor may be added to each regulator. This will increase the maximum output current by a factor of the external transistor beta. The circuit for current boosted operation is shown in Figure 7.21.

***Note:** In the 14-pin package (N and S packages) the -SENSE pin (pin 6) has been brought out of the chip, and therefore should be connected to the $-V_O$ pin (pin 7). The remaining applications circuits are shown for the TO-5 package. These circuits also apply for the 14-pin N package, provided that the $-V_O$ pin is connected to the -SENSE pin (normally done at the load to eliminate effects of supply line voltage drop).




(A)




(B)

**FIGURE 7.20. Internal Current Limiting Characteristics**

In the boosted mode, current limiting is often a necessary requirement to insure that the external pass device is not overheated or destroyed. Experience shows this to be the usual cause of IC regulator failure. If the regulator output is grounded the pass device may fail and short, destroying the regulator. To limit the maximum output current, a series resistor ($R_{CL}$ in Figure 7.21) is used to sense load current. The regulator will current limit when the voltage drop across $R_{CL}$ equals the current limit sense voltage found in Figure 7.22. Figure 7.23 shows the external current limiting characteristics unboosted and Figure 7.24 shows the external current limiting characteristics in the boosted mode.

To ensure circuit stability at high currents in this configuration, it may be necessary to bypass each input with low inductance, tantalum capacitors to prevent forming resonant circuits with long input leads; $C \geqslant 1.0\mu F$ is recommended. The same problem can also occur at the regulator output where a $C \geq 10\mu F$ tantalum will ensure stability and increase ripple rejection.

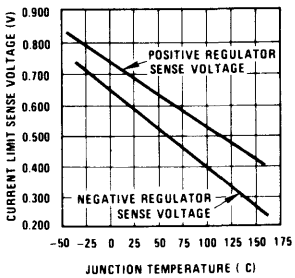



**FIGURE 7.22. Current Limit Sense Voltage for a 0.1% Change in Regulated Output Voltage**

The 2N3055 pass device is low in cost and maintains a reasonably high beta at collector currents up to several amps. The devices 2N3055 may be of either planar or alloy junction construction. The planar devices, have a high $f_T$ providing more stable operation due to low phase shift. The alloy devices, with $f_T$ typically less than 1.0 MHz, may require additional compensation to guarantee stability. The simplest compensation for the slower devices is the use of output filter capacitor values greater than $50\mu F$ (tantalum). An alternative is to use an RC filter to create a leading phase response to cancel some of the phase lag of the devices. The stability problem with slower pass transistors, if it occurs at all, is usually seen only on the negative regulator. This is because the positive regulator output stage is a conventional Darlington while the negative output stage contains three devices in a modified triple Darlington connection giving slightly more internal phase shift. Additional compensation may be added to the negative regulator by connecting a small capacitor in the 100 pF range from the negative boost terminal to the internal reference. Since the positive regulator uses the negative regulator output for a reference, this also offers some additional indirect compensation to the positive regulator.

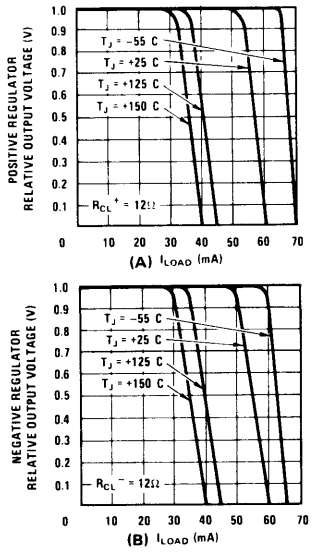



**FIGURE 7.23. External Current Limiting Characteristic-Unboosted**

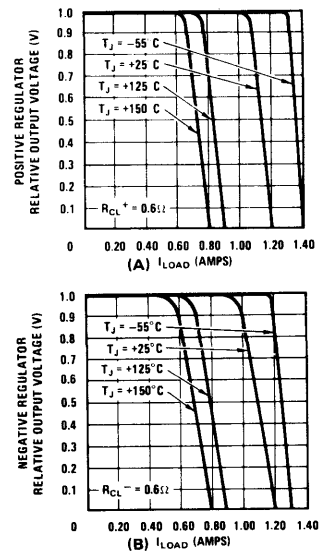



**FIGURE 7.24. External Current Limiting Characteristics-Boosted**

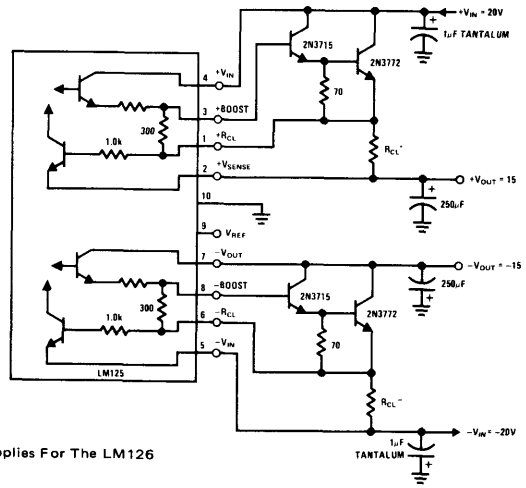
### 7.3.2 7-Amp Regulator

In Figure 7.25 the single external pass transistor has been replaced by a conventional Darlington using a 2N3715 and a 2N3772. With this configuration the output current can reach values to 10A with very good stability. The external Darlington stage increases the minimum input-output voltage differential to 4.5V. When current limit protection resistor is used, as in Figure 7.25, the maximum output current is limited by power dissipation of the 2N3772 (150W at 25°C). During normal operation this is $(V_{IN}-V_{OUT})\ I_{OUT}$ (W), but it increases to $V_{IN}\ I_{SC}$ (W) under short circuit conditions. The short circuit output current is then:

$$I_{SC} = \frac{P_{MAX}\ (T_C = 25^\circ C)}{V_{IN}}$$

$$= \frac{150W}{20V\ (min)} = 7.5A\ max.$$

$I_L$ could be increased to 10A or more only if $I_{SC} < I_L$. A foldback current limit circuit will accomplish this. The typical load regulation is 40 mV from no load to a full load. ($T_j$ = 25°C, pulsed load with 20 ms $t_{ON}$ and 250 ms $t_{OFF}$.)




Note: The Same Circuit Applies For The LM126

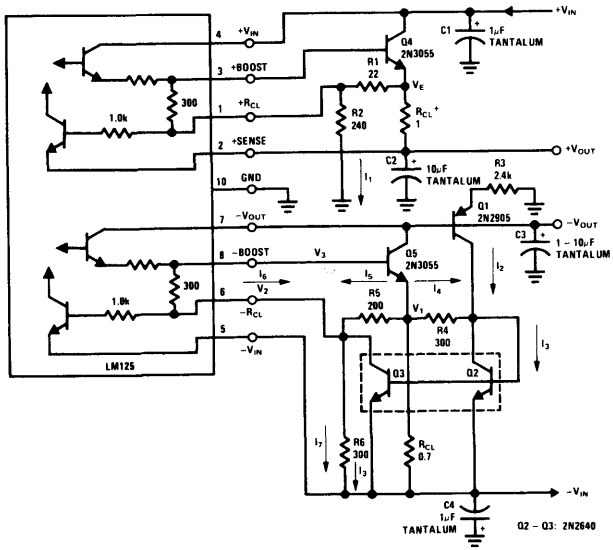
**FIGURE 7.25. High Current Regulator Using a Darlington Pair for Pass Elements**

### 7.3.3 Foldback Current Limiting

In many regulator applications, the normal operation power dissipation in the pass device can easily be multiplied by a factor of ten or more when the output is shorted. This may destroy the pass device, and possibly the regulator, unless the heat sink is oversized to handle this fault condition. A foldback current limiting circuit reduces short circuit output current to a fraction of the full load output current thus avoiding the need for larger heat sink. Figure 7.26 shows a foldback current limiting circuit on both positive and negative regulators.

The foldback current limiting, a fraction of the output voltage must be used to oppose the voltage across the current limit sense resistor. Current limiting does not occur until the voltage across the sense resistor is higher than this opposing voltage by the amount shown in Figure 7.22. When the output is grounded, the opposing voltage is no longer present so current limiting occurs at a lower level. This is accomplished in Figure 7.26 by using a programmable current source to give a constant voltage drop across R5 for the negative regulator, and by a simple resistor divider for the positive regulator. The reason for the difference between the two is that the negative regulator current limiting circuit is located between the output pass transistor and the unregulated input while the positive regulator current limiter is between the output pass transistor and the regulated output.

The operation of the positive foldback circuit is similar to that described in NSC application note AN-23. A voltage divider R1 and R2 from $V_E$ to ground creates a fixed voltage drop across R1 opposite in polarity to the drop across $R_{CL}^+$. When the load current increases to the point where the drop across $R_{CL}^+$ is equal to the drop across R1 plus the current limit sense voltage given in Figure 7.22, the positive regulator will begin to current limit. As the positive output begins to drop, the voltage across R1 will also decrease so that it now requires less load current to produce the current limit sense voltage. With




Note: For LM126; $V_{IN}^+ = 25$ V, $V_{IN}^- = 25$V
$R_1 = 20$, $R_2 = 180$
$R_{CL}^+ = 0.9$
$R_3 = 1.35$ K, $R_6 = 290$; $R_{CL}^- = 0.9$
$I_{FB} = \pm 2$A, $I_{SC} = \pm 0.75$A

**FIGURE 7.26. Foldback Current Limiting Circuit**

the regulator output fully shorted to ground ($+V_{OUT} = 0$) the current limit will be set by the value of $+R_{CL}$ alone.

If $\frac{I_{FB}}{I_{SC}} \leq 5$

then the following equations can be used for calculating the positive regulator foldback current limiting resistors.

$$R_{CL}^{+} \approx \frac{V_{SENSE}}{I_{SC}} \qquad (7.16)$$

where $V_{SENSE}$ is from Figure 7.22.

At the maximum load current foldback point:

$$V_{RCL}^{+} = I_{FB}\, R_{CL}^{+} \qquad (7.17)$$

$$V_{R1} = V_{RCL}^{+} - V_{SENSE} \qquad (7.18)$$

$$V_{R1} = I_{FB}\, R_{CL}^{+} - V_{SENSE} \qquad (7.19)$$

Then

$$R1 = \frac{V_{R1}}{I_1} \qquad (7.20)$$

and

$$R2 = \frac{+V_{OUT} + V_{SENSE}}{I_1} \qquad (7.21)$$

The only point of caution is to ensure that the total current ($I_1$) through R2 is much greater than the current contribution from the internal 300Ω resistor. This can be checked by:

$$\frac{I_{FB}\, R_{CL}^{+}}{300} \ll I_1 \qquad (7.22)$$

Note: The current from the internal 300Ω resistor is $V_{3\text{-}1}/300\Omega$, but $V_{3\text{-}1} = V_{BE} + V_{RCL} - V_{SENSE}^{+}$ assuming $V_{BE} \approx V_{SENSE}^{+}$ at the foldback point, $V_{3\text{-}1} \approx V_{RCL}^{+} = I_{FB}\, R_{CL}^{+}$.

**Example:**

Design a 2 amp regulator using LM125 and positive foldback current limiting (see Figure 7.26).

Given:

$I_{FOLDBACK} = 2.0A$

$I_{SHORT\text{-}CIRCUIT} = 500$ mA

$V_{SENSE}$ (see Figure 7.22).

$+V_{IN} = 25V$

$+V_{OUT} = 15V$

$\beta_{PASS\ DEVICE} = 70$

$\theta_{JA} = 150°C/W$

$T_A = 50°C$

With a beta of 70 in the pass device and a maximum output current of 2.0A the regulator must deliver:

$$\frac{2A}{\beta} = \frac{2A}{70} = 29\text{ mA}$$

The LM125 power dissipation will be calculated ignoring any negative output current for this example.

$$P_{LM125} = (V_{IN} - V_{OUT})\, I_{OUT}$$
$$= (25 - 15)\, 29\text{ mA}$$
$$= 290\text{ mW}$$

$T_{RISE} @ \theta_{JA} = 150°C/W = 150°C \times 0.29 = 44°C$

$T_J = T_A + T_{RISE} = 50°C + 44°C = 94°C$

From Figure 7.22

$V_{SENSE} @ (T_J \approx 94°C) = 520$ mW

From equation (7.17)

$$R_{CL}^{+} = \frac{V_{SENSE}}{I_{SC}} = \frac{520\text{ mV}}{500\text{ mA}} \cong 1\Omega$$

From equation (7.18)

$$V_{RCL}^{+} = I_{FB}\, R_{CL}^{+} = 2A \cdot 1\Omega = 2V$$

From equation (7.19)

$$V_{R1} = V_{RCL}^{+} - V_{SENSE}$$

$$V_{R1} = 2V - 520\text{ mV} = 1.480V$$

A value for $I_1$ can now be found from equation (7.22)

$$\frac{I_{FB}\, R_{CL}^{+}}{300} = \frac{2A \cdot 1\Omega}{300\Omega} = 6.6\text{ mA}$$

So set $I_1 = 10 \times 6.6\text{ mA} = 66\text{ mA}$

Equating equation (7.28) with equation (7.29) and inserting resistor values shown in Figure 7.26,

$$I_2 + I_4 = I_5 + I_6 - I_7$$

$$I_2 + \frac{I_{FB}\,R_{CL}^- - V_{SENSE}}{300} = I_5 + \frac{I_{FB}\,R_{CL}^-}{300} - \frac{V_{SENSE}}{300} \qquad (7.34)$$

Canceling, we find:

$$I_2 = I_5 \qquad (7.35)$$

This is the key to the negative foldback circuit. Current source Q1 forces current $I_2$ to flow through resistor R5. The voltage drop across R5 opposes the normal current limit sense voltage so that the regulator will not current limit until the drop across $R_{CL}^-$ due to load current, equals the controlled drop across R5 plus $V_{SENSE}$ (given in Figure 7.22). This can be written as:

$$I_{FB} = \frac{V_{SENSE} + I_2\,R5}{R_{CL}^-} \qquad (7.36)$$

$$I_{FB} = \frac{V_{SENSE} + 200\,I_2}{R_{CL}^-}$$

**Example:**

Given:

$I_{FOLDBACK} = 2.5A$

$I_{SHORT\text{-}CIRCUIT} = 750\ mA$

$V_{SENSE}$ (See Figure 7.22)

$-V_{IN} = 25V$

$-V_{OUT} = -15V$

$\beta_{PASS\ DEVICE} = 90$

$\theta_{JA} = 150°C/W$

$T_A = 25°C$

The same calculations are used here to figure $V_{SENSE}$ as with the positive regulator foldback example maximum regulator output current is calculated from:

$$I_{OUT} = \frac{2.5\ A}{90} = 28\ mA$$

$$P_{LM125} = (V_{IN} - V_O)\,I_{OUT}$$
$$= 10V \times 28\ mA$$
$$= 280\ mW$$

$$T_{RISE} = 150°C/W \times 0.28W = 42°C$$

$$T_J = T_A + T_{RISE} = 25°C + 42°C = 67°C$$

From Figure 7.22:

$$V_{SENSE} = 500\ mV$$

From equation (7.23):

$$R_{CL}^- = \frac{500\ mV}{750\ mA} = 0.68\Omega$$

From equation (7.36):

$$I_2 = \frac{I_{FB}\,R_{CL}^- - V_{SENSE}}{200\Omega} = 6.0\ mA$$

From equation (7.24):

$$R3 = \frac{V_{OUT} - V_{BEQ1}}{I_2}$$

$$R3 \simeq \frac{14.3}{6.0\ mA} = 2.4k$$

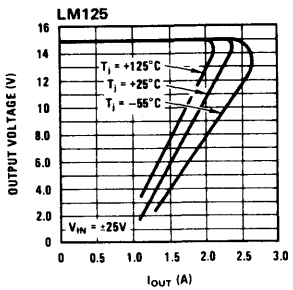



**FIGURE 7.28. Negative Regulator Foldback Current Limiting Characteristics**

Figure 7.27 and 7.28 show the measured foldback characteristics for the values derived in the design examples. The value of R5 is set low so that the magnitude of $I_5$ for foldback is greater than $I_4$ through $I_6$. This reduces the foldback point sensitivity to the TC of the internal 300Ω resistor and any mismatch in the TC of Q2, Q3 or the pass device.

R6 can be computed from equation (7.33):

$$R6 = \frac{V_{SENSE}^-}{I_7} = \frac{V_{SENSE}^-}{I_5 + I_6 - I_3}$$

combining (7.28) and (7.35).

$$R6 = \frac{V_{SENSE}^-}{I_6 - I_4} = \frac{V_{SENSE}^-}{I_{FB}\, R_{CL}^- \left(\frac{1}{300} - \frac{1}{R4}\right) + \frac{V_{BE}}{R4}} \quad (7.37)$$

Setting $V_{BE} \simeq V_{SENSE}$ and R4 = 300 to match the internal 300Ω (22) becomes:

$$R6 = R4$$

Also setting $\frac{I_4}{I_5} = \frac{2}{3} \rightarrow R5 = 200$

### 7.3.4 A 10-Amp Regulator

Figure 7.29 illustrates the complete schematic of a 10A regulator with foldback current limiting. The design approach is similar to that of the 2A regulator. However, in this design, the current contribution from the internal 300Ω resistor is greater due to the 2 $V_{BE}$ drop across the Darlington pair. Expression (7.22) becomes:

$$\frac{I_{FB}\, R_{CL}^+ + V_{BE}}{300} << I_1 \; ; \quad (7.38)$$

and, for the negative regulator, expression (7.39) becomes:

$$R6 = \frac{V_{SENSE}^-}{I_{FB}\, R_{CL}^- \left[\frac{1}{300} - \frac{1}{R4}\right] + V_{BE}\left[\frac{1}{300} + \frac{1}{R4}\right]} \quad (7.40)$$

The disagreement between the theoretical and experimental values for the negative regulator is not alarming. In fact $R_{CL}$ was based on equation (7.23), which is correct if for zero $V_{OUT}$, $I_5$ is zero as well. This implies:

$$V_{SENSE}\ (\text{at SC}) = \frac{V_{BEQ4} + V_{BEQ5}}{2}\ (\text{at SC})$$

which is a first order approximation.

Figure 7.30 illustrates the power dissipation in the external power transistor for both sides. Maximum power dissipation occurs between full load and short circuit so the heat sink for the 2N3772 must be designed accordingly, remembering that

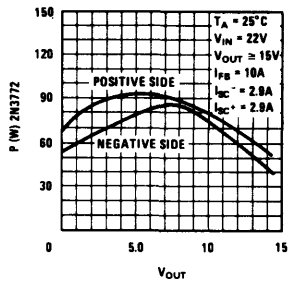



**FIGURE 7.30. Power Dissipation in the External Pass Transistor (Q5, Q7)**

the 2N3772 must be derated according to 0.86W/°C above 25°C. This corresponds to a thermal resistance junction to case of 1.17°C/W.

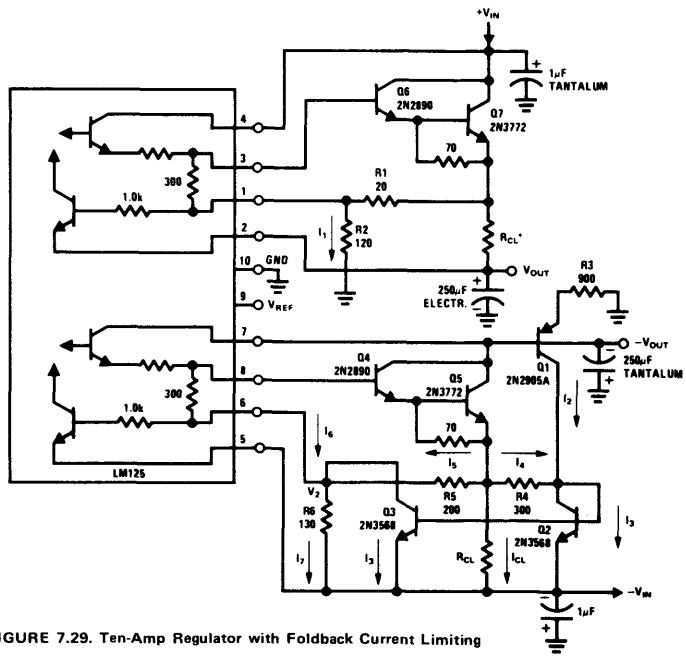



**FIGURE 7.29. Ten-Amp Regulator with Foldback Current Limiting**

**Example**

| Positive Side | Theoretical Value | Experimental Results |
|---|---|---|
| $I_{FB}$ = 10 A | $I_{125}$ = 13 mA | $I_{FB}$ = 9.8 A |
| $I_{SC}$ = 2.5 A | $P_{LM125}$ = 150 mW | $I_{SC}$ = 2.9 A |
| $V_{IN}$ = 22V | $R_{CL}^+$ = 0.26Ω | $R_{CL}^+$ = 0.26Ω |
| $V_{OUT}$ = 15V | R1 = 21Ω | R1: adjusted to 20Ω |
| $\beta = \beta 1\, \beta 2$ = 15 X 50 = 750 min | R2 = 130Ω | R2: adjusted to 120Ω |
| $T_A$ = 25°C | $V_{SENSE}^+$ = 650 mV | |

| Negative Side | Theoretical Value | Experimental Results |
|---|---|---|
| $I_{FB}$ = 10 A | $R_{CL}^-$ = 0.22Ω | $I_{FB}$ = 10 A |
| $I_{SC}$ = 2.5 A | R4 = 300Ω | $I_{SC}$ = 2.9 A |
| $V_{IN}$ = 22V | R5 = 200Ω | $R_{CL}^-$: adjusted to 0.3Ω |
| $V_{OUT}$ = 15V | R6 = 150Ω | R6: adjusted to 130Ω |
| $\beta$ = 800 | R3 = 1.6 kΩ | R3: adjusted to 900Ω |
| $T_A$ = 25° | $V_{SENSE}^-$ = 550 mV | |
| $\frac{I_4}{I_5} = \frac{2}{3}$ | | |

**Note:** For this example, in designing each side, the power dissipation of the opposite side has not been taken into the account.

### 7.3.5 Positive Current Dependent Simultaneous Current Limiting

The LM125/126 uses the negative output as a reference for the positive regulator. As a consequence, whenever the negative output current limits, the positive output follows tracks to within 200–800 mV of ground. If, however, the positive regulator should current limit the negative output will remain in full regulation. This imbalance in output voltages could be a problem in some supply applications.

As a solution to this problem, a simultaneous limiting scheme, dependent on the positive regulator output current, is presented in Figure 7.31. The output current causes an I-R drop across R1 which brings transistor Q1 into conduction. As the positive load current increases $I_1$ increases until the voltage drop across R2 equals the negative current limit sense voltage. The negative regulator will then current limit, and positive side will closely follow the negative output down to a level of 700 – 800 mV. For $V_{OUT}^+$ to drop the final 700 – 800 mV with small output current change, $R_{CL}^+$ should be adjusted so that the positive current limit is slightly larger than the simultaneous limiting. Figure 7.32 illustrates the simultaneous current limiting of both sides.

The following design equations may be used:

$$R1\, I_{CL}^+ = R3\, I_1 + V_{BEQ1} \tag{7.41}$$

$$I_1 = \frac{V_{SENSE}^-}{R2} \tag{7.42}$$

Combining (7.41) and (7.42)

$$I_{CL}^+ = \frac{\frac{R3}{R2} V_{SENSE}^- + V_{BEQ1}}{R1} \tag{7.43}$$

with

$$R_{CL}^+ = \frac{V_{SENSE}^+}{1.1\, I_{CL}^+} \tag{7.44}$$

The negative current limit (independent of $I_{CL}^+$) can be set at any desired level.

$$I_{CL}^- = \frac{V_{SENSE}^- + V_{DIODE}}{R_{CL}^-} \tag{7.45}$$

Transistor Q2 turns off the negative pass transistor during simultaneous current limiting.

From equations (7.20) and (7.21)

$$R1 = \frac{V_{R1}}{I_1} = \frac{1.480V}{66\ mA} \cong 22\Omega$$

$$R2 = \frac{+V_{OUT} + V_{SENSE}}{I_1} = \frac{15 + 0.520}{66\ mA}$$

$$\cong 240\Omega$$

The foldback limiting characteristics are shown in Figure 7.27 for the values calculated above at various operating temperatures.

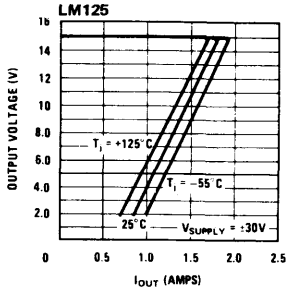



**FIGURE 7.27. Positive Regulator Foldback Current Limiting Characteristics**

The negative regulator foldback current limiting works essentially the same way as the positive side. Q1 forces a constant current, $I_2$, determined by $-V_{OUT}$ and R3, through Q2. Transistors Q2 and Q3 are matched so a current identical to $I_3$ will flow through Q3. With the output short-circuited ($-V_{OUT}$ = 0), Q1 will be OFF, setting $I_2$ = 0. The load current will be limited when $V_1$ increases sufficiently due to load current to make $V_2$ higher than $-V_{IN}$ by the current limit sense voltage.

The short circuit current is:

$$I_{SC} \simeq \frac{V_{SENSE}}{R_{CL}^-} \qquad (7.23)$$

For calculating the maximum full load current with the output still in regulation, current $I_2$

$$I_2 = \frac{V_{OUT} - V_{BEQ1}}{R3} \qquad (7.24)$$

At the point of maximum load current, $I_{FB}$, where the regulator should start folding back:

$$V_1 = -V_{IN} + I_{FB}\ R_{CL}^- \qquad (7.25)$$

and

$$V_2 = -V_{IN} + V_{SENSE} \qquad (7.26)$$

The current through, Q2 (and Q3) will have increased from $I_2$ by the amount of $I_4$ due to the voltage $V_1$ increasing above its no-load quiescent value. Since the voltage across Q2 is simply the diode drop of a base-emitter junction:

$$I_4 = \frac{[V_1 - (-V_{IN})] - V_{BE}}{R4}$$

Substituting in equation (7.25) gives:

$$I_4 = \frac{I_{FB}\ R_{CL}^- - V_{BE}}{R4} = \frac{I_{FB}\ R_{CL}^- - V_{BE}}{300\Omega} \qquad (7.27)$$

The current through Q2 is now

$$I_3 = I_2 + I_4 \qquad (7.28)$$

and the current through Q3 is:

$$I_3 = I_5 + I_6 - I_7 \qquad (7.29)$$

The drop accross R5 is found from:

$$V_1 - V_2 = (-V_{IN} + I_{FB}\ R_{CL}^-) - [V_{SENSE} + (-V_{IN})];$$

simplifying,

$$V_1 - V_2 = I_{FB}\ R_{CL}^- - V_{SENSE} \qquad (7.30)$$

Since $V_{SENSE}$ is the base to emitter voltage drop of the internal limiter transistor, the $V_{SENSE}$ in equation (7.30) very nearly equals the $V_{BE}$ in equation (7.27). Therefore the drop across R5 approximately equals the drop across R4. The current through R5, $I_5$, can now be determined as:

$$I_5 = \frac{I_{FB}\ R_{CL}^- - V_{SENSE}}{R5} \qquad (7.31)$$

Summing the currents through Q3 is now possible assuming the base-emitter drop of the 2N3055 pass device can be given by $V_{BE} \approx V_{SENSE}$:

$$I_6 = \frac{V_3 - V_2}{300} \qquad (7.32)$$

where $V_3 = V_1 + V_{BE} \approx V_1 + V_{SENSE}$

$$I_6 = \frac{V_1 + V_{SENSE} - V_2}{300}$$

Substituting in equation (7.30)

$$I_6 = \frac{I_{FB}\ R_{CL}^-}{300}$$

$$I_7 = \frac{V_2 - (-V_{IN})}{R6} = \frac{V_{SENSE}}{R6} \qquad (7.33)$$

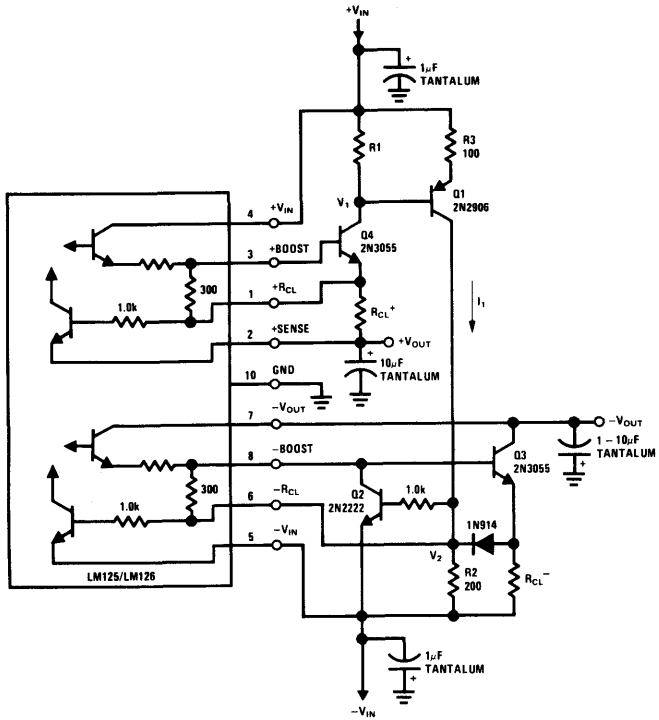



**FIGURE 7.31. Positive Current Dependent Simultaneous Current Limiting**

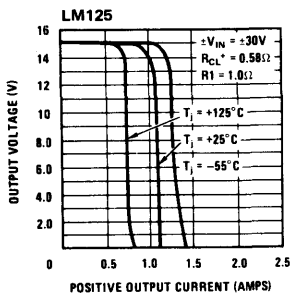



**FIGURE 7.32. Positive Current Dependent Simultaneous Shutdown**

### 7.3.6 Electronic Shutdown

In some regulated supply applications it is desirable to shutdown the regulated outputs ($\pm V_O = 0$) without having to shutdown the unregulated inputs (which may be powering additional equipment). Various shutdown methods may be used. The simplest is to insert a relay, a saturated bipolar device, or some other type switch in series with either the regulator inputs or outputs. The switch must be able to open and close under maximum load current which may be several amps.

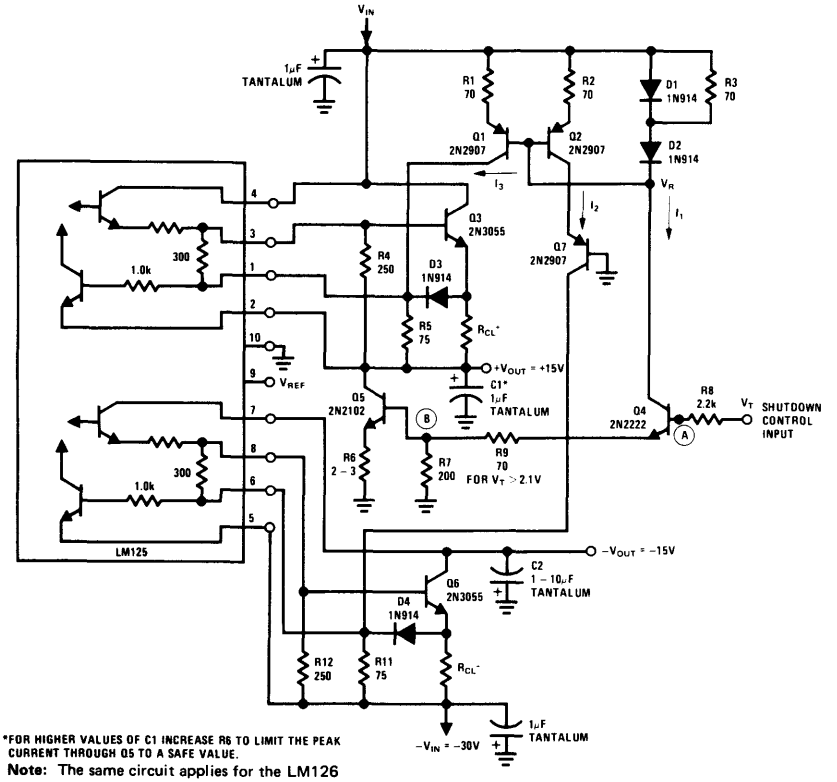
As an alternate solution, the internal reference voltage of the regulator may be shorted to ground. (See Figure 7.37)

This will force the positive and negative outputs to approximately +700 mV and +300 mV respectively. Both outputs are fully active so the full output current can still be supplied into a low impedance load. If this is unacceptable, another solution must be found.

The circuit in Figure 7.33 provides complete electronic shutdown of both regulators. The shutdown control signal is TTL compatible but by adjusting R8 and R9 the regulator may be shutdown at any desired level above 2 $V_{BE}$, calculated as follows:

$$V_T \simeq \left[\frac{R8}{R3\,\beta\,Q4} + \frac{R9}{R3}\right] V_{BE} + 2\,V_{BE} \quad (7.46)$$

Positive and negative shutdown operations are similar. When a shutdown signal $V_T$ is applied, Q4 draws current through R3 and D2 establishing a voltage $V_R$ which starts the current sources Q1 and Q2. Assuming that Q1 and Q2 are matched, and making R1 = R2 = R3, the currents $I_1$, $I_2$, $I_3$ are equal and both sides of the regulator shutdown simultaneously.




*FOR HIGHER VALUES OF C1 INCREASE R6 TO LIMIT THE PEAK CURRENT THROUGH Q5 TO A SAFE VALUE.

**Note:** The same circuit applies for the LM126

**FIGURE 7.33. Electronic Shutdown for the Boosted Regulator**

The current $I_3$ creates a drop across R5, which equals or exceeds the limit sense voltage of the positive regulator, causing it to shutdown. Since $I_3$ has no path to ground except through the load, a fixed load is provided by Q5, which is turned on by the variable current source Q4. C1 also discharges through Q5 and current limiting resistor R6. Resistor R4 prevents Q3 turn on during shutdown, which could otherwise occur due to the drop across R5 plus the internal 300Ω resistor. Diode D3 prevents $I_3$ from being shunted through $R_{CL}$.

Capacitor C2 discharges through the load. Q7 shares the total supply voltage with Q2, thus limiting power dissipation of Q2. Another power dissipation problem may occur when the design is done for $V_T$ = 2.0V for example, and $V_T$ is increased above the preset threshold value. $I_1$ is increased and Q4 has to dissipate $(V_{IN} - 3\ V_{BE} - V_T)\ I_1$ (W). The simplest solution is to increase R8. If this is insufficient, a set of diodes may be added between nodes A and B to clamp. $I_1$ to a reasonable value. This is illustrated in Figure 7.34.

$$I_1 = \frac{V_{R9}}{R9} \simeq \frac{V_T - V_{BE} - \left[V_T - 2\ V_{BE}\right]}{R9}$$

$$= \frac{V_{BE}}{R9}$$

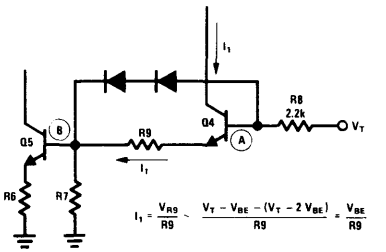



**FIGURE 7.34.**

So $I_1$ is made independent of $V_T$ and by setting a minimum value of 10 mA (R9 = 70Ω). The regulator will shutdown at any desired level above 3 $V_{BE}$, without overheating transistor Q4. Also using

Figure 7.34 the diode D1 in Figure 7.33 may be omitted. The shutdown characteristics of Figure 7.33 are shown in Figure 7.34.

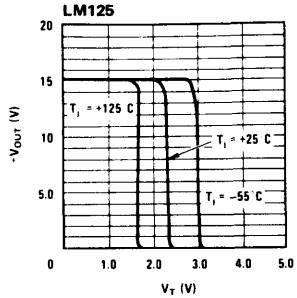
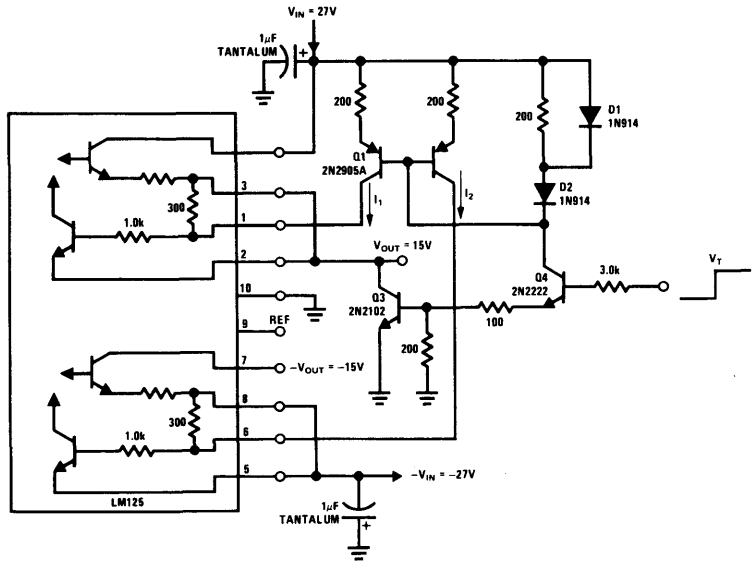



**FIGURE 7.35. Electronic Shutdown Characteristics**

The normal current limiting current is set by equation (7.47)

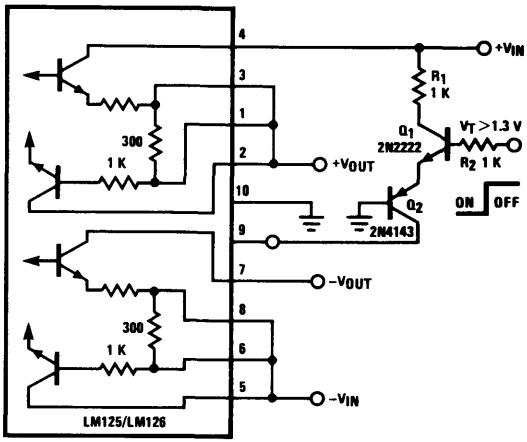
$$I_{CL} = \frac{V_{SENSE} + V_{DIODE}}{R_{CL}} \qquad (7.47)$$

The same approach is used with the unboosted regulator shown in Figure 7.36. In this case the voltage sense resistor is the internal 300Ω one. Since output capacitors are no longer required Q3 is just used as a current sink and its emitter load has been removed.




Note: The Same Circuit Applies For The LM126

**FIGURE 7.36. Electronic Shutdown for the Basic Regulator**




NOTE: PIN NUMBERS FOR METAL CAN PACKAGE ONLY

**FIGURE 7.37. Simplified Shutdown**

### 7.3.7 *Power Dissipation*

The power dissipation of the LM125 is:

$$P_d = (V_{IN}^+ - V_{OUT}^+)\, I_{OUT}^+ + (V_{IN}^- - V_{OUT}^-)\, I_{OUT}^- + V_{IN}^+ I_S^+ + V_{IN}^- I_S^-$$

where $I_S$ is the standby current.

**Example:**
±1A regulator using 2N3055 pass transistors. Assuming a $\beta$ = 100, and ±25V supply,

$$P_d = 400 \text{ mW}.$$

The temperature rise for the TO-5 package will be:

$$T_{RISE} = 0.4 \times 150^\circ\text{C/W} = 60^\circ\text{C}$$

Therefore the maximum ambient temperature is $T_{AMAX} = T_{jMAX} - T_{RISE} = 90^\circ$C. If the device is to operate at $T_A$ above 90°C then the TO-5 package must have a heat sink. $T_{RISE}$ in this case will be:

$$T_{RISE} = P_d\,(\theta_{J\text{-}C} + \theta_{C\text{-}S} + \theta_{S\text{-}A}).$$

## 7.4 ADJUSTABLE VOLTAGE REGULATORS

### 7.4.1 A New Production Technique for Trimming Voltage Regulators

Three-terminal adjustable voltage regulators such as the LM317 and LM337 are becoming popular for making regulated supplies in instruments and various other OEM applications. Because the regulated output voltage is easily programmed by two resistors, the designer can choose any voltage in a wide range such as 1.2V to 37V. In a typical example (*Figure 1*) the output voltage will be:

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

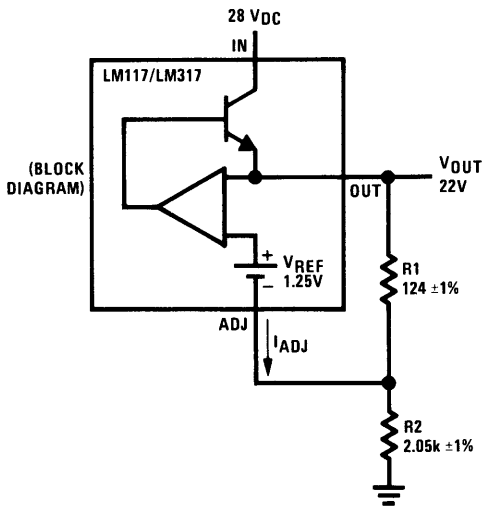



**FIGURE 1. Basic Regulator**

In many applications, when R1 and R2 are inexpensive ±1% film resistors, and the room temperature accuracy of the LM117 is better than ±3%, the overall accuracy of ±5% will be acceptable. In other cases, a tighter tolerance such as ±1% is required. Then a standard technique is to make up part of R2 with a small trim pot, as in *Figure 2*. The effective range of R2 is 2.07k ±10%, which is adequate to bring $V_{OUT}$ to exactly 22.0V. (Note that a 200Ω rheostat in series with 1.96 kΩ ±1% would not necessarily give a ±5% trim range, because the end resistance and wiper resistance could be as high as 10Ω or 20Ω; and the maximum value of an inexpensive 10% or 20% tolerance trimmer might be as low as 180Ω or 160Ω.)

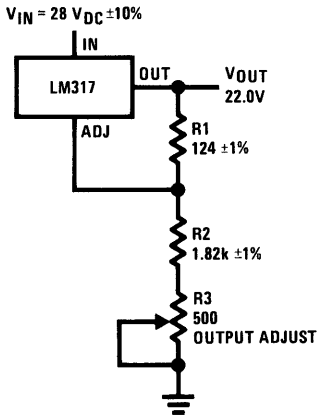



**FIGURE 2. Regulator with Small Adjustment Range**

In some designs, the engineering policy may frown on the use of such trim pots, for one or more of the following reasons:

— Good trim pots are not cheap.

— Cheap trim pots may be drifty or unreliable.

— Any trim pot which can be adjusted can be (and probably *will* be) *mis*adjusted, sooner or later.

To get a tighter accuracy on a regulated supply, while avoiding these disadvantages of trim pots, consider the scheme in *Figure 3*.

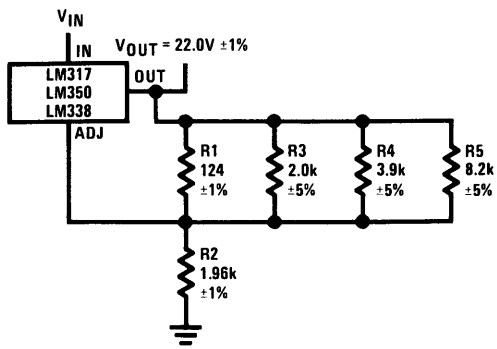



**FIGURE 3. Regulator with Trimmable Output Voltage**

When first tested, $V_{OUT}$ will tend to be 4% to 6% higher than the 22.0V target. Then, while monitoring $V_{OUT}$, snip out R3, R4, and/or R5 as appropriate to bring $V_{OUT}$ closer to 22.0V. This procedure will bring the tolerance inside ±1%:

— If $V_{OUT}$ is 23.08V or higher, cut out R3 (if lower, don't cut it out).

— Then if $V_{OUT}$ is 22.47V or higher, cut out R4 (if lower, don't).

— Then if $V_{OUT}$ is 22.16V or higher, cut out R5 (if lower, don't).

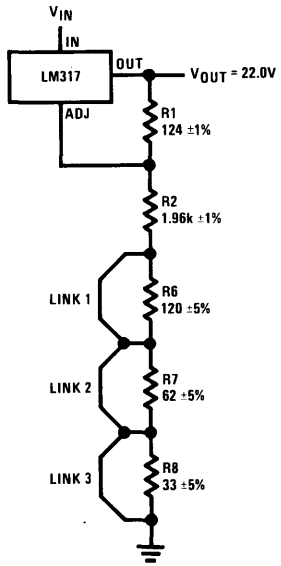
The entire production distribution will be brought inside 22.0V ±1%, with a cost of 3 inexpensive carbon resistors, much lower than the cost of any pot. After the circuit is properly trimmed, it is relatively immune to being misadjusted by a screwdriver. Of course, the resistors' carcasses must be properly removed and disposed of, for *full reliability to be maintained.*

An alternate scheme shown in *Figure 4* has R6, R7, and R8 all shorted out initially with a stitch or jumper of wire. The trim procedure is to open up a link to bring a resistor into effect. The advantage of this circuit is that $V_{OUT}$ starts out *lower* than the target value, and never exceeds that voltage during trimming. In this scheme, note that a total "pot resistance" of 215Ω is plenty for a 10% trim span, because the *minimum* resistance is always below 1Ω, and the maximum resistance is always more than 200Ω—it can cover a much wider range than a 200Ω pot.

The circuit of *Figure 5* shows a combination of these trims which provides a new advantage, that a ±2% max tolerance is adequate. You may snip out R4, or link L1, or both, to accommodate the worst case tolerance, but in most cases, the output will be within spec without doing any trim work at all. This takes advantage of the fact that most ±1% resistors are well within ±⅓%, and most LM337's output voltage tolerances are between −½% and +1½%, to cut the average trim labor to a minimum. Note that L1 could be made up of a 2.7Ω ±10% resistor which may be easier to handle than a piece of wire.

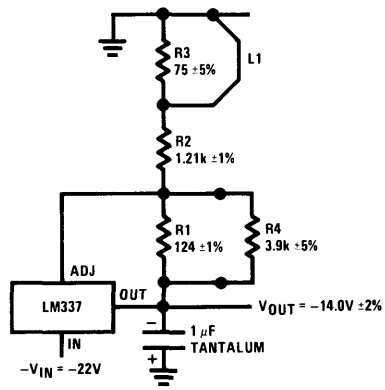
In theory, a 10% total tolerance can be reduced by a factor of $(2^n - 1)$ when n binary-weighted trims are used. In practice, the factor would be $(1.8^n - 1)$ if ±10% trim resistors are used, or $(1.9^n - 1)$ if ±5% resistors are used. For n = 2, a 10% tolerance can be cut to 3.8% p-p or ±1.9%. For n = 3, the spread will be 1.7% p-p or ±0.85%, and most units will be inside ±0.5%, perfectly adequate for many regulator applications.

National Semiconductor manufactures several families of adjustable regulators including LM117, LM150, LM138, LM117HV, LM137, and LM137HV, with output capabilities from 0.5A to 5A and from 1.2V to 57V. For complete specifications and characteristics, refer to the appropriate data sheet.




If $V_{OUT}$ is lower than 20.90V, snip link 1 (if not, don't).
*Then* if $V_{OUT}$ is lower than 21.55V, snip link 2 (if not, don't).
*Then* if $V_{OUT}$ is lower than 21.82V, snip link 3 (if not, don't).

**FIGURE 4. Alternate Trim Scheme**




If $|V_{OUT}|$ is smaller than 13.75V, snip L1 and it will get bigger by 6%.
Then if $|V_{OUT}|$ is bigger than 14.20V, snip R4 and it will get smaller by 3%.

**FIGURE 5. Circuit Which Usually Needs No Trim to Get $V_{OUT}$ Within ±2% Tolerance**

### 7.4.2 Applications for an Adjustable IC Power Regulator

A new 3-terminal adjustable IC power regulator solves many of the problems associated with older, fixed regulators. The LM117, a 1.5A IC regulator is adjustable from 1.2V to 40V with only 2 external resistors. Further, improvements are made in performance over older regulators. Load and line regulation are a factor of 10 better than previous regulators. Input voltage range is increased to 40V and output characteristics are fully specified for loads of 1.5A. Reliability is improved by new overload protection circuitry as well as *100% burn-in* of all parts. The table below summarizes the typical performance of the LM117.

**TABLE I.**

| | |
|---|---|
| Output Voltage Range | 1.25V–40V |
| Line Regulation | 0.01%/V |
| Load Regulation $I_L$ = 1.5A | 0.1% |
| Reference Voltage | 1.25V |
| Adjustment Pin Current | 50 μA |
| Minimum Load Current (Quiescent Current) | 3.5 mA |
| Temperature Stability | 0.01%/°C |
| Current Limit | 2.2A |
| Ripple Rejection | 80 dB |

The overload protection circuitry on the LM117 includes current limiting, safe-area protection for the internal power transistor and thermal limiting. The current limit is set at 2.2A and, unlike presently available positive regulators, remains relatively constant with temperature. Over a −55°C to +150°C temperature range, the current limit only shifts about 10%.

At high input-to-output voltage differentials the safe-area protection decreases the current limit. With the LM117, full output current is available to 15V differential and, even at 40V, about 400 mA is available. With some regulators, the output will shut completely off when the input-to-output differential goes above 30V, possibly causing start-up problems. Finally, the thermal limiting is always active and will protect the device even if the adjustment terminal should become accidentally disconnected.

Since the LM117 is a floating voltage regulator, it sees only the input-to-output voltage differential. This is of benefit, especially at high output voltage. For example, a 30V regulator nominally operating with a 38V input can have a 70V input transient before the 40V input-to-output rating of the LM117 is exceeded.

#### BASIC OPERATION

The operation of how a 3-terminal regulator is adjusted can be easily understood by referring to *Figure 1*, which shows a functional circuit. An op amp, connected as a unity gain buffer, drives a power Darlington. The op amp and biasing circuitry for the regulator is arranged so that all the quiescent current is delivered to the regulator output (rather than ground) eliminating the need for a separate ground terminal. Further, all the circuitry is designed to operate over the 2V to 40V input-to-output differential of the regulator.

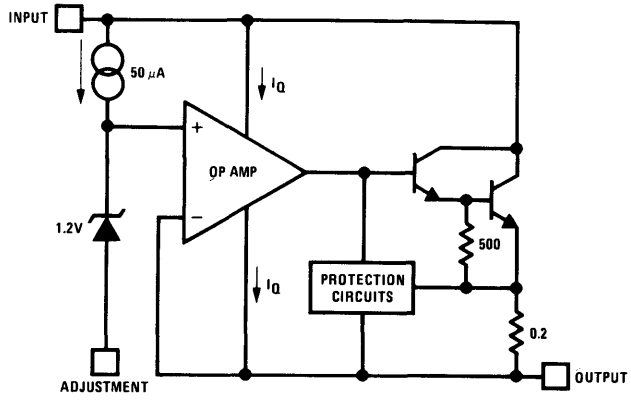



**FIGURE 1. Functional Schematic of the LM117**

A 1.2V reference voltage appears inserted between the non-inverting input of the op amp and the adjustment terminal. About 50 $\mu$A is needed to bias the reference and this current comes out of the adjustment terminal. In operation, the output of the regulator is the voltage of the adjustment terminal plus 1.2V. If the adjustment terminal is grounded, the device acts as a 1.2V regulator. For higher output voltages, a divider R1 and R2 is connected from the output to ground as is shown in *Figure 2*. The 1.2V reference across resistor R1 forces 10 mA of current to flow. This 10 mA then flows through R2, increasing the voltage at the adjustment terminal and therefore the output voltage. The output voltage is given by:

$$V_{OUT} = 1.2V \times \left(1 + \frac{R2}{R1}\right) + 50\,\mu A\ R2$$

The 50 $\mu$A biasing current is small compared to 5 mA and causes only a small error in actual output voltages. Further, it is extremely well regulated against line voltage or load current changes so that it contributes virtually no error to dynamic regulation. Of course, programming currents other than 10 mA can be used depending upon the application.

Since the regulator is floating, all the quiescent current must be absorbed by the load. With too light of a load, regulation is impaired. Usually, a 5 mA programming current is sufficient; however, worst case minimum load for commercial grade parts requires a minimum load of 10 mA. The minimum load current can be compared to the quiescent current of standard regulators.

## APPLICATIONS

An adjustable lab regulator using the LM117 is shown in *Figure 2* and has a 1.2V to 25V output range. A 10 mA program current is set by R1 while the output voltage is set by R2. Capacitor C1 is optional to improve ripple rejection so that 80 dB is obtained at any output voltage. The diode, although not necessary in this circuit since the output is limited to 25V, is needed with outputs over 25V to protect against the capacitors discharging through low current nodes in the LM117 when the input or output is shorted.

The programming current is constant and can be used to bias other circuitry, while the regulator is used as the power supply for the system. In *Figure 3*, the LM117 is used as a 15V regulator while the programming current powers an LM129 zener reference. The LM129 is an IC zener with less than 1$\Omega$ dynamic impedance and can operate over a range of 0.5 mA to 15 mA with virtually no change in performance.

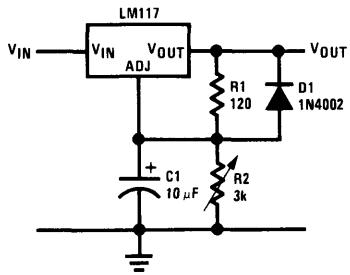



**FIGURE 2. Basic Voltage Regulator**

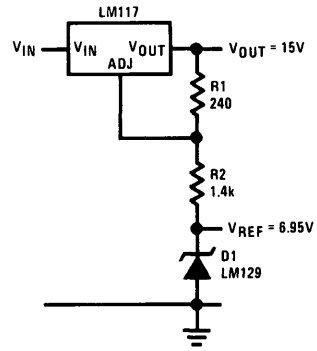



**FIGURE 3. Regulator and Voltage Reference**

Another example of using the programming current is shown in *Figure 4* where the output setting resistor is tapped to provide multiple output voltage to op amp buffers. An additional transistor is included as part of the overload protection. When any of the outputs are shorted, the op amp will current limit and a voltage will be developed across its inputs. This will turn "ON" the transistor and pull down the adjustment terminal of the LM117, causing all outputs to decrease, minimizing possible damage to the rest of the circuitry.

Ordinary 3-terminal regulators are not especially attractive for use as precision current regulators. Firstly, the quiescent current can be as high as 10 mA, giving at least 1% error at 1A output currents, and more error at lower currents. Secondly, at least 7V is needed to operate the device. With the LM117, the only error current is 50 $\mu$A from the adjustment terminal, and only 4.2V is needed for operation at 1.5A or 3.2V at 0.5A. A simple 2-terminal current regulator is shown in *Figure 5* and is usable anywhere from 10 mA to 1.5A.

*Figure 6* shows an adjustable current regulator in conjunction with the voltage regulator from *Figure 2* to make constant voltage/constant current lab-type supply. Current sensing is done across R1, a 1$\Omega$ resistor,

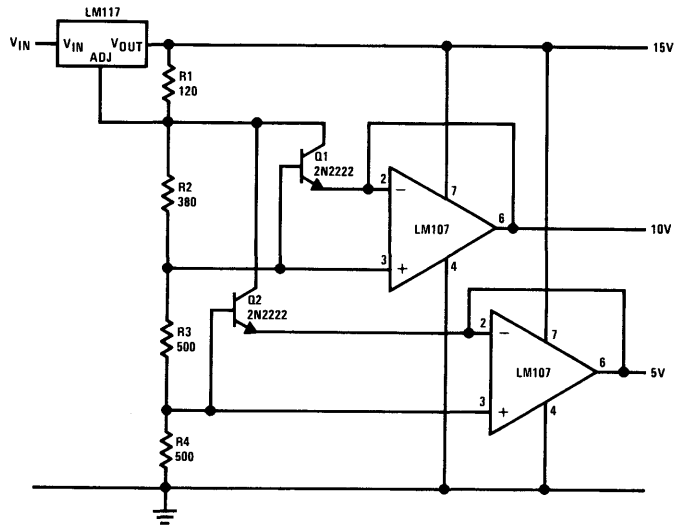



**FIGURE 4. Regulator with Multiple Outputs**

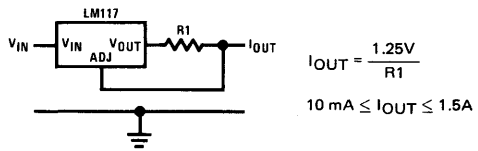



**FIGURE 5. 2-Terminal Current Regulator**

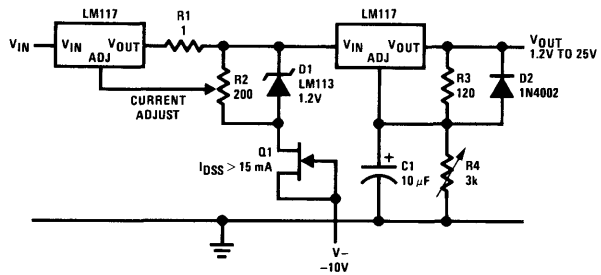



**FIGURE 6. Adjustable Regulator. Constant Voltage/Constant Current, 10 mA to 1.2A**

while R2 sets the current limit point. When the wiper of R2 is connected, the 1Ω sense resistor current is regulated at 1.2A. As R2 is adjusted, a portion of the 1.2V reference of the LM117 is cancelled by the drop across the pot, decreasing the current limit point. At low output currents, current regulation is degraded since the voltage across the 1Ω sensing resistor becomes quite low. For example, with 50 mA output current, only 50 mV is dropped across the sense resistor and the supply rejection of the LM117 will limit the current regulation to about 3% for a 40V change across the device. An alternate current regulator is shown in *Figure 7* using an additional LM117 to provide the reference, rather than an LM113 diode. Both current regulators need a negative supply to operate down to ground.

*Figure 8* shows a 2-wire current transmitter with 10 mA to 50 mA output current for a 1V input. An LM117 is biased as a 10 mA current source to set the minimum current and provide operating current for the control circuitry. Operating off the 10 mA is an LM108 and an LM129 zener. The zener provides a common-mode voltage for operation of the LM108 as well as a 6.9V reference, if needed. Input signals are impressed across R3, and the current through R3 is delivered to the output of the regulator by Q1 and Q2. For a 25Ω resistor, this gives a 40 mA current change for a 1V input. This circuit can be used in 4 mA to 20 mA applications, but the LM117 must be selected for low quiescent current. Minimum operating voltage is about 12V.

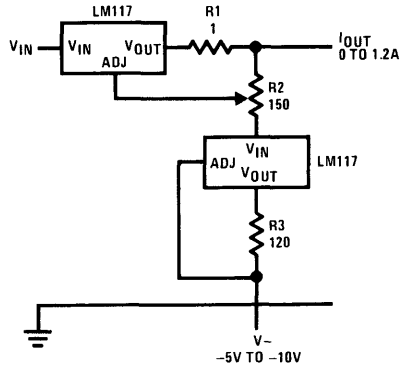



**FIGURE 7. Adjustable Current Regulator**

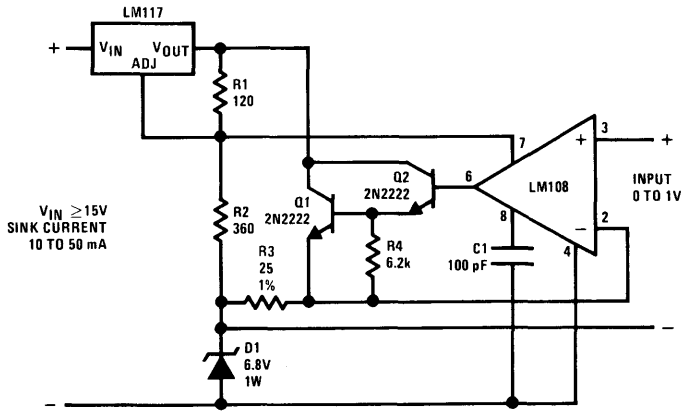



**FIGURE 8. 10 mA to 50 mA 2-Wire Current Transmitter**

### 7.4.3 3-Terminal Regulator is Adjustable

Until now, all of the 3-terminal power IC voltage regulators have a fixed output voltage. In spite of this limitation, their ease of use, low cost, and full on-chip overload protection have generated wide acceptance. Now, with the introduction of the LM117, it is possible to use a single regulator for any output voltage from 1.2V to 37V at 1.5A. Selecting close-tolerance output voltage parts or designing discrete regulators for particular applications is no longer necessary since the output voltage can be adjusted. Further, only one regulator type need be stocked for a wide range of applications. Additionally, an adjustable regulator is more versatile, lending itself to many applications not suitable for fixed output devices.

In addition to adjustability, the new regulator features performance a factor of 10 better than fixed output regulators. Line regulation is 0.01%/V and load regulation is only 0.1%. It is packaged in standard TO-3 transistor packages so that heat sinking is easily accomplished with standard heat sinks. Besides higher performance, overload protection circuitry is improved, increasing reliability.

#### ADJUSTABLE REGULATOR CIRCUIT

The adjustment of a 3-terminal regulator can be easily understood by referring to *Figure 1*, which shows a functional circuit. An op amp, connected as a unity gain buffer, drives a power Darlington. The op amp and biasing circuitry for the regulator are arranged so that all the quiescent current is delivered to the regulator output (rather than ground) eliminating the need for a separate ground terminal. Further, all the circuitry is designed to operate over the 2V to 40V input to output differential of the regulator.

A 1.2V reference voltage appears inserted between the non-inverting input of the op amp and the adjustment terminal. About 50 $\mu$A is needed to bias the reference and this current comes out of the adjustment terminal. In operation, the output of the regulator is the voltage of the adjustment terminal plus 1.2V. If the adjustment terminal is grounded, the device acts as a 1.2V regulator. For higher output voltages, a divider R1 and R2 is connected from the output to ground as is shown in *Figure 2*. The 1.2V reference across resistor R1 forces 5 mA of current to flow. This 5 mA then flows through R2, increasing the voltage at the adjustment terminal and therefore the output voltage. The output voltage is given by:

$$V_{OUT} = 1.2V \left(1 + \frac{R2}{R1}\right) + 50\,\mu A\ R2$$

The 50 $\mu$A biasing current is small compared to 5 mA and causes only a small error in actual output voltages. Further, it is extremely well regulated against line voltage or load current changes so that it contributes virtually no error to dynamic regulation. Of course, programming currents other than 5 mA can be used depending upon the application.

Since the regulator is floating, all the quiescent current must be absorbed by the load. With too light of a load, regulation is impaired. Usually the 5 mA programming current is sufficient; however, worst case minimum load for commercial grade parts requires a minimum load of 10 mA. The minimum load current can be compared to the quiescent current of standard regulators.

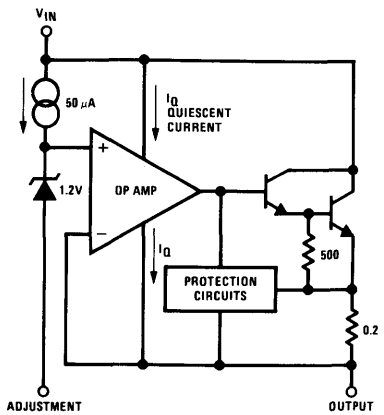
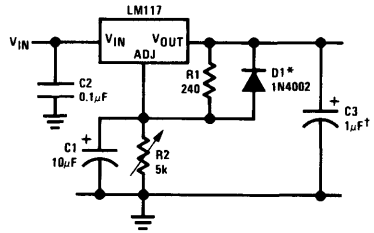



FIGURE 1. Functional Schematic of the LM117




†Solid tantalum
*Discharges C1 if output is shorted to ground

FIGURE 2. Adjustable Regulator with Improved Ripple Rejection

## OVERLOAD PROTECTION CIRCUITRY

An important advancement in the LM117 is improved current limit circuitry. Current limit is set internally at about 2.2A and the current limit remains constant with temperature. Older devices such as the LM309 or LM7800 regulators use the turn-on of an emitter-base junction of a transistor to set the current limit. This causes current limit to typically change by a factor of 2 over a −55°C to +150°C temperature range. Further, to insure adequate output current at 150°C the current limit is relatively high at 25°C, which can cause problems by overloading the input supply.

Also included is safe-area protection for the pass transistor to decrease the current limit as input-to-output voltage differential increases. The safe area protection circuit in the LM117 allows full output current at 15V differential and does not allow the current limit to drop to zero at high input-to-output differential voltages, thus preventing start up problems with high input voltages. *Figure 3* compares the current limit of the LM117 to an LM340 regulator.

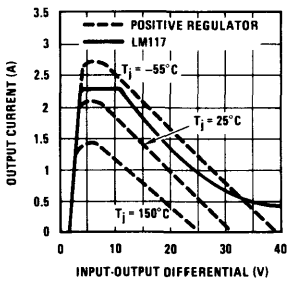



**FIGURE 3. Comparison of LM117 Current Limit with Older Positive Regulator**

Thermal overload protection, included on the chip, turns the regulator OFF when the chip temperature exceeds about 170°C, preventing destruction due to excessive heating. Previously, the thermal limit circuitry required about 7V to operate. The LM117 has a new design that is operative down to about 2V. Further, the thermal limit and current limit circuitry in the LM117 are functional, even if the adjustment terminal should be accidentally disconnected.

## OPERATING THE LM117

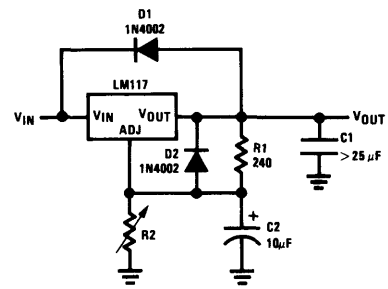
The basic regulator connection for the LM117, as shown in *Figure 2*, only requires the addition of 2 resistors and a standard input bypass capacitor. Resistor R2 sets the output voltage while R1 provides the 5 mA programming current. The 2 capacitors on the adjustment and output terminals are optional for improved performance.

Bypassing the adjustment terminal to ground improves ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μF bypass capacitor, 80 dB ripple rejection is obtainable at any output level. Increases over 10 μF do not appreciably improve the ripple rejection at 120 Hz. If a bypass capacitor is used, it is sometimes necessary to include protection diodes as discussed later, to prevent the capacitor from discharging through internal low current paths in the LM117 and damaging the device.

Although the LM117 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. 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 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 LM117, this discharge path is through a large junction that is able to sustain a 20A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal (C2) can discharge through a low current junction. Discharge occurs when either the input or output is shorted. Internal to the LM117 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V and less than 10 μF capacitance. *Figure 4* shows an LM117 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.




D1 protects against C1 (input shorts)
D2 protects against C2 (output shorts)

**FIGURE 4. Regulator with Protection Diodes Against Capacitor Discharge**

Some care should be taken in making connection to the LM117 to achieve the best load regulation. Series resistance between the output of the regulator and programming resistor R1 should be minimized. Any voltage drop due to load current through this series resistance appears as a change in the reference voltage and degrades regulation. If possible, 2 wires should be connected to the output—1 for load current and 1 for

resistor R1. The ground of R2 can be returned near the ground of the load to provide remote sensing and improve load regulation.

## APPLICATIONS

*Figure 5* shows a 0V to 25V general purpose lab supply. Operation of the LM317 down to 0V output requires the addition of a negative supply so that the adjustment terminal can be driven to −1.2V. An LM329 6.9V reference is used to provide a regulated −1.2V reference to the bottom of adjustment pot R2. The LM129 is an IC zener which has exceptionally low dynamic impedance so the negative supply need not be well regulated. Note that a 10 mA programming current is used since lab supplies are often used with no-load, and the LM317 requires a worst-case minimum load of 10 mA.

The 1.2V minimum output of the LM117 makes it easy to design power supplies with electrical shut-down. At 1.2V, most circuits draw only a small fraction of their normal operating current. In *Figure 6* a TTL input signal causes Q1 to ground the adjustment terminal decreasing the output to 1.2V. If true zero output is desired, the adjustment can be driven to −1.2V; however, this does require a separate negative supply.

When fixed output voltage regulators are used as on-card regulator for multiple cards, the normal output voltage tolerance of ±5% between regulators can cause as much as 10% difference in operating voltage between cards. This can cause operating speed differences in digital circuitry, interfacing problems or decrease noise margins.

*Figure 7* shows a method of adjusting multiple on-card regulators so that all outputs track within ±100 mV. The adjustment terminals of all devices are tied together and a single divider is used to set the outputs. Programming current is set at 10 mA to minimize the effects of the 50 μA biasing current of the regulators and should further be increased if many LM117's are used. Diodes connected across each regulator insure that all outputs will decrease if 1 regulator is shorted.

Two terminal current regulators can be made with fixed-output regulators; however, their high output voltage and high quiescent current limit their accuracy. With the LM117 as shown in *Figure 8*, a high performance current source useful from 10 mA to 1.5A can be made. Current regulation is typically 0.01%/V even at low currents since the quiescent current does not cause an error. Minimum operating voltage is less than 4V, so it is also useful as an in-line adjustable current limiter for protection of other circuitry.

Low cost adjustable switching regulators can be made using an LM317 as the control element. *Figure 9* shows the simplest configuration. A power PNP is used as the switch driving an L-C filter. Positive feedback for hysteresis is applied to the LM317 through R6. When the PNP switches, a small square wave is generated across R5. This is level shifted and applied to the adjustment terminal of the regulator by R4 and C2, causing it to

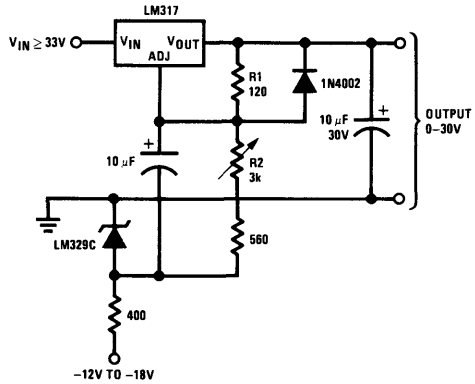



**FIGURE 5. General Purpose 0–30V Power Supply**

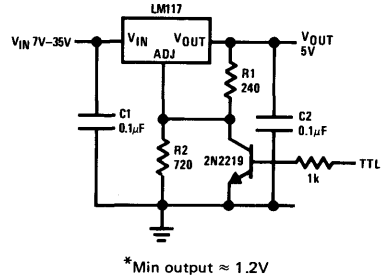



**FIGURE 6. 5V Logic Regulator with Electronic Shutdown***

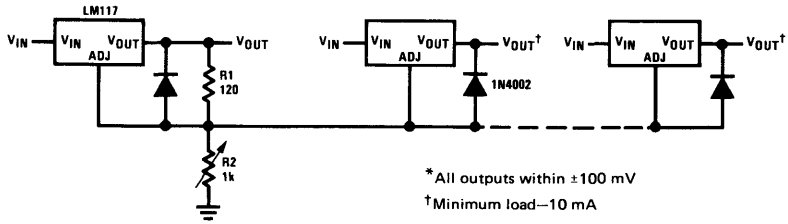
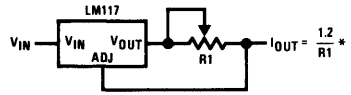
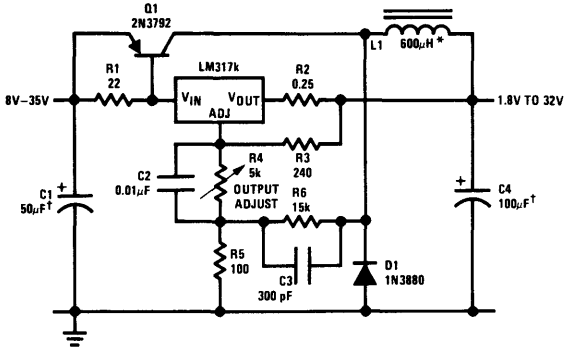



**FIGURE 7. Adjusting Multiple On-Card Regulators with Single Control***




*0.8Ω ≤ R1 ≤ 120Ω

**FIGURE 8. Precision Current Limiter**




†Solid tantalum
*Core—Arnold A-254168-2 60 turns

**FIGURE 9. Low Cost 3A Switching Regulator**

switch ON or OFF. Negative feedback is taken from the output through R3, making the circuit oscillate. Capacitor C3 acts as a speed-up, increasing switching speed, while R2 limits the peak drive current to Q1.

The circuit in *Figure 9* provides no protection for Q1 in case of an overload. A blow-out proof switching regulator is shown in *Figure 10*. The PNP transistor has been replaced by a PNP-NPN combination with LM395's used as the NPN transistors. The LM395 is an IC which acts as an NPN transistor with overload protection. Included on the LM395 is current limiting, safe-area protection and thermal overload protection making the device virtually immune to any type of overload.

Efficiency for the regulators ranges from 65% to 85%, depending on output voltage. At low output voltages, fixed power losses are a greater percentage of the total output power so efficiency is lowest. Operating frequency is about 30 kHz and ripple is about 150 mV, depending upon input voltage. Load regulation is about 50 mV and line regulation about 1% for a 10V input change.

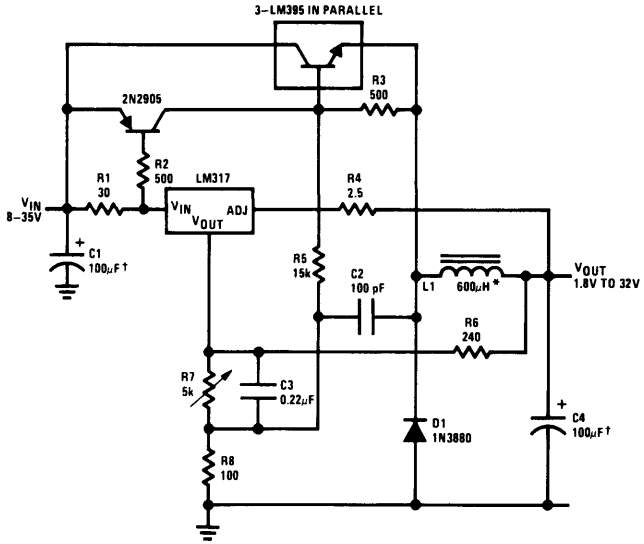
One of the more unique applications for these switching regulators is as a tracking pre-regulator. The only DC connection to ground on either regulator is through the 100Ω resistor (R5 or R8) that sets the hysteresis. Instead of tying this resistor to ground, it can be connected to the output of a linear regulator so that the switching regulator maintains a constant input-to-output differential on the linear regulator. The switching regulator would typically be set to hold the input voltage to the linear regulator about 3V higher than the output.

Battery charging is another application uniquely suited for the LM117. Since battery voltage is dependent on electrochemical reactions, the charger must be designed specifically for the battery type and number of cells. Ni-Cads are easily charged with the constant current sources shown previously. For float chargers on lead-acid type batteries all that is necessary is to set the output of the LM117 at the float voltage and connect it to the battery. An adjustable regulator is mandatory since, for long battery life the float voltage must be precisely controlled. The output voltage temperature coefficient can be matched to the battery by inserting diodes in series with the adjustment resistor for the regulator and coupling the diodes to the battery.

A high performance charger for gelled electrolite lead-acid batteries is shown in *Figure 11*. This charger is designed to quickly recharge a battery and shut off at full charge.

Initially, the charging current is limited to 2A by the internal current limit of the LM117. As the battery voltage rises, current to the battery decreases and when the current has decreased to 150 mA, the charger switches to a lower float voltage preventing overcharge. With a discharged battery, the start switch is not needed since the charger will start by itself; however, it is included to allow topping off even slightly discharged batteries.

When the start switch is pushed, the output of the charger goes to 14.5V set by R1, R2 and R3. Output current is sensed across R6 and compared to a fraction of the 1.2V reference (across R2) by an LM301A op




†Solid tantalum
*Core–Arnold A-254168-2 60 turns

**FIGURE 10. 4A Switching Regulator with Overload Protection**

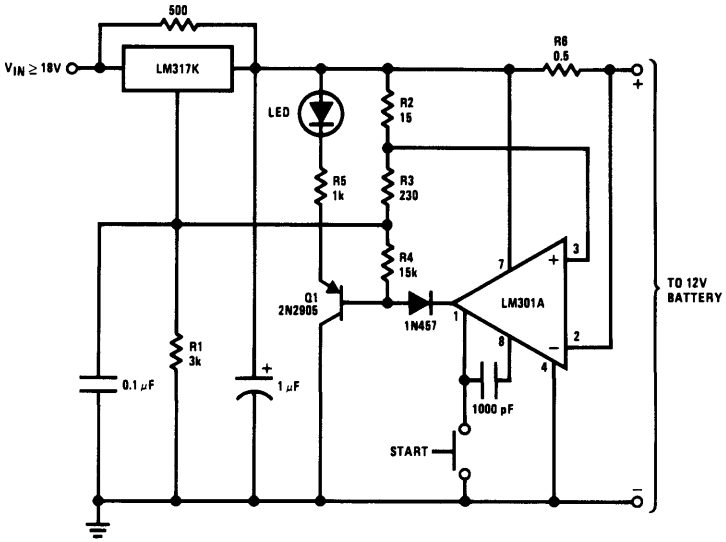



**FIGURE 11. 12V Battery Charger**

amp. As the voltage across R6 decreases below the voltage across R2, the output of the LM101A goes low shunting R1 with R4. This decreases the output voltage from 14.5V to about 12.5V terminating the charging. Transistor Q1 then lights the LED as a visual indication of full charge.

The LM117 can even be used as a peak clipping AC voltage regulator. Two regulators are used, 1 for each polarity of the input as shown in *Figure 12*. Internal to the LM117 is a diode from input-to-output which conducts the current around the device when the opposite regulator is active. Since each regulator is operating independently, the positive and negative peaks must be set separately for a symmetrical output.

## CONCLUSIONS

A new IC power voltage regulator has been developed which is significantly more versatile than older devices. The output voltage is adjustable, in addition to improved regulation specifications. Further, reliability is increased in 2 fashions. Overload protection circuitry has been improved to make the device less susceptable to fault conditions and under short circuit conditions, minimum stress is transmitted back to the input power supply. Secondly, the device is 100% burned-in under short circuit conditions at the time of manufacture. Finally, the LM117 is made with a standard IC production process and packaged in a standard TO-3 power package, keeping costs low.

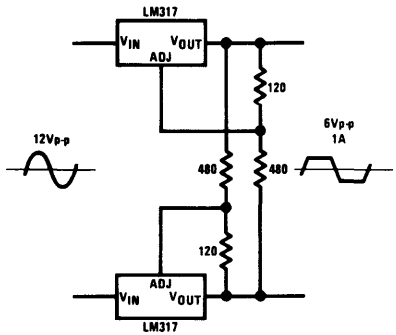



**FIGURE 12. AC Voltage Regulator**

## 7.5 VOLTAGE REGULATORS IN AUTOMOTIVE APPLICATIONS

Most of you have designed and built, at one time or another, a circuit of some sort to go in your car. Maybe it was a timer to turn off your headlights, or a buzzer to remind you to release your handbrake, or a voltage regulator to adapt a stereo system from 6 volts to 12 volts, or whatever.

When you had it all wired up and checked out, and you connected the circuit to the battery of your car, parked in the driveway, it worked fine. But when you started to drive off with your new circuit, did it keep running correctly? *Sometimes it didn't!*

Why?

A 12 volt battery by itself is a very nice well-behaved power supply. *But* when your engine is running, and the alternator is trying to charge the battery, all hell breaks loose!

1. There normally are 1-to-10 volt P-P transients on the 12 volt power-supply which will not usually harm or damage semiconductor circuits, but which can cause severe noise and instability problems, and false-triggering of sensitive circuits such as resettable flip-flops, multivibrators, and high-gain amplifiers. You have to add good filtering and decoupling to the power-supply leads to knock down this problem, as we will discuss below.
2. The automobile is not a very favorable overall environment. Even when you have a circuit completely isolated from the car, ignition noise and CB radio transmissions and miscellaneous transients can cause interference with sensitive circuits (such as the types mentioned above). To avoid electrostatic interference, it is normally advisable to enclose sophisticated or "delicate" circuits in a metal box, which provides electrostatic shielding.
3. In addition to the 1-to-10 volt transients mentioned in 1, there are severe transients on the 12 volt supply at various times. These are especially likely to occur when a battery is temporarily disconnected, or, when the battery terminals become corroded. These transients, known in the industry as "load dump", can be as large as +60 to 80 volts, for a few hundred milliseconds. Another severe transient, which usually occurs when the ignition is turned off, can go to −50 volts for 100 milliseconds. This is known as "field decay", as the excitation in the alternator dies away.

   Other transients which can occur at any time can be as big as 200 to 400 volts for a few microseconds, and these transients can go positive, or negative, or both (ac). Needless to say, no ordinary solid-state circuits can survive this kind of transient without protection. For example, the popular CMOS circuits,which are ideal for low-power designs, can be destroyed by supply voltages larger than +15V or −1 volt.

Let's discuss some protection principles and philosophies. First, let's think about the degree of confidence required . . . .

1. What kind of protection would you provide for your car radio? If it stops working, you'll have to ride home in silence . . . .
2. What kind of protection would you provide for a design of an experimental electronic ignition system for your car? If it doesn't work, how far would you have to walk?
3. What kind of protection would you design in if you are building 10,000 radar detectors? Who's going to pay for warrantee repairs, if any?
4. What kind of protection would you design for a computerized ignition computer for 3 million cars? How will you be sure to avoid a million disgruntled customers and lawsuits if cars quit because of electrical problems.?

Needless to say, the consequences of each level of confidence can be *extremely* different, and extremely serious. In this article, we will comment mostly on the protection and design approaches for levels 1, 2 and 3. (While these approaches may be perfectly applicable to level 4, they would require thousands of man-hours of testing, and millions of dollars, to achieve full confidence.)

Now, lets discuss several circuit approaches for protecting a circuit.

The first is simple decoupling and bypassing. There are many low-power circuits which will run reliably and well in a car if you simply add a large R-C filter in the supply line. As the cost of 2000μF is very reasonable, Figure 1 is a good basic scheme. All the positive and negative transients mentioned above will be heavily quashed by the simple 100Ω, 2000μF filter. For low-power applications, Figure 1 will provide adequate protection at "level 1". But Figure 2 is better, and it costs only a bit more — only a few dimes more.

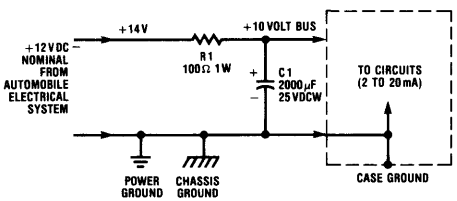



**FIGURE 1. Basic Decoupling for Low-Power Application**

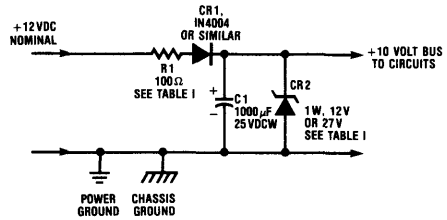



FIGURE 2. Good Decoupling Circuit

In Figure 2, the diode CR1 will provide full tolerance of negative transients on the 12-volt bus; and positive transients will cause less ripple, too. Also, this diode will prevent any harm in case you connect your supply wires backwards, or in case the car battery is reversed. For ten cents' worth of precaution, it's the best insurance you can buy!

The zener diode CR2 also helps to clamp the "10-volt bus" and prevent it from rising too high. If you use a 27-volt zener, this circuit will be highly resistant to any short-term 60-volt transients on the input. It will also withstand the use of a 24-volt battery which some mechanics use for emergency starting.

If you want to use a 12-volt zener to limit the output to less than 15 volts, you will have to use a higher value of resistance for R1, because during fault conditions, most of the current will then go into CR2 rather than C1. If an even lower value of R1 is needed, to permit a larger output current to be drawn, a higher-power zener diode should be used. See Table I. In normal operation, a low-power zener will never get warm, but it can be destroyed by a load-dump transient if R1 is too low. Thus for good reliability, the resistor values of Table I should not be decreased further.

In some applications Metal-Oxide Varistors (MOV's) are recommended as a voltage limiter with capabilities similar to a zener diode. They have the advantage that, as a bulk material, they can dissipate a considerably larger power pulse than a zener diode, and at a lower price. Unfortunately, most MOV's are high voltage devices and are unsuitable for the low voltages (12 to 30 volts) of automotive usage, and we cannot recommend them here.

Table 1. List of Zener Diodes and Component Values for Figure B

| CR1 Voltage & Wattage | Representative JEDEC Type | List Price (in 100's qty.) (1979) | R1 Resistance | Rated Output Current |
|---|---|---|---|---|
| 12V, ½ W | 1N759 or 1N963 | $.31 | 300Ω | 8mA |
| 27V, ½ W | 1N971A or 1N5254 | .31 | 150Ω | 15mA |
| 12V, 1W | 1N4742 | .50 | 150Ω | 15mA |
| 27V, 1W | 1N4750 | .50 | 75Ω | 30mA |
| 12V, 5W | 1N5349A | $1.20 | 27Ω | 75mA |
| 27V, 5W | 1N5361A | 1.20 | 15Ω | 150mA |
| 12V, 50W | 1N2810A or | 5.75 | 1.5Ω | (1.5A) |
| 27V, 50W | 1N3311A | | | |
| 25V, 75W | Motorola MR2525 | $2.60 | 1Ω | (2A) |

The use of a 27-volt zener presumes your circuit can tolerate a +30 volt supply. What if your circuit includes CMOS which is rated for 16 volts absolute maximum?

You might be able to partition your circuit. If the high-current part can tolerate +27 volts briefly, and the CMOS is, of course, drawing only a small current drain, then the circuit in Figure 3 will do nicely. The path to the CMOS circuitry is doubly protected. Note that a fuse has been added to this circuit. The resistor will normally prevent the fuse from blowing, but the fuse is intended to open up in case of a severe overload, such as repetitive 60-volt pulses, or a short on the 10-volt bus. Should you use a fast-blow or a slow-blow fuse? The latter will be more suitable for critical systems where you really don't want the fuse to blow. An instrument-type fuse can open up quickly and provide better protection to delicate circuits. The choice of fuse type is likely to depend on the "level of confidence" you are planning for.

Another good way to run CMOS along with medium-power circuits is shown in Figure 4. These days, a three-terminal regulator that can put out 0.2 or 0.5 amperes

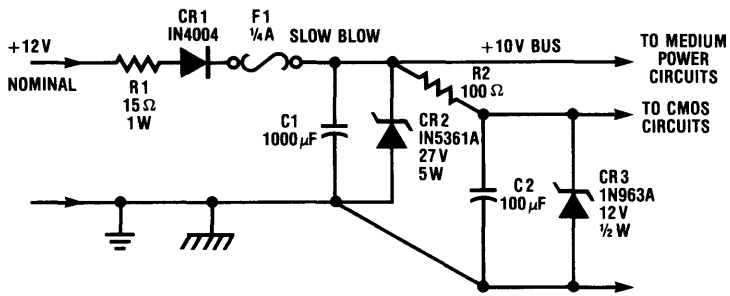



FIGURE 3. Decoupling for CMOS and Other Circuits

costs much less than a dollar — and can easily cost less than a 1-watt zener. The 5-volt bus in Figure 4 will be much less noisy than any of the protected but unregulated voltages above, for a very reasonable price. Most 5-volt regulators are rated to 25 or 30 volts input, and transients on the "10 volt bus" will be rejected by 60dB or more.

The circuit in Figure 5 represents an ultimate in protection and reliability. It incorporates a lot of moderately-priced features, and while you may not want to use all of them, you may pick and choose . . . .

In the case of a 60-volt load-dump, the voltage on the 10-volt bus will not rise above 40 volts because the inductor L1 ($2 or less) will prevent the current from rising for 10 or 20 milliseconds. A large 5,000μF capacitor costs only a couple dollars, and prevents the brief 5 ampere pulse through L1 from pulling the 10-volt bus to an excessive level. A circuit-breaker provides instant reset — (no searching for spare fuses) and the LM2930 provides a 5.0 volt regulated output for critical circuits, while it survives transients as large as +40 volts. And as the LM2930 was especially designed for automotive uses, it will not be damaged by −12 volts on its input bus. Thus in this particular case, a diode is not needed in the power path (presuming that the medium power circuits can tolerate fault reversal of supplies). (Other National 3-terminal regulators such as LM317HV will tolerate as high as +66 volts input with a well-regulated 6-volt output.)

How do we insure that a circuit is really protected against these automotive transients? When your breadboard or prototype is running okay, connect it as shown, in the circuit of Figure 6, and throw S1, for several "transients" at each voltage. When you see the circuit keeps on running, even during and after these tests, you'll know that the protection circuit is really doing its job! That's the way to attain the reliable operation that is being designed into the electronic systems of the 1981½ and 1982½ cars!

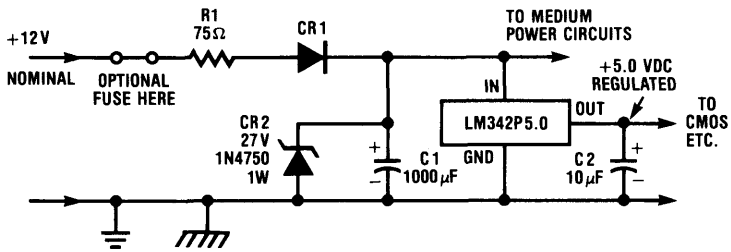



FIGURE 4. Decoupling and Regulation

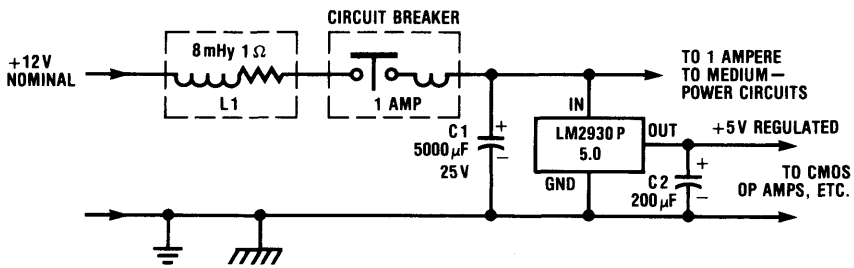
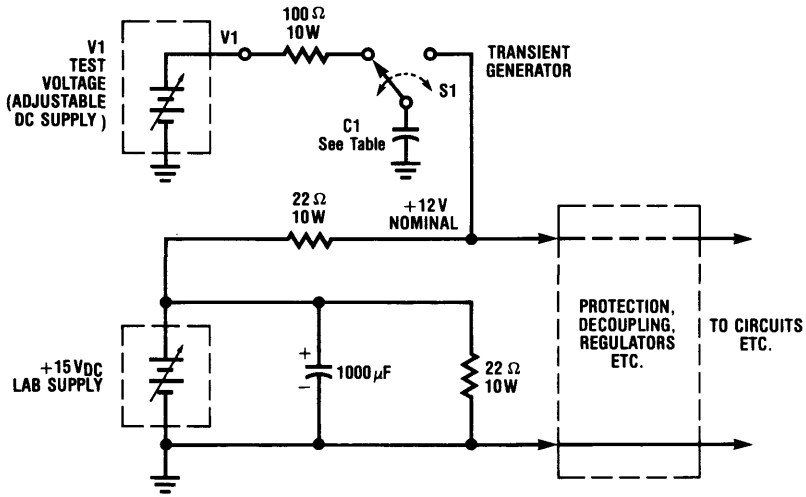



FIGURE 5. Full-Feature Decoupling and Regulation

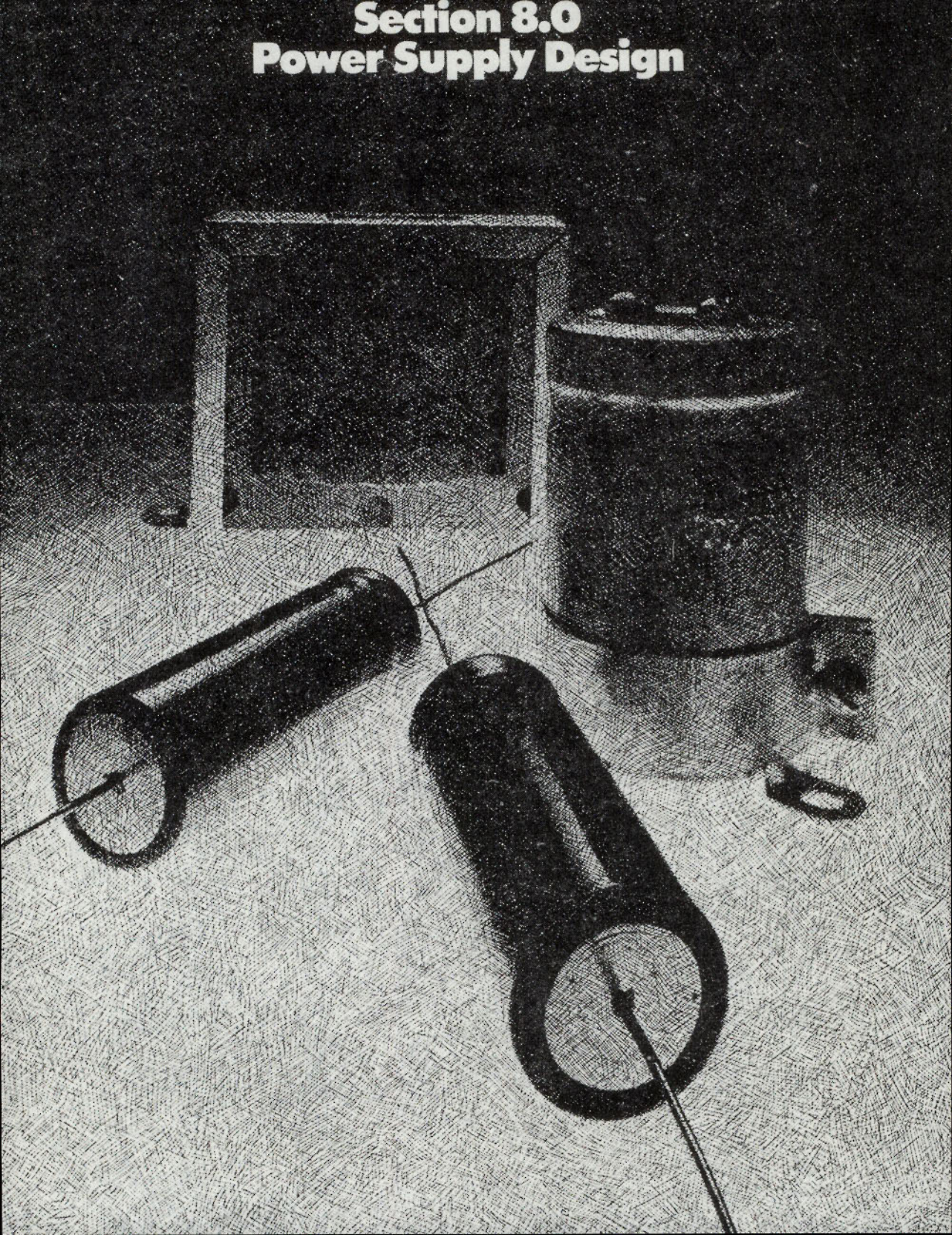



| V1 | C1 | |
|---|---|---|
| +60 to +80V | 2,000 TO 10,000μF | 100V |
| −50V | 1,000 TO 5,000μ | 60V |
| +200V | 1.0μ | 400V |
| −200V | 1.0μ | 400V |
| +400V | 0.1μ | 600V |
| −400V | 0.1μ | 600V |

CAUTION — OBSERVE CORRECT POLARITY & VOLTAGE RATINGS ON C1

FIGURE 6. Transient Generator and Tester

# Section 8.0
# Power Supply Design



# 8.0 POWER SUPPLY DESIGN

*by Ed Polen*
*Signal Transformer, Inc.*

## 8.1 SCOPE

The purpose of this section is to provide a practical guide for the selection of a power supply transformer and filter components. A number of basic assumptions are made to avoid an academic discussion of unnecessary material. For those interested in a rigorous theoretical analysis, there are a number of fine references available.

One of the more esoteric problems encountered by the circuit designer is the selection of power transformer ratings for a particular DC power supply. The designer is immediately confronted with a number of rectifier circuits and filter configurations. For the sake of simplicity, we will make some assumptions which should be valid for 99% of the average designer's applications.

### FILTERS

We will immediately discard the consideration of choke input filters and confine our choice to capacitor input filters because of the following:

1. It is desirable to eliminate the weight and cost of chokes.
2. It can be assumed that the regulator circuit will provide sufficient extra ripple reduction so that an L-C section is not required. In addition, the regulator will compensate for the poor output voltage regulation with load, inherent in capacitor input systems.

The remaining disadvantages of the capacitive input filter system are caused by the discontinuous secondary current flow (high peak-to-average ratio of forward diode current). Current is drawn in short, high amplitude pulses to replace the charge of the filter capacitor which discharges into the load during diode off time. This results in higher effective RMS values of transformer secondary current. However, the transformer average VA rating is the same as the choke input filter because the higher DC output voltage obtained at the capacitor compensates for this effect. In addition, except perhaps for supplies handling very high currents, average semiconductor diodes will meet most of the peak or surge current requirements of capacitive filters.

### RECTIFIER CIRCUIT

The remaining choice is that of a rectifier circuit configuration. The most common single phase circuits are:

1. Half-Wave (single diode)
2. Full-Wave Center-Tapped (two diodes)
3. Full-Wave Bridge (four diodes)
4. Dual Complementary Supply – "Full-Wave Center Tap" (four diodes)

The only advantages of the half-wave rectifier are its simplicity and the savings in cost of one diode. Its disadvantages are many:

1. Extremely high current spikes drawn during the capacitor charging interval (only one current surge per cycle). This current is limited only by the effective transformer and rectifier series impedance, but it must not be too high or it will result in rectifier damage. This short once-per-cycle current spike also results in very high secondary RMS currents.

2. The unidirectional DC current in the transformer secondary biases the transformer core with a component of DC flux density. As a result, more "iron" is needed to avoid core saturation.

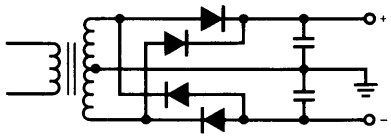
About the only time it would pay to consider using the half-wave rectifier is for very low DC power levels of about ½ watt or less. At these levels a power transformer cannot be reduced very much in size (at reasonable cost) and a small filter capacitor will be large enough for adequate DC smoothing.

The remaining single-phase rectifier circuits are of the "full-wave" type. Secondary current surges occur twice per cycle so that they are of smaller magnitude and the fundamental ripple frequency is double the supply frequency (i.e., 120 Hz rather than the 60 Hz of a half-wave system). All full-wave rectifiers also have the same basic rectified waveform applied to the filter capacitor.

### OTHER FACTORS

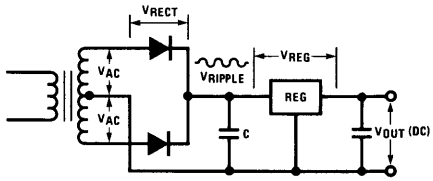
| Full-Wave Center-Tap | Full-Wave Bridge |
|---|---|
| Uses ½ of secondary winding at a time | Uses full secondary winding continuously |
| Requires center-tap | No center-tap required |
| Uses 2 diodes | Uses 4 diodes |

As can be seen above, the choice between FWCT and Bridge configurations is a tradeoff. The bridge rectifier has the best transformer utilization but requires the use of 4 diodes. The extra diodes result in twice the diode voltage drop of a FWCT circuit so that the latter may be preferable in low voltage supplies.



**Dual Complementary Rectifier**

The "dual complementary rectifier circuit" is the combination of two FWCT circuits and is a very efficient way of obtaining two identical outputs of reversed polarity sharing a common ground. It is also called a "center-tapped bridge rectifier."




**Full Wave Center Tap**

The above diagram represents a full-wave center-tapped rectifier using a capacitive filter and is the most common selection for moderate power, regulated DC supplies.

The following assumptions can be made:

1. $V_{REG}$ must be 3 volts DC or greater.
2. $V_{RECT}$ is about 1.25 volts DC.
3. $V_{RIPPLE}$ is about 10% $V_{DC}$ peak.

The following formula may be used for determining the transformer secondary voltage:

$$V_{AC} = \frac{(V_{OUT} + V_{REG} + V_{RECT} + V_{RIPPLE})}{0.92} \times \frac{V_{NOM}}{V_{LOW\ LINE}} \times \frac{1}{\sqrt{2}}$$

where: 0.92 = rectifier efficiency (typical)

$\frac{V_{NOM}}{V_{LOW\ LINE}}$ = the ratio of the nominal AC line voltage to the required low line conditions

A sample illustration of the above will be shown for a supply requiring an output of 5 V DC at 2 A DC to operate down to an input voltage of 95 V RMS.

$V_{OUT} = 5\ V$ $\quad V_{RECT} = 1.25\ V$

$V_{REG} = 3\ V$ $\quad V_{RIPPLE} = 0.5\ (1\ V\ p\text{-}p)$

$$V_{AC} = \frac{9.75}{0.92} \times \frac{115}{95} \times \frac{1}{\sqrt{2}} = 9.07\ V\ AC$$

Therefore, the transformer secondary voltage can be specified as about 18 V CT.

For a bridge rectifier of the same output requirements, the only change is that:

$V_{RECT} = 2 \times 1.25 = 2.5\ V$

As a result $V_{AC}$ will be reformulated as:

$$V_{AC} = \frac{11}{0.92} \times \frac{115}{95} \times \frac{1}{\sqrt{2}} = 10.23\ V\ AC$$

So that the transformer secondary voltage now becomes about 10 V.

## TRANSFORMER SECONDARY CURRENT

The remaining step is to determine the transformer RMS secondary circuit. This can be accurately determined only by complex analysis. However, for practical engineering purposes the chart below may be used.

| Rectifier Type | Filter Type* | Required RMS Secondary Current Rating |
|---|---|---|
| Full-Wave Center-Tap | Choke Input | 0.7 x DC Current |
| Full-Wave Center-Tap | Capacitor Input | 1.2 x DC Current |
| Full-Wave Bridge | Choke Input | DC Current |
| Full-Wave Bridge | Capacitor Input | 1.8 x DC Current |

*Even though we have dropped choke input filters from this discussion, they are included for reference.

For instance, in our particular example (5 V, 2 A DC supply) the transformer RMS current would be:

for FWCT $\quad 1.2 \times 2 = 2.4\ A$

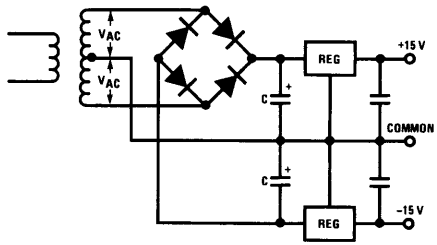
for bridge $\quad 1.8 \times 2 = 3.6\ A$

The total transformer specification would then be:

| Circuit | Secondary Rating |
|---|---|
| FWCT | 18 V CT @ 2.4 A RMS = 43.2 VA |
| bridge | 10 V @ 3.6 A RMS = 36 VA |

## DUAL COMPLEMENTARY SUPPLY

One more common example will be given, i.e., a dual complementary supply for ±15 V @ 100 mA DC.




$V_{OUT} = \pm 15$ $V_{RECT} = 1.25$

$V_{REG} = 3$ $V_{RIPPLE} = 0.75$ ($\approx 1.5$ V p-p)

$$V_{AC} = \frac{(15 + 3 + 1.25 + 0.75)}{0.92} \times \frac{115}{95} \times \frac{1}{\sqrt{2}} = 18.6 \text{ V}$$

$I_{AC} = 1.8 \times 100 \text{ mA} = 180 \text{ mA RMS}$

So that the transformer secondary rating is 37 V CT @ 180 mA RMS.

A precautionary calculation remains to be made. That is, the increase in voltage at the filter capacitor (into the regulator) caused by a high line condition. If we assume our highest line voltage to be 130 V AC then the transformer output (compared to low line) would rise by the ratio 130/95. In the 5 V supply, for instance, the following would happen:

$$V_{AC} = \frac{130}{95} \times 9 = 12.3 \text{ V}$$

In the dual complementary ±15 V supply:

$$V_{AC} = \frac{130}{95} \times 18.6 = 25.5 \text{ V}$$

The increase in output must be absorbed by the regulator, which results in higher regulator power dissipation. The illustrated values are safe for the typical IC regulator but should be checked in any specific application.

## ADDITIONAL FACTORS TO BE CONSIDERED IN TRANSFORMER SELECTION

### LOAD REGULATION

It has been assumed in the previous discussion of the change in transformer secondary voltage with line voltage that no change has been occurring in load current. Therefore, the transformers would seem to be ideal and the transformer secondary voltage ($V_{AC}$) will always be the same.

Actually, all the voltages calculated are assumed to be *full load*. Most reputable transformer manufacturers will rate their parts in this manner, i.e., secondary voltage at full load.

Since transformers are not ideal and have an internal impedance or "regulation" characteristic, variations in load current may cause a problem. If the load should be "light" at "high line," then there will be an additional rise in secondary voltage, beyond that due to the rising line voltage, caused by the decreasing voltage drop in the transformer windings.

Most smaller VA transformers (< 10 VA) have a load regulation of 20% or higher. This means that the transformer no-load voltage will be 20% or more higher than CTS rated full-load voltage. This must then be taken into account in the calculation of maximum $V_{AC}$ (and DC voltage into regulator) with low load currents.

Due to the inherent design characteristics of transformers, "regulation" will vary inversely with size (or VA rating). In larger transformers size is determined primarily by the heat generated by internal losses. In smaller transformers (low VA rating) size is determined by the maximum permissible no-load to full-load regulation. Even though this is an important design limitation, virtually no transformer manufacturer publishes load regulation data in its catalog. Therefore, it would pay to check with the manufacturer in marginal applications.

### TEMPERATURE RISE

In power transformers over 25 VA, temperature rise becomes a factor. The transformer may be constructed with materials capable of withstanding higher temperatures and be a perfectly valid design. However, the extra power dissipated may cause heating of nearby components.

This added power loss adds to the total power dissipated in the circuit area. The problem is not the internal temperature of the transformer but the actual increase in watts lost.

The actual power loss is also not normally published by transformer manufacturers, but may be obtained on request. It should be taken into account in the thermodynamic calculations of equipment temperature.

### SHIELDING

Certain AC power line noise and transients will be fed through to the transformer secondary because of the capacitance between windings. This is a problem which is very difficult to analyze. Whether or not it is a problem in a particular application can best be determined empirically.

If such feedthrough is a problem the most common first step is to use an electrostatic shield between windings. This effectively reduces the inter-winding capacitance. An equal and sometimes superior approach is to choose transformers with non-concentric windings, i.e., with

primary and secondary wound side-by-side rather than one over the other. Both result in at least order of magnitude reductions in capacitance. The "non-concentric" approach, however, also results in higher insulation resistance and makes it simpler to obtain higher insulation test voltages.

Certain types of feedthrough cannot be much affected by the transformer design and other approaches such as line filters or "MOVs" may have to be considered.

### SUMMARY

This has been an attempt to provide a simple, practical method of determining transformer ratings. Certain basic assumptions have been made and this section is not meant as a rigorous academic analysis. However, such material is readily available in the literature (see footnotes). This, we feel, may help bridge the gap for the working designer.

Most transformer catalogs are quite mute regarding the extra details of transformer ratings. Therefore, some inquiries to the manufacturer and/or some empirical testing may be necessary to achieve an optimum selection. The electronic transformer industry is highly fractionalized and has no real industry standards. Therefore, it behooves the designer to be somewhat skeptical and to try to deal with reputable, established sources.

### FOOTNOTES

1. Reuben Lee, *Electronic Transformers & Circuits*, 1947, John Wiley & Sons
   EE Staff – MIT, *Magnetic Circuits & Transformers*, 1943, John Wiley & Sons
   O. H. Schade, *Proc. IRE*, vol 31, p. 356, 1943

## 8.2 CAPACITOR SELECTION

For low current supplies ($I_{OUT} \leq 1$ A) capacitor selection is relatively straightforward. Capacitance is found by the simple formula:

$$C = \frac{I_L}{\Delta V} \times 6 \times 10^{-3}$$

where: $I_L$ = DC load current

$\Delta V$ = peak-to-peak ripple voltage

ripple frequency = 120 Hz

This yields 2000 $\mu$F/amp for 3 V p-p ripple. At DC currents below 1 amp, capacitor heating is usually not a problem and peak-to-peak ripple voltage is the determining factor in capacitor size.

At higher values of capacitance, where the ratio of capacitor outside surface area to volume is significantly lower, internal heating becomes a problem. Ripple current rating may be the determining factor in capacitor selection, rather than ripple voltage. In many cases, capacitor size will have to be increased to prevent excessive internal heating. Manufacturers' data sheets should be consulted (after an initial selection is made) to ensure that capacitor ripple current ratings are met. Remember that the RMS ripple current ratings shown on capacitor data sheets are *not* the same as DC load current. RMS ripple current in a capacitor input filter is *2 to 3 times* the load current. In addition, the time-to-failure used to rate capacitors on data sheets is often 10,000 hours. For five-year life (40,000 hours), ambient temperature may have to be derated 30°C from the data sheet rating. Capacitor life roughly doubles for each 15°C reduction in operating temperature. The following calculations illustrate a typical design example:

assume $I_L = 3$ A, $\Delta V = 4$ V p-p, $V_{DC} = 12$ V

$$C = \frac{(6 \times 10^{-3})(3\text{ A})}{4\text{ V}} = 4{,}500\,\mu\text{F}$$

Manufacturer's rating on a 4,600 $\mu$F/20 V capacitor @ $T_A = 65$°C is 3.1 A RMS. Dividing by 2.5 to convert from RMS ripple current to output current yields a maximum DC load current of 1.24 amps. Obviously either a larger capacitor is required or ambient temperature must be reduced.

As a final note, be sure to check whether the data sheet ratings are for still or moving air. Computer grade capacitors are often rated only for moving air. Other types may be rated for still air, and are therefore actually more conservatively rated.

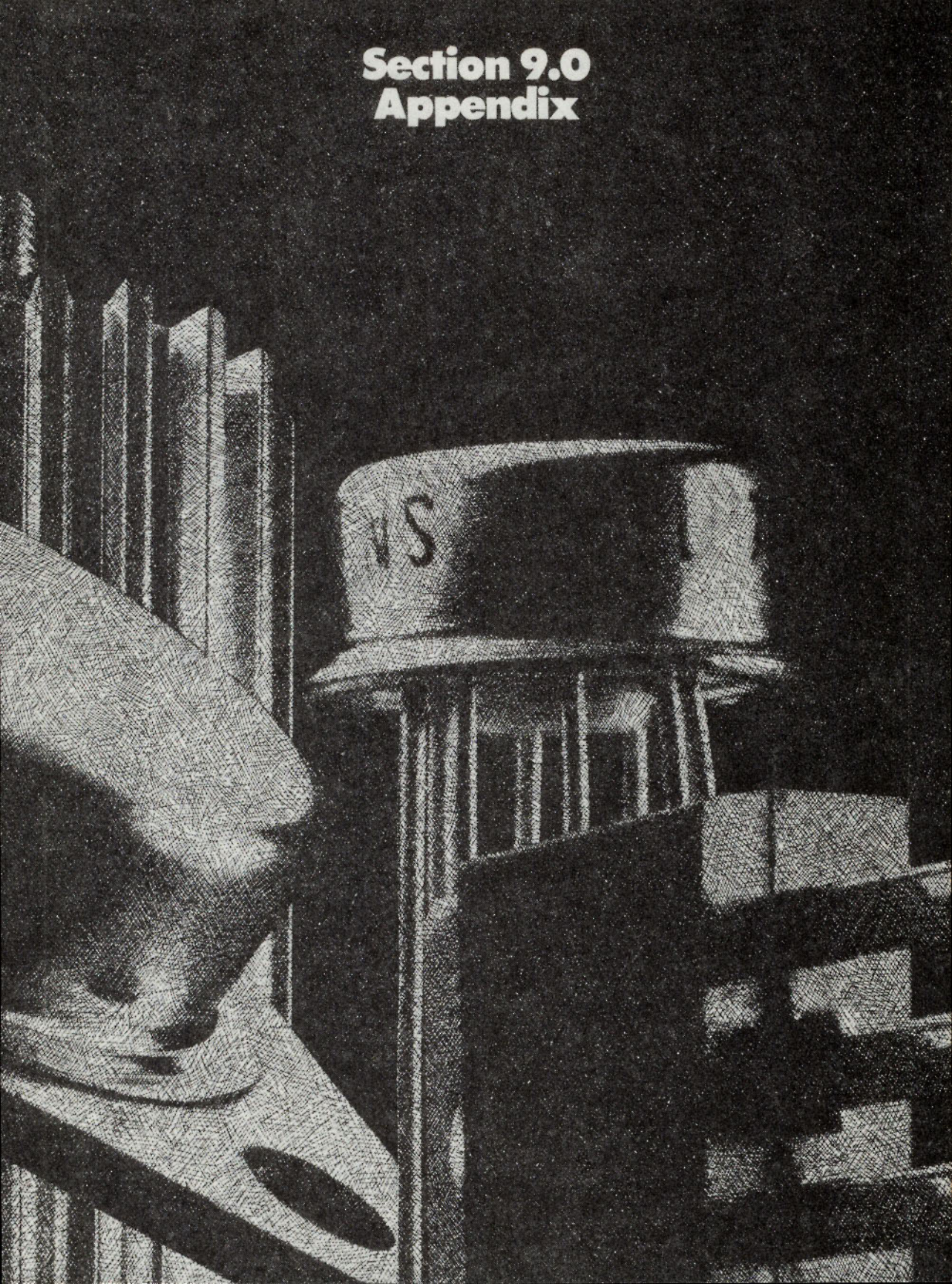
Remember that capacitors are the number one cause of power supply failure. Don't let your supplies dominate the statistics column!

## 8.3 DIODE SELECTION

The RMS value of the current flowing into a capacitor input filter is 2 - 3 times the DC output current because the current is delivered in short pulses. Assuming a full-wave center tap or bridge, this means that although each diode is conducting only on alternate half cycles, it should be rated for *at least* the full output current. To ensure adequate surge capability during turn-on, a diode rating of at least twice the output current is recommended, especially for higher current supplies where the ratio of filter capacitance to output current is somewhat higher. Keep in mind that axial lead diodes achieve most of their heat sinking through the leads. Short leads soldered to large area standoffs or printed circuit pads are definitely recommended.

For "short circuit proof" IC regulated supplies using three-terminal regulators, an additional diode derating may have to be used. Long-term output shorts do not harm the regulator, which goes into a current limit or thermal limit mode to protect itself. The diodes, however, may experience a substantial current increase during the short. Regulator data sheets should be consulted for current limit values, keeping in mind that current limit is a function of input-output voltage differential. At high input voltages, the short circuit current of IC regulators is often less than full load current, tending to alleviate this problem.

# Section 9.0
# Appendix



## A1 DEFINITION OF TERMS

$L_r$, LINE REGULATION = The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

$L_r$, LOAD REGULATION = The change in output voltage for a change in load current at constant chip temperature. Also a pulse test.

DROPOUT VOLTAGE = The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. This is dependent upon load current and junction temperature.

$I_Q$, QUIESCENT CURRENT = That part of input current to the regulator which is not delivered to the load (+ or - standby current for the dual tracking regulators).

RIPPLE REJECTION = The ratio of rms input ripple voltage to rms output ripple voltage.

OUTPUT VOLTAGE BALANCE = The difference in magnitude of the positive and negative output voltage (dual tracking regulators only).

FORCED $V_O$ = That voltage to which the output may be forced without damage to the device (dual tracking regulators).

OUTPUT NOISE VOLTAGE = The rms voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

LONG TERM STABILITY = Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature. .

MAXIMUM POWER DISSIPATION = The maximum total device dissipation for which the regulator will operate withing specifications.

$\theta_{JC}$ = Thermal resistance, junction to case.

$\theta_{JA}$ = Thermal resistance, junction to ambient.

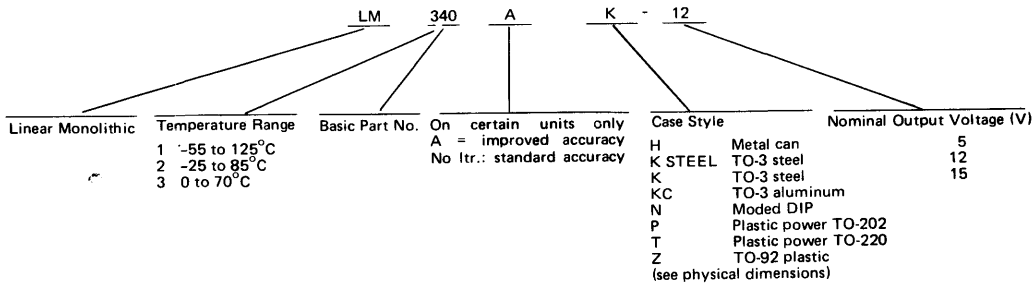
$\theta_{CA}$ = Thermal resistance, case to ambient.

$\theta_{CS}$ = Thermal resistance, case to heat sink.

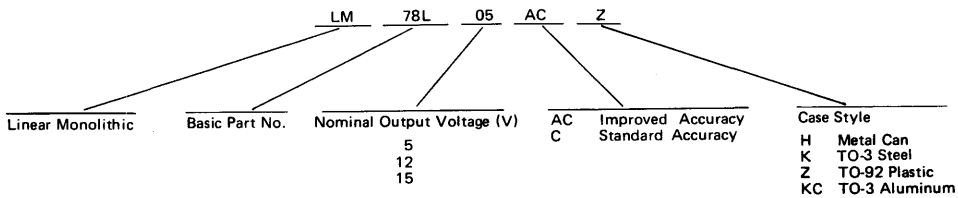
## A2 ORDERING INFORMATION AND PHYSICAL DIMENSIONS

Voltage regulator part numbers include package type and voltage designations. Some also include the letter A to indicate respectively improved. Part number designation is as follows:

Not all regulator basic part numbers are available in all variations of temperature range, case style, or output voltage. See Figure 1.2, Table 2.1, or individual data sheets.

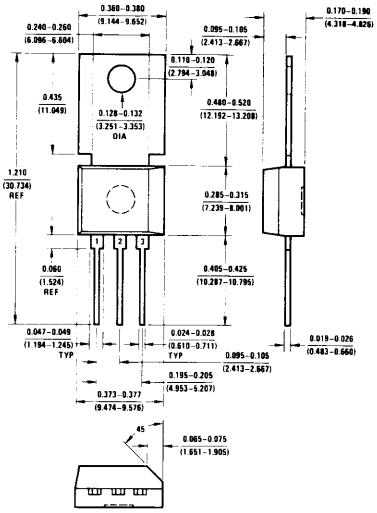



A few regulators use a somewhat different designation as follows:

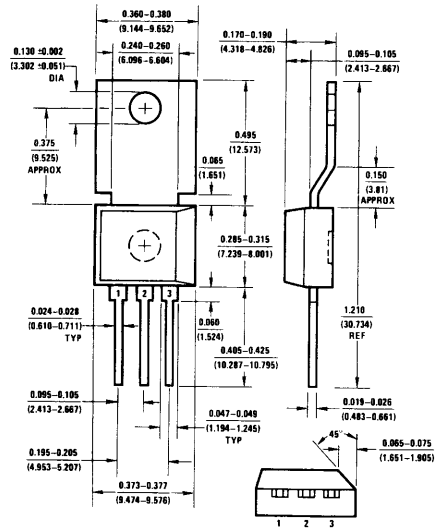


## PHYSICAL DIMENSIONS – PACKAGE OUTLINES

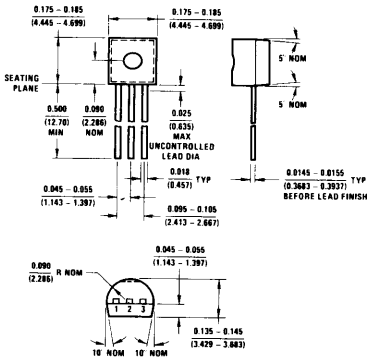
(*All Dimensions* in Inches and Millimeters)



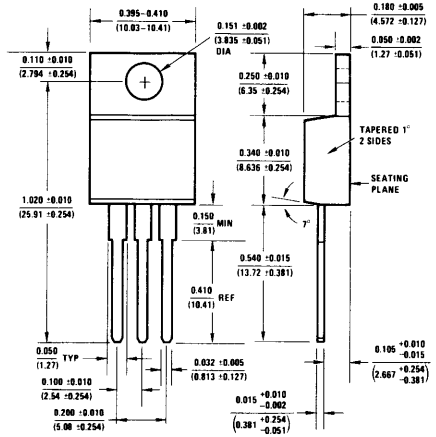

**TO-202**
**Molded Power**
**NS Package Number P03A**




**T-202**
**Molded (T)**
**NS Package Number PO3E**



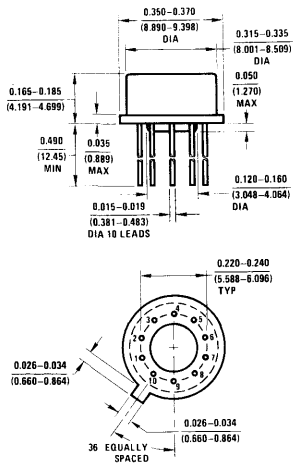

**TO-92**
**Molded Plastic**
**NS Package Number Z03A**



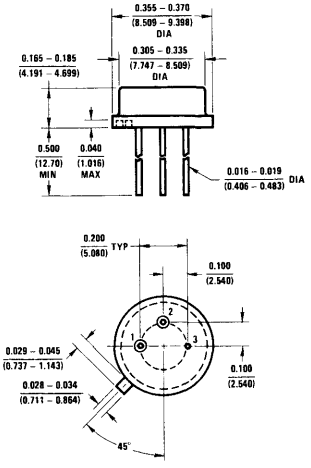

**TO-220**
***Molded (T)***
**NS Package Number TO3B**

## PHYSICAL DIMENSIONS – PACKAGE OUTLINES

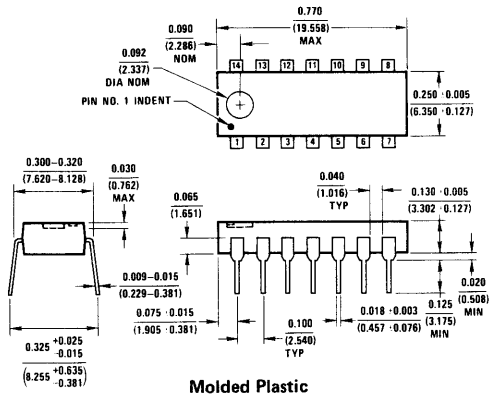
(All Dimensions in Inches and Millimeters)



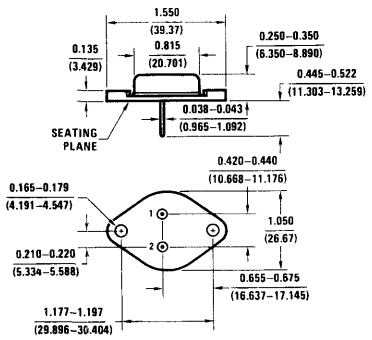

**10-Lead TO-5 Metal Can Package (H)**
**(Low Profile)**
**NS Package H10C**



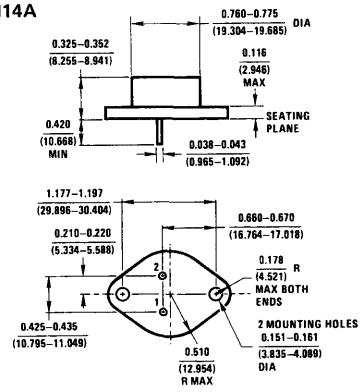

**TO-39 Metal Can (H)**
**NS Package Number H03G**



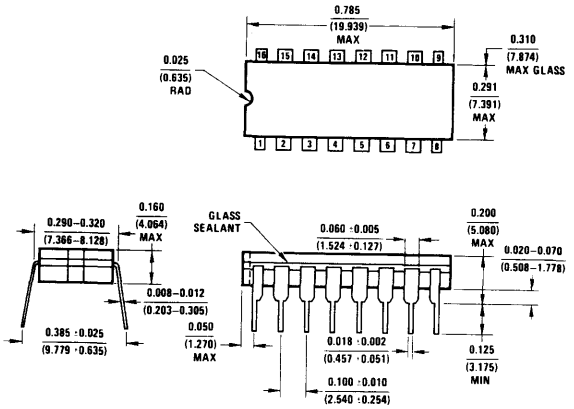

**Molded Plastic**
**Dual-in-Line**
**NS Package Number N14A**



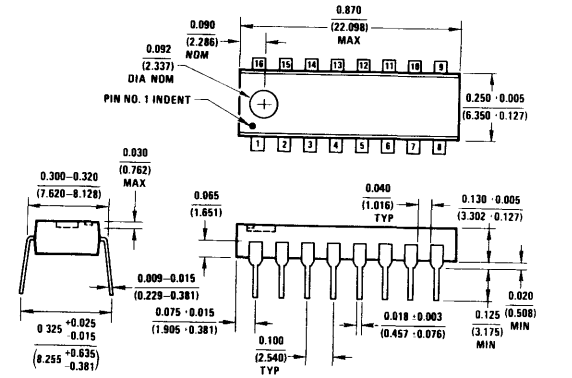

**TO-3 Aluminum**
**Metal Can**
**NS Package Number K02A**




**TO-3 STEEL**
**Metal Can**
**NS Package Number K02A**




**16-Lead Cavity DIP (J)**
**NS Package J16A**




**16-Lead Molded DIP (N)**
**NS Package N16A**

# A3 INTERNAL CIRCUIT FEATURES

## A3.1 Basic Regulator Operation

The basic circuit functions included in all of the three-terminal regulators are shown in Figure A3.1.

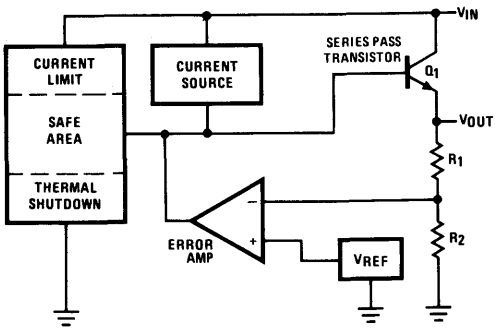



**FIGURE A3.1. Basic Regulator**

$V_{REF}$ is a temperature-stabilized voltage developed from a zener or $\Delta V_{BE}$ circuit as discussed below. The error amplifier compares $V_{REF}$ with a fraction of the output voltage determined by the feedback ratio of $R_2/(R_1 + R_2)$, and thereby controls the base drive of the series pass transistor to provide regulation.

All the regulator protection circuits, current limit, safe area and thermal shutdown, when activated, limit or turn off the base drive for the series pass transistor, so output current is either limited or the series pass transistor is turned completely off.

## A3.2 The Voltage References

There are two types of references which are commonly used in the regulators. The first, known as a "band-gap" or $\Delta V_{BE}$ reference is shown in simplified form in Figure A3.2. Operation of this reference, which was first used in National's LM109, relies on the fact that two monolithic transistors operating at different current densities develop a predictable voltage, $\Delta V_{BE}$, at the emitter of $Q_2$:

$$\Delta V_{BE} = \frac{kT}{q} \ln \frac{I_1}{I_2}$$

This voltage, which has a positive temperature coefficient (TC), is amplified and added to the base-emitter voltage of $Q_3$, which has a negative TC:

$$V_{REF} = \phi_3 + \frac{R_2}{R_1} \Delta V_{BE}$$

If the gain $R_2/R_1$ is properly chosen, the negative TC of $\phi_3$ can be made to cancel the positive TC of $\Delta V_{BE}$ producing nearly zero temperature drift.

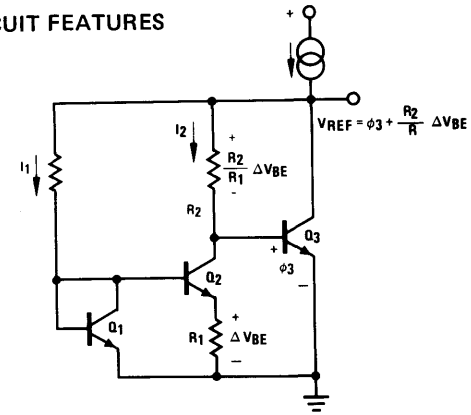



**FIGURE A3.2. Simplified Schematic of Band Gap Reference**

Advantages of the band-gap reference compared with a zener reference are: (1) low noise, since avalanche breakdown devices such as "zeners" are noisy, and (2) better long-term stability. This last property results since transistor $V_{BE}$'s are very stable and insensitive to surface effects. Disadvantages include: (1) it is more difficult to accurately control initial voltage tolerance since $V_{BE}$ varies with transistor base width, (2) temperature drift is usually higher, and (3) thermal gradient effects (see below) are much more severe. The gradient effects arise because the band-gap reference consists of many components, each of which sees slightly different temperatures as heating occurs in the output transistor.

The major drawback of the zener reference, poor long-term stability, can be eliminated if the zener breakdown site is placed below the die surface where it is shielded from high field effects of mobile surface ions. It is difficult to achieve a controlled subsurface breakdown with normal diffusion techniques, but by using a new technology known as *ion implantation*, one can bury a highly doped region below the surface, thereby generating a stable and reproducible avalanche diode (see Figure A3.3).

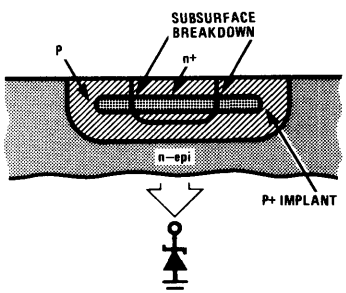



**FIGURE A3.3. Zener (avalanche) Reference Employing Ion Implantation to Produce a Subsurface Breakdown**

In National's line of three-terminal regulators, both band-gap and subsurface zeners are used. Band-gap references are generally chosen for the higher current devices (0.5 A to 3 A), where they offer low noise without significantly increasing die area, while zeners are chosen for small die, lower current (0.1 A and 0.25 A) devices. Because of the good initial voltage control with the zener, National offers ±2% initial voltage tolerances (LM3910 family) for users having a need for high precision.

### A3.3 Operation of the Regulator in Fault Modes

#### Current Limit

With $V_{IN}$ - $V_{OUT}$ less than the 6 V breakdown of zener diode $D_1$ (Figure A3.4), there is no current in $R_3$ and only base current in $R_4$. Therefore the base-emitter voltage on the current limit transistor $Q_2$ essentially equals the voltage developed across current limit sense resistor $R_{CL}$. As the regulator output current increases the voltage across $R_{CL}$ and the base-emitter of $Q_2$ increases until $Q_2$ turns on, preventing additional base drive from reaching the series pass transistor $Q_1$ and thereby limiting the output current.

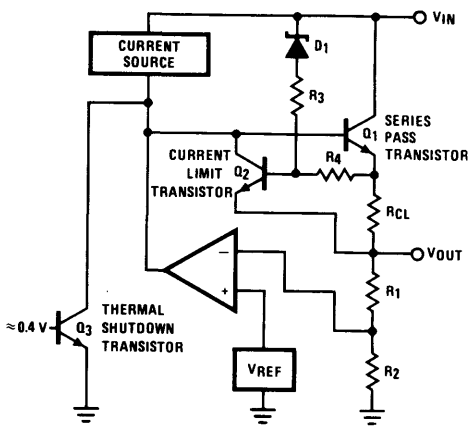



**FIGURE A3.4. Basic Regulator with Protection Circuit**

#### Safe Area Protection

With $V_{IN}$ - $V_{OUT}$ greater than the breakdown voltage of $D_1$, current proportional to $V_{IN}$ - $V_{OUT}$ flows through $D_1$, $R_3$, and $R_4$ to the output. This causes the base-emitter voltage of $Q_2$ to be greater than the voltage drop across $R_{CL}$. Therefore $Q_2$ turns on at lower output currents through $R_{CL}$ and the current limit point of the regulator is reduced. The rate of reduction of current limit with increase in $V_{IN}$ - $V_{OUT}$ is equal to

$$\frac{\Delta I_{CL}}{\Delta(V_{IN} - V_O)} = -\frac{R_4}{R_3 R_{CL}}$$

amps per volt. This is the slope of the safe area curves in Figure A3.5. These curves also show a reduction in current limit with increased junction temperature, which results since a reduced base-emitter voltage is required to turn on the current limit transistor as its junction temperature increases. It is important to note in selecting a regulator that the safe area circuitry causes the maximum output current to drop significantly for large $V_{IN}$ - $V_{OUT}$.

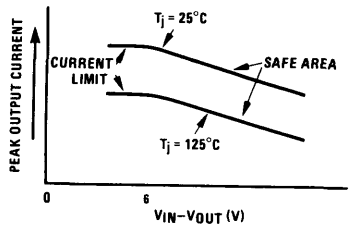



**FIGURE A3.5. Peak Output Current Graph**

#### Thermal Shutdown

The thermal shutdown transistor, $Q_3$ (Figure A3.4), is physically located next to $Q_1$, the major heat source on the die. The base of $Q_3$ is held at approximately 0.4 V, which is below its turn-on voltage at room temperature. As the die temperature increases, the voltage required to turn on $Q_3$ will decrease to 0.4 V. When $Q_3$ turns on it removes all base drive from $Q_1$ and turns off the output. Various regulators have thermal shutdown temperatures ranging from 150°C to 190°C. The regulators also have hysteresis built into their thermal shutdown circuits so that the shutdown temperature is several degrees above the temperature at which the regulator turns back on. This reduces the *chance* of high frequency thermal oscillations.

### A3.4 Output Impedance, Line and Load Regulation: Thermal and Electronic Effects

Few people realize that many of the important specification limits of high power regulators are determined by thermal characteristics rather than electrical ones. To illustrate, suppose a high current step load is placed on a regulator and the output voltage is observed on a storage oscilloscope as shown in Figure A3.6. The response is due to both electronic and thermal effects.

a) Initially a large negative spike (not shown in Figure A3.6) can occur due to the presence of regulator and circuit lead inductance.

b) This is followed by the electronic response of the regulator loop which will consist of a small negative step of a few microseconds duration. Details of this response are effected by the load

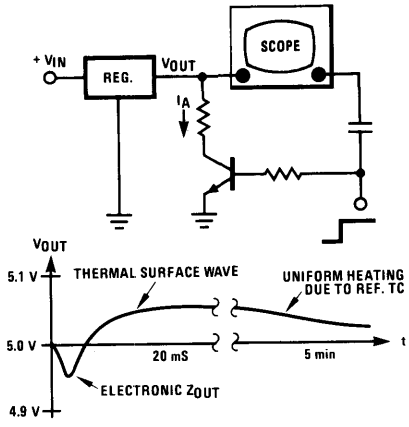



**FIGURE A3.6. Thermal and Electronic Effects on Output Impedance for a Representative Regulator**

capacitor used and by internal wirebond resistance in the regulator. Wirebond resistance ranges from approximately 150 milliohms in the 100 mA TO-92 regulators to 40 milliohms in the 1 A LM340. The 3 A regulators use electronic compensation to cancel effects of wire resistance, so this effect, which would otherwise dominate output impedance, is reduced.

c) As the electronic response decays, a third exponential response is observed with a time constant in the 20 mS to 40 mS region (see Figure A3.6). This is the major thermal response which results from the "thermal surface wave." A qualitative feel for this thermal effect can be obtained by studying the simplified thermal model of the IC die and package shown in Figure A3.7. Referring to Figure A3.7 (b), we see that the power transistor and reference circuitry can be visualized as being coupled thermally by a distributed RC transmission line. This line is, of course, the electrical analog of a thermal line, with temperature replacing voltage, thermal resistances replacing normal Rs, etc.

Applying this electrical analog for a step increase of power in the pass transistor, it is seen that there is an immediate increase in the power transistor temperature, $T_P$. Temperature gradients then begin to set up across the die as the heat propogates through the die (transmission line), see Figure A3.7 (a). The various components of the reference circuitry now are no longer at a single temperature, so small thermally-induced shifts occur in the reference voltage. These shifts then reflect to the output as a change in output voltage in response to a change in *dissipated power* in the pass transistor. We see, therefore, that changes in either load current or input voltage can cause a thermal response, so both load and line regulation have thermal components.

d) The last portion of the response in Figure A3.6 shows a long term (minutes) settling effect, which is due largely to uniform heating effects in the die, header and sink. Such heating gives rise to normal temperature drift effects in the voltage reference which then reflect as small output voltage changes.

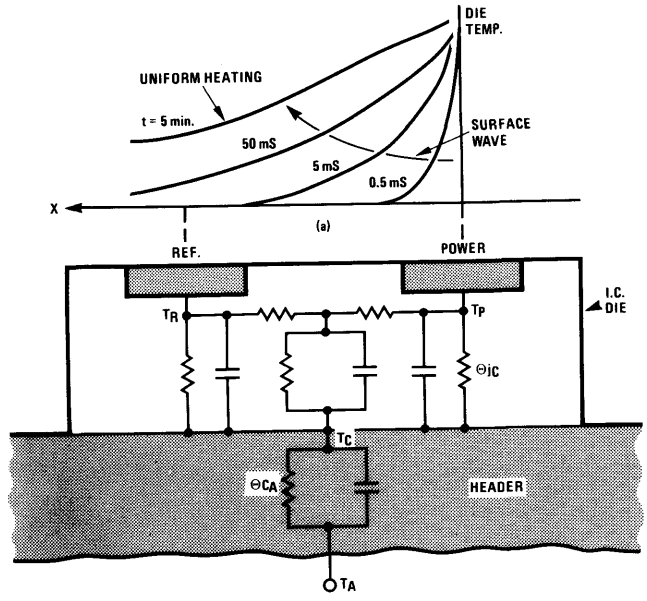



**FIGURE A3.7(a). Plot of Die Temperature vs Distance (x) Along Die After Power Transistor is Turned On.**
**(b). Simplified thermal model of IC power regulator mounted to metal header.**

## A4 TEST CIRCUITS

Figure A4.1 illustrates a circuit for testing line and load regulation, $I_Q$ variations and output voltage of a positive three-terminal regulator. For line and load regulation, a pulse technique is used. An LM555CN timer, connected as an astable multivibrator, is the pulse generator. Duty cycle and pulse width can be adjusted with $R_A$ and $R_B$. The test method is summarized in Table A4.1.

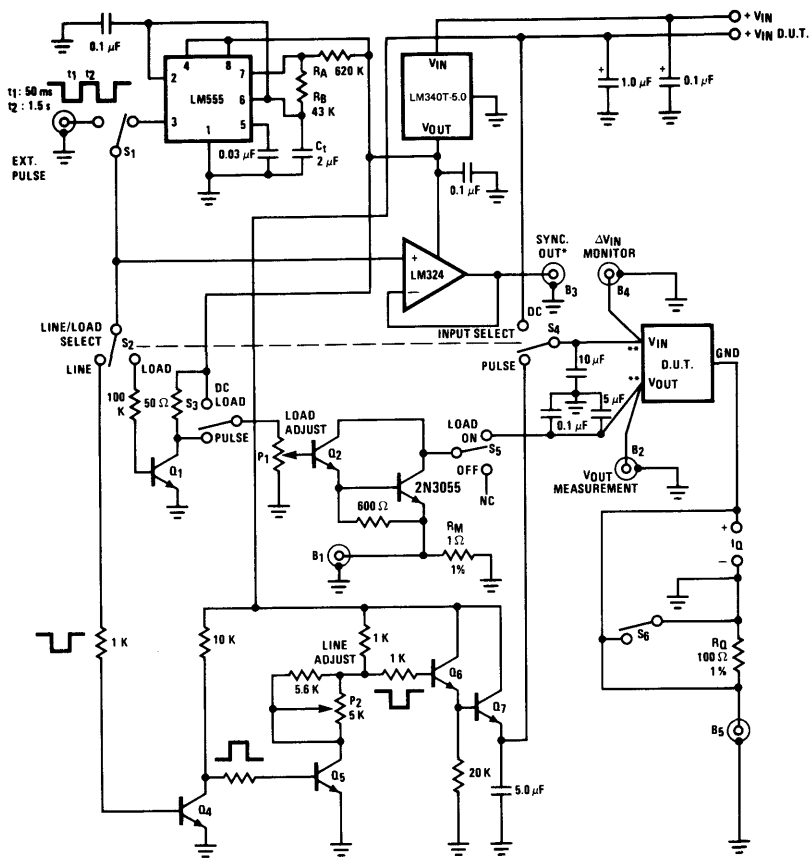
Notice that line regulation is measured with constant load and pulsed input voltage, whereas load regulation is measured with constant input voltage and pulsed load.

Figure A4.2 shows a similar test circuit for negative three-terminal regulators. The schematic does not include a pulse generator, but an LM555CN can be used for generating variable amplitude negative pulses to drive the PNP switch $Q_3$. The loop composed of the two LM101As insures that live voltage variation is within data sheet specifications for LM120, independent of the value of the fixed output voltages of the negative regulator. An LM101A converted as a current-to-voltage converter, is used to monitor quiescent current variations during the load and line regulation test.

The test method is summarized in Table A4.2.

During any kind of measurement the regulator should be lightly preloaded as already shown [$R_P$ = 0.2 $V_{OUT}$ (k$\Omega$)].

Load and line regulation of a dual tracking regulator can be tested in the circuit of Figure A4.3.




NOTE: SELECT $Q_3$, $Q_7$ ACCORDING TO THE RATED POWER OF THE REGULATORS
HEAT SINK $Q_3$, $Q_7$
$Q_2$, $Q_6$, $Q_1$, $Q_4$, $Q_5$ : 2N5030
*OPTIONAL
**KELVIN CONTACTS

**FIGURE A4.1. Test Circuit for Three Terminal Positive Regulators**

**TABLE A4.1.**

| TEST | SWITCH POSITIONS | | | | | Measurement at Connector |
|---|---|---|---|---|---|---|
| | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | |
| Load Regulation (pulsed mode) | LOAD | PULSE | DC | ON | CLOSED | $B_2$ |
| Line Regulation (DC load ON) | LINE | DC | PULSE | ON | CLOSED | $B_2$ |
| Quiescent current, $I_Q$ | LOAD | DC | DC | ON | OPEN | $B_5$ |
| $I_Q$ change: 1) with load | LOAD | PULSE | DC | ON | OPEN | $B_5$ |
| 2) with line | LINE | DC | PULSE | ON | OPEN | $B_5$ |
| Output Voltage | LOAD | DC | DC | ON | CLOSED | $B_2$ |

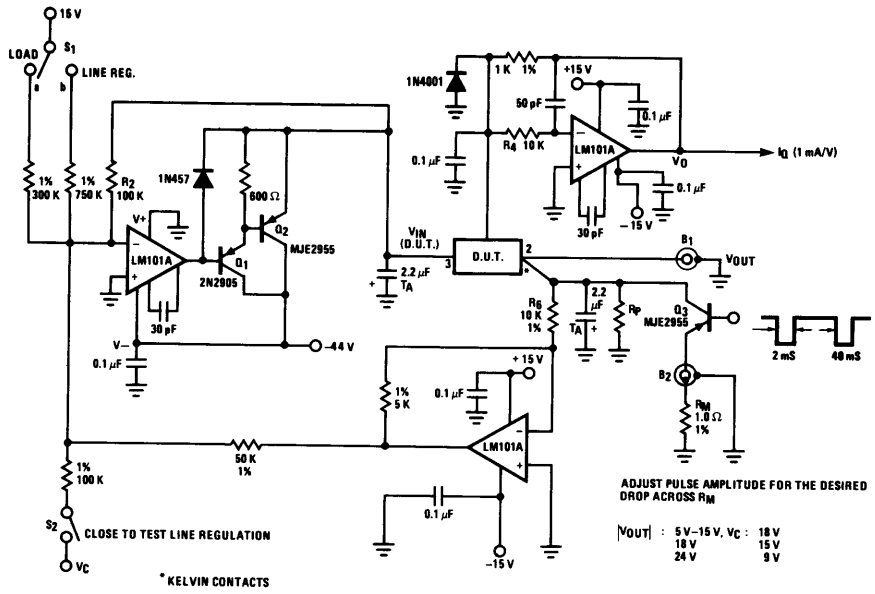



**FIGURE A4.2. LM320 Test Circuit**

**TABLE A4.2**

| TEST | $Q_3$ | $S_1$ | $S_2$ | Measurement at Connector |
|---|---|---|---|---|
| Load Regulation | ON-OFF | a | open | $B_1$ |
| Line Regulation | OFF | b | open-close | $B_1$ |
| Quiescent current, $I_Q$ | OFF | a | open | $V_O$ |
| $I_Q$ change: 1) with load | ON-OFF | a | open | $V_O$ |
| 2) with line | OFF | b | open-closed | $V_O$ |

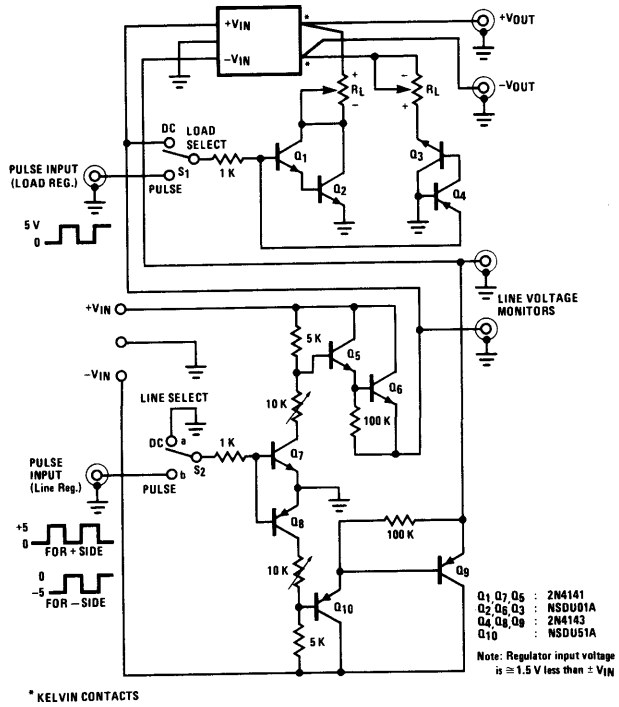



**Figure A4.3. Line and Load Regulation Test Circuit for the Dual Tracking Regulators**

**TABLE A4.3.**

| TEST | $S_1$ | $S_2$ | Measure |
|---|---|---|---|
| Line regulation | DC | PULSE | $\pm V_{OUT}$ |
| Load regulation | PULSE | DC | $\pm V_{OUT}$ |

## A5 RELIABILITY

### IMPROVING POWER SUPPLY RELIABILITY AN182 DEVICE RELIABILITY

For steady state operation within the operating junction temperature range of the part, most failure modes are due to die surface related effects such as zener voltage drift due to field effect changes caused by movement of ions in the oxide. After extensive life testing, National Semiconductor has developed some average "acceleration factors" relating increased surface related failure rates to increased junction temperature. For example: an IC device operating steady state at $T_J = 125^\circ C$ for 500 hours will experience approximately the same failure rate as if operated at $T_J = 70^\circ C$ for 72,500 hours. The acceleration factor from 70°C to 125°C ($T_J$) would be 145. From 125°C to 150°C ($T_J$) the acceleration factor is 6.3. This indicates the greatly increased part lifetime the user can realize by maintaining the part at a low operating junction temperature.

## A6 IMPROVING POWER SUPPLY RELIABILITY WITH IC POWER REGULATORS

Three-terminal IC power regulators include on-chip overload protection against virtually any normal fault condition. Current limiting protects against short circuits fusing the aluminum interconnects on the chip. Safe-area protection decreases the available output current at high input voltages to insure that the internal power transistor operates within its safe area. Finally, thermal overload protection turns off the regulator at chip temperatures of about 170°C, preventing destruction due to excessive heating. Even though the IC is fully protected against normal overloads, careful design must be used to insure reliable operation in the system.

### SHORT CIRCUITS CAN OVERLOAD THE INPUT

The IC is protected against short circuits, but the value of the on-chip current limit can overload the input rectifiers or transformer. The on-chip current limit is usually set by the manufacturer so that with worst-case production variations and operating temperature the device will still provide rated output current. Older types of regulators, such as the LM309, LM340 or LM7800 can have current limits of 3 times their rated output current.

The current limit circuitry in these devices uses the turn-on voltage of an emitter-base junction of a transistor to set the current limit. The temperature coefficient of this junction combined with the temperature coefficient of the internal resistors gives the current limit a −0.5%/°C temperature coefficient. Since devices must operate and provide rated current at 150°C, the 25°C current limit is 120% higher than typical. Production variations will add another ±20% to initial current limit tolerance so a typical 1A part may have a 3A current limit at 25°C. This magnitude of overload current can blow the input transformer or rectifiers if not considered in the initial design—even though it does not damage the IC.

One way around this problem (other than fuses) is by the use of minimum size heat sinks. The heat sink is designed for only normal operation. Under overload conditions, the device (and heat sink) are allowed to heat up to the thermal shut-down temperature. When the device shuts down, loading on the input is reduced.

Newer regulators have improved current limiting circuitry. Devices like the LM117 adjustable regulator, LM123 3A, 5V logic regulator or the LM120 negative regulators have a relatively temperature-stable current limit. Typically these devices hold the current limit within ±10% over the full −55°C to +150°C operating range. A device rated for 1.5A output will typically have a 2.2A current limit, greatly easing the problem of input overloads.

Many of the older IC regulators can oscillate when in current limit. This does not hurt the regulator and is mostly dependent upon input bypassing capacitors. Since there is a large variability between regulator types and manufacturers, there is no single solution to eliminating oscillations. Generally, if oscillations cause other circuit problems, either a solid tantalum input capacitor or a solid tantalum in series with 5Ω to 10Ω will cure the problem. If one doesn't work, try the other.

Start-up problems can occur from the current limit circuitry too. At high input-output differentials, the current limit is decreased by the safe-area protection. In most regulators the decrease is linear, and at input-output voltages of about 30V the output current can decrease to zero. Normally this causes no problem since, when the regulator is initially powered, the output increases as the input increases. If such a regulator is running with, for example, 30V input and 15V output and the output is momentarily shorted, the input-output differential increases to 30V and available output current is zero. Then the output of the regulator stays at zero even if the short is removed. Of course, if the input is turned OFF, then ON, the regulator will come up to operating voltage again. The LM117 is the only regulator which is designed with a new safe-area protection circuit so output current does not decrease to zero, even at 40V differential.

This type of start-up problem is particularly load dependent. Loads to a separate negative supply or constant-current devices are among the worst. Another, usually overlooked, load is pilot lights. Incandescent bulbs draw 8 times as much current when cold as when operating. This severely adds to the load on a regulator,

and may prevent turn-on. About the only solutions are to use an LM117 type device, or bypass the regulator with a resistor from input to output to supply some start-up current to the load. Resistor bypassing will not degrade regulation if, under worst-case conditions of maximum input voltage and minimum load current, the regulator is still delivering output current rather than absorbing current from the resistor. *Figure 1* shows the output current of several different regulators as a function of output voltage and temperature.

When a positive regulator (except for the LM117) is loaded to a negative supply, the problem of start-up can be doubly bad. First, there is the problem of the safe-area protection as mentioned earlier. Secondly, the internal circuitry cannot supply much output current when the output pin is driven more negative than the ground pin of the regulator. Even with low input voltages, some positive regulators will not start when loaded by 50 mA to a negative supply. Clamping the output to ground with a germanium or Schottky diode usually solves this problem. Negative regulators, because of different internal circuitry, do not suffer from this problem.

## DIODES PROTECT AGAINST CAPACITOR DISCHARGE

It is well recognized that improper connections to a 3-terminal regulator will cause its destruction. Wrong polarity inputs or driving current into the output (such as a short between a 5V and 15V supply) can force high currents through small area junctions in the IC, destroying them. However, improper polarities can be applied accidently under many normal operating conditions, and the transient condition is often gone before it is recognized.

Perhaps the most likely sources of transients are external capacitors used with regulators. *Figure 2* shows the discharge path for different capacitors used with a positive regulator. Input capacitance, C1, will not cause a problem under any conditions. Capacitance on the ground pin (or adjustment pin in the case of the LM117) can discharge through 2 paths which have low current junctions.

If the output is shorted, C2 will discharge through the ground pin, possibly damaging the regulator. A reverse-biased diode, D2, diverts the current around the regulator, protecting it. If the input is shorted, C3 can discharge through the output pin, again damaging the regulator. Diode D1 protects against C3, preventing damage. Also, with both D1 and D2 in the circuit, when the input is shorted, C2 is discharged through both diodes, rather than the ground pin.

In general, these protective diodes are a good idea on all positive regulators. At higher output voltages, they become more important since the energy stored in the capacitors is larger. With negative regulators and the LM117, there is an internal diode in parallel with D1 from output-to-input, eliminating the need for an external diode if the output capacitor is less than 25 $\mu$F.

Another transient condition which has been shown to cause problems is momentary loss of the ground connection. This charges the output capacitor to the unregulated input voltage minus a 1–2V drop across the regulator. If the ground is then connected, the output capacitor, C3, discharges through the regulator output to the ground pin, destroying it. In most cases, this problem occurs when a regulator (or card) is plugged into a powered system and the input pin is connected

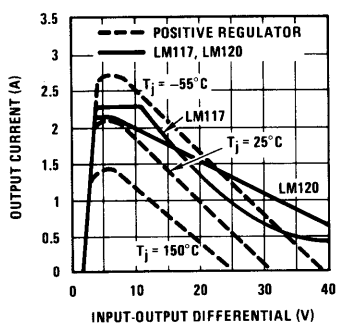



**FIGURE 1. Comparison of LM117 Current Limit with Older Regulators**

before the ground. Control of the connector configuration, such as using 2 ground pins to insure ground is connected first, is the best way of preventing this problem. Electrical protection is cumbersome. About the only way to protect the regulator electrically is to make D2 a power zener 1V to 2V above the regulator voltage and include 10Ω to 50Ω in the ground lead to limit the current.

## LOW OPERATING TEMPERATURE INCREASES LIFE

Like any semiconductor circuit, lower operating temperature improves reliability. Operating life decreases at high junction temperatures. Although many regulators are rated to meet specifications at 150°C, it is not a good idea to design for continuous operation at that temperature. A reasonable maximum operating temperature would be 100°C for epoxy packaged devices and 125°C for hermetically sealed (TO-3) devices. Of course, the lower the better, and decreasing the above temperatures by 25°C for normal operation is still reasonable.

Another benefit of lowered operating temperatures is improved power cycle life for low cost soft soldered packages. Many of today's power devices (transistors included) are assembled using a TO-220 or TO-3 aluminum soft solder system. With temperature excursions, the solder work-hardens and with enough cycles the solder will ultimately fail. The larger the temperature change, the sooner failure will occur. Failures can start at about 5000 cycles with a 100°C temperature excursion. This necessitates, for example, either a large heat sink or a regulator assembled with a hard solder, such as steel packages, for equipment that is continuously cycled ON and OFF.

## THERMAL LIMITING GIVES ABSOLUTE PROTECTION

Without thermal overload protection, the other protection circuitry will only protect against short term overloads. With thermal limiting, a regulator is not destroyed by long time short circuits, overloads at high temperatures or inadequate heat sinking. In fact, this overload protection makes the IC regulator tolerant of virtually any abuse, with the possible exception of high-voltage transients, which are usually filtered by the capacitors in most power supplies.

One problem with thermal limiting is testing. With a 3-terminal regulator, short-circuit protection and safe-area protection are easily measured electrically. For thermal limiting to operate properly, the electrical circuitry on the IC must function and the IC chip must be well die-attached to the package so there are no hot spots. About the only way to insure that thermal limiting works is to power the regulator, short the output, and let it cook. If the regulator still works after 5 minutes (or more) the thermal limit has protected the regulator.

This type of testing is time consuming and expensive for the manufacturer so it is not always done. Some regulators, such as the LM317, LM337, LM320, LM323, and LM340 do receive an electrical burn-in in thermal shutdown as part of their testing. This insures that the thermal limiting works as well as reducing infant mortality. If it is probable that a power supply will have overloads which cause the IC to thermally limit, testing the regulator is in order.

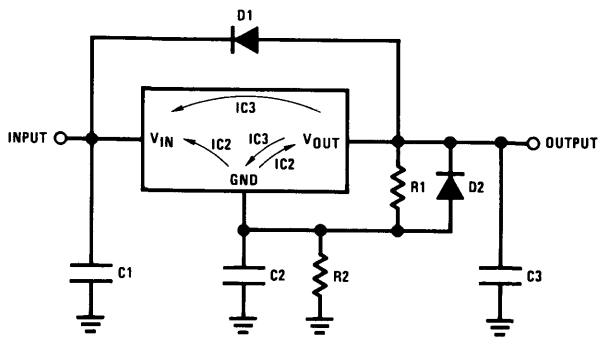



**FIGURE 2. Positive Regulator with Diode Protection Against Transient Capacitor Discharge**

## A7 VOLTAGE REGULATOR CROSS REFERENCE GUIDE

| Part # | Package | Voltage | Temp. | Max. Current | NSC Equiv. |
|---|---|---|---|---|---|
| | | | **RAYTHEON** | | |
| RC4194TK | TO-66 | Variable | COM | 250mA | – |
| RM4194TK | TO-66 | Variable | MIL | 250mA | – |
| RC4194D | TO-116 DIP | Variable | COM | 150mA | – |
| RM4194D | TO-116 DIP | Variable | MIL | 150mA | – |
| RC4195TK | TO-66 | 115 | COM | 150mA | LM325N*** |
| RM4195TK | TO-66 | 115 | MIL | 150mA | LM125N*** |
| RC4195T | TO-99 | 115 | COM | 150mA | LM325H*** |
| RM4195T | TO-99 | 115 | MIL | 150mA | LM125H*** |
| RC4195DN | TO-116 DIP | 115 | COM | 150mA | LM325N*** |
| LM104H | TO-78 | Variable | MIL | 20mA | LM104H |
| LM204H | TO-78 | Variable | IND | 20mA | LM204H |
| LM304H | TO-78 | Variable | COM | 20mA | LM304H |
| LM104F | TO-86 | Variable | MIL | 20mA | LM104F |
| LM105H | TO-78 | Variable | MIL | 25mA | LM105H |
| LM205H | TO-78 | Variable | IND | 25mA | LM205H |
| LM305H | TO-78 | Variable | COM | 25mA | LM305H |
| LM105AH | TO-78 | Variable | MIL | 25mA | – |
| LM205AH | TO-78 | Variable | IND | 25mA | – |
| LM305AH | TO-78 | Variable | COM | 25mA | LM305AH |
| LM105F | TO-86 | Variable | MIL | 25mA | LM105F |
| LM105AF | TO-86 | Variable | MIL | 25mA | – |
| LM109K | TO-3 | 5V | MIL | 1.5A | LM109K |
| LM209K | TO-3 | 5V | IND | 1.5A | LM209K |
| LM309K | TO-3 | 5V | COM | 1.5A | LM309K |
| LM109H | TO-78 | 5V | MIL | 0.5A | LM109H |
| LM209H | TO-78 | 5V | IND | 0.5A | LM209H |
| LM309H | TO-78 | 5V | COM | 0.5A | LM309H |
| RM723T | TO-78 | Variable | MIL | 150mA | LM723H |
| RC723T | TO-78 | Variable | COM | 150mA | LM723CH |
| RM723D | TO-116 | Variable | MIL | 150mA | LM723J |
| RC723D | TO-116 | Variable | COM | 150mA | LM723CJ |
| RC723DP | TO-116 | Variable | COM | 150mA | LM723CN |
| | | | **MOTOROLA** | | |
| MC7805CT | TO-220 | 5V | COM | 1.5A | LM7805CT |
| MC7806CT | TO-220 | 6V | COM | 1.5A | LM317T*** |
| MC7808CT | TO-220 | 8V | COM | 1.5A | LM317T*** |
| MC7812CT | TO-220 | 12V | COM | 1.5A | LM7812CT |
| MC7815CT | TO-220 | 15V | COM | 1.5A | LM7815CT |
| MC7818CT | TO-220 | 18V | COM | 1.5A | LM317T*** |
| MC7824CT | TO-220 | 24V | COM | 1.5A | LM317T*** |
| MC7805CK | TO-3 | 5V | COM | 1.5A | LM7805CK |
| MC7806CK | TO-3 | 6V | COM | 1.5A | LM317K STEEL*** |
| MC7808CK | TO-3 | 8V | COM | 1.5A | LM317K STEEL*** |
| MC7812CK | TO-3 | 12V | COM | 1.5A | LM7812CK |
| MC7815CK | TO-3 | 15V | COM | 1.5A | LM7815CK |
| MC7818CK | TO-3 | 18V | COM | 1.5A | LM317K STEEL*** |
| MC7824CK | TO-3 | 24V | COM | 1.5A | LM317K STEEL*** |
| MC78L05CP | TO-92 | 5V | COM | 0.1A | LM78L05ACZ |
| MC78L05ACP | TO-92 | 5V | COM | 0.1A | LM78L05ACZ |
| MC78L06CP | TO-92 | 6V | COM | 0.1A | LM317H*** |
| MC78L06ACP | TO-92 | 6V | COM | 0.1A | LM317H*** |
| MC78L08CP | TO-92 | 8V | COM | 0.1A | LM317H*** |
| MC78L08ACP | TO-92 | 8V | COM | 0.1A | LM317H*** |
| MC78L12CP | TO-92 | 12V | COM | 0.1A | LM78L12ACZ |
| MC78L12ACP | TO-92 | 12V | COM | 0.1A | LM78L12ACZ |
| MC78L15CP | TO-92 | 15V | COM | 0.1A | LM78L15ACZ |
| MC78L15ACP | TO-92 | 15V | COM | 0.1A | LM78L15ACZ |
| MC78L18CP | TO-92 | 18V | COM | 0.1A | LM317H*** |
| MC78L18ACP | TO-92 | 18V | COM | 0.1A | LM317H*** |
| MC78L24CP | TO-92 | 24V | COM | 0.1A | LM317H*** |
| MC78L24ACP | TO-92 | 24V | COM | 0.1A | LM317H*** |

***Not Pin for Pin

| Part # | Package | Voltage | Temp. | Max. Current | NSC Equiv. |
|---|---|---|---|---|---|
| | | **MOTOROLA (cont.)** | | | |
| MC78M05CT | TO-220 | 5V | COM | 0.5A | LM78M05CP* |
| MC78M06CT | TO-220 | 6V | COM | 0.5A | LM317MP*** |
| MC78M08CT | TO-220 | 8V | COM | 0.5A | LM317MP*** |
| MC78M12CT | TO-220 | 12V | COM | 0.5A | LM78M12CP* |
| MC78M15CT | TO-220 | 15V | COM | 0.5A | LM78M15CP* |
| MC78M18CT | TO-220 | 18V | COM | 0.5A | LM317MP*** |
| MC78M24CT | TO-220 | 24V | COM | 0.5A | LM317MP*** |
| MC78M05CG | TO-39 | 5V | COM | 0.5A | LM340LAH-5.0** |
| MC78M06CG | TO-39 | 6V | COM | 0.5A | LM317H*** |
| MC78M08CG | TO-39 | 8V | COM | 0.5A | LM317H*** |
| MC78M12CG | TO-39 | 12V | COM | 0.5A | LM340LAH-12** |
| MC78M15CG | TO-39 | 15V | COM | 0.5A | LM340LAH-15** |
| MC78M18CG | TO-39 | 18V | COM | 0.5A | LM317H*** |
| MC78M24CG | TO-39 | 24V | COM | 0.5A | LM317H*** |
| MC79M05CT | TO-220 | -5V | COM | 0.5A | LM79M05CP* |
| MC79M05.2CT | TO-220 | -5.2V | COM | 0.5A | LM337MP*** |
| MC79M06 | TO-220 | -6V | COM | 0.5A | LM337MP*** |
| MC79M08CT | TO-220 | -8V | COM | 0.5A | LM337MP*** |
| MC79M12CT | TO-220 | -12V | COM | 0.5A | LM79M12CP* |
| MC79M15CT | TO-220 | -15V | COM | 0.5A | LM79M15CP* |
| MC79M18CT | TO-220 | -18V | COM | 0.5A | LM337MP*** |
| MC79M24CT | TO-220 | -24V | COM | 0.5A | LM337MP*** |
| MC79L05ACP | TO-92 | -5V | COM | 0.1A | LM79L05ACZ |
| MC79L12ACP | TO-92 | -12V | COM | 0.1A | LM79L12ACZ |
| MC79L15ACP | TO-92 | -15V | COM | 0.1A | LM79L15ACZ |
| MC79L18ACP | TO-92 | -18V | COM | 0.1A | LM337H*** |
| MC79L24ACP | TO-92 | -24V | COM | 0.1A | LM337H*** |
| MC79L05ACG | TO-39 | -5V | COM | 0.1A | LM320H-5.0 |
| MC79L12ACG | TO-39 | -12V | COM | 0.1A | LM320H-12 |
| MC79L15ACG | TO-39 | -15V | COM | 0.1A | LM320H15 |
| MC79L18ACG | TO-39 | -18V | COM | 0.1A | LM337H*** |
| MC79L24ACG | TO-39 | -24V | COM | 0.1A | LM337H*** |
| 123 | TO-3 | 5V | MIL | 3A | LM123K STEEL |
| 223 | TO-3 | 5V | IND | 3A | LM223K STEEL |
| 323 | TO-3 | 5V | COM | 3A | LM323K STEEL |
| 117K | TO-3 | Adjustable | MIL | 1.5A | LM117K STEEL |
| 217K | TO-3 | Adjustable | IND | 1.5A | LM217K STEEL |
| 317K | TO-3 | Adjustable | COM | 1.5A | LM317K STEEL |
| 317T | TO-220 | Adjustable | COM | 1.5A | LM317T |
| 117H | TO-39 | Adjustable | MIL | 0.5A | LM117H |
| 217H | TO-39 | Adjustable | IND | 0.5A | LM217H |
| 317H | TO-39 | Adjustable | COM | 0.5A | LM317H |
| MC3420L | DIP | Switch Mode | COM | – | LM3524J |
| MC3420P | DIP | Switch Mode | COM | – | LM3524N |
| MC3520L | DIP | Switch Mode | MIL | – | LM3524J |
| MC7902CT | TO-220 | -2V | COM | 1A | LM337T*** |
| MC7905CT | TO-220 | -5V | COM | 1A | LM7905CT |
| MC7905.2CT | TO-220 | -5.2V | COM | 1A | LM337T*** |
| MC7906CT | TO-220 | -6V | COM | 1A | LM337T*** |
| MC7908CT | TO-220 | -8V | COM | 1A | LM337T*** |
| MC7912CT | TO-220 | -12V | COM | 1A | LM7912CT |
| MC7915CT | TO-220 | -15V | COM | 1A | LM7915CT |
| MC7918CT | TO-220 | -18V | COM | 1A | LM337T*** |
| MC7924CT | TO-220 | -24V | COM | 1A | LM337T*** |
| MC7902CK | TO-3 | -2V | COM | 1A | LM337K STEEL*** |
| MC7905CK | TO-3 | -5V | COM | 1A | LM7905CK |
| MC7905.2CK | TO-3 | -5.2V | COM | 1A | LM337K STEEL*** |
| MC7906CK | TO-3 | -6V | COM | 1A | LM337K STEEL*** |
| MC7908CK | TO-3 | -8V | COM | 1A | LM337K STEEL*** |
| MC7912CK | TO-3 | -12V | COM | 1A | LM7912CK |

*Pin compatible TO-202 package
**Lower output current – 100mA

| Part # | Package | Voltage | Temp. | Max. Current | NSC Equiv. |
|---|---|---|---|---|---|
| | | **MOTOROLA (cont.)** | | | |
| MC7915CK | TO-3 | -15V | COM | 1A | LM7915CK |
| MC7918CK | TO-3 | -18V | COM | 1A | LM377K STEEL*** |
| MC7924CK | TO-3 | -24V | COM | 1A | LM337K STEEL*** |
| MC1723L | Cer. DIP | Variable | MIL | 150mA | LM723J |
| MC1723G | TO-78 | Variable | MIL | 150mA | LM723H |
| MC1723CL | Cer. DIP | Variable | COM | 150mA | LM723CJ |
| MC1723CG | TO-78 | Variable | COM | 150mA | LM723CH |
| MLM105G | TO-78 | Variable | MIL | 20mA | LM105H |
| MLM109K | TO-3 | 5V | MIL | 1.5A | LM109K |
| MLM205G | TO-78 | Variable | MIL | 20mA | LM205H |
| MLM305G | TO-78 | Variable | COM | 20mA | LM305H |
| MLM309K | TO-3 | 5V | COM | 1.5A | LM309K |
| MC1468R | TO-3 | 115V | COM | 100mA | LM325J*** |
| MC1468G | TO-78 | 115V | COM | 100mA | LM325H*** |
| MC1468L | DIP | 115V | COM | 100mA | LM325N*** |
| MC1568R | TO-3 | 115V | MIL | 100mA | LM325N*** |
| MC1568G | TO-78 | 115V | MIL | 100mA | LM325H*** |
| | | **TI** | | | |
| 117LA | TO-39 | Adjustable | MIL | 0.5A | LM117H |
| 217LA | TO-39 | Adjustable | IND | 0.5A | LM217H |
| 317LA | TO-39 | Adjustable | COM | 0.5A | LM317H |
| 317KD | TO-202 | Adjustable | COM | 0.5A | LM317MP |
| 317KC | TO-220 | Adjustable | COM | 1.5A | LM317T |
| 340KC-5 | TO-220 | 5V | COM | 1.5A | LM340T-5.0 |
| 340KC-6 | TO-220 | 6V | COM | 1.5A | LM317T*** |
| 340KC-8 | TO-220 | 8V | COM | 1.5A | LM317T*** |
| 340KC-10 | TO-220 | 10V | COM | 1.5A | LM317T*** |
| 340KC-12 | TO-220 | 12V | COM | 1.5A | LM340T-12 |
| 340KC-15 | TO-220 | 15V | COM | 1.5A | LM340T-15 |
| 340KC-18 | TO-220 | 18V | COM | 1.5A | LM317T*** |
| 340KC-24 | TO-220 | 24V | COM | 1.5A | LM317T*** |
| 1524J | DIP | – | Switch Mode | – | LM1524J |
| 2524J | DIP | – | Switch Mode | – | LM2524J |
| 3524J/N | DIP | – | Switch Mode | – | LM3524J/N |
| TL494MJ | DIP | – | Switch Mode | – | LM1524J |
| TL494IJ | DIP | – | Switch Mode | – | LM2524J |
| TL494CJ/N | DIP | – | Switch Mode | – | LM3524J/N |
| TL497AMJ | DIP | – | Switch Mode | – | LM1524J |
| TL497AIJ | DIP | – | Switch Mode | – | LM2524J |
| TL497ACJ/N | DIP | – | Switch Mode | – | LM3524J/N |
| 7805AACKC | TO-220 | 5V | COM | 1.5A | LM340AT-5.0 |
| 7805KC | TO-220 | 5V | COM | 1.5A | LM7805CT |
| 7806KC | TO-220 | 6V | COM | 1.5A | LM317T*** |
| 7808KC | TO-220 | 8V | COM | 1.5A | LM317T*** |
| 7885KC | TO-220 | 8.5V | COM | 1.5A | LM317T*** |
| 7810KC | TO-220 | 10V | COM | 1.5A | LM317T*** |
| 7812KC | TO-220 | 12V | COM | 1.5A | LM7812CT |
| 7815KC | TO-220 | 15V | COM | 1.5A | LM7815CT |
| 7818KC | TO-220 | 18V | COM | 1.5A | LM317T*** |
| 7824KC | TO-220 | 24V | COM | 1.5A | LM317T*** |
| 78L05ACLP | TO-92 | 5V | COM | 0.1A | LM78L05ACZ |
| 78L06ACLP | TO-92 | 6V | COM | 0.1A | LM317H*** |
| 78L08ACLP | TO-92 | 8V | COM | 0.1A | LM317H*** |
| 78L10ACLP | TO-92 | 10V | COM | 0.1A | LM317H*** |
| 78L12ACLP | TO-92 | 12V | COM | 0.1A | LM78L12ACZ |
| 78L15ACLP | TO-92 | 15V | COM | 0.1A | LM78L15ACZ |
| 78M05MLA/CLA | TO-39 | 5V | MIL/COM | 0.5A | LM140LAH / LM340LAH-5.0*** |
| 78M06MLA/CLA | TO-39 | 6V | MIL/COM | 0.5A | LM117H / LM317H*** |
| 78M08MLA/CLA | TO-39 | 8V | MIL/COM | 0.5A | LM117H / LM317H*** |

*Pin compatible TO-202 package
**Lower output current – 100mA
***Not pin for pin equivalent

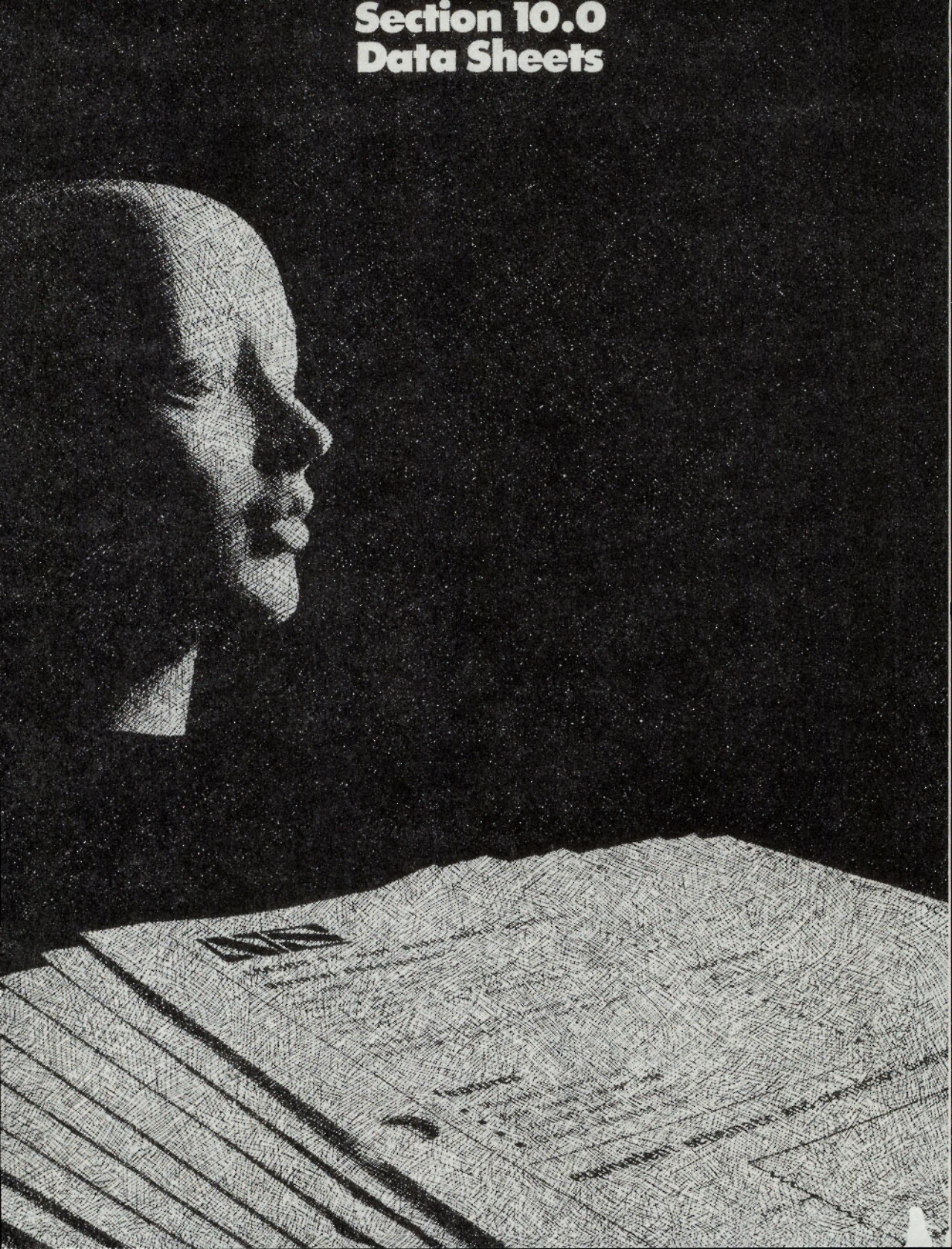
| Part # | Package | Voltage | Temp. | Max. Current | NSC Equiv. |
|---|---|---|---|---|---|
| | | **TI (cont.)** | | | |
| 78M12MLA/CLA | TO-39 | 12V | MIL/COM | 0.5A | LM140LAH / LM340LAH-12** |
| 78M15MLA/CLA | TO-39 | 15V | MIL/COM | 0.5A | LM140LAH / LM340LAH-15 |
| 78M24MLA/CLA | TO-39 | 24V | MIL/COM | 0.5A | LM117H / LM317H*** |
| 78M05CKC | TO-220 | 5V | COM | 0.5A | LM78M05CP** |
| 78M06CKC | TO-220 | 6V | COM | 0.5A | LM317MP*** |
| 78M08CKC | TO-220 | 8V | COM | 0.5A | LM317MP*** |
| 78M12CKC | TO-220 | 12V | COM | 0.5A | LM78M12CP** |
| 78M15CKC | TO-220 | 15V | COM | 0.5A | LM78M15CP** |
| 78M24CKC | TO-220 | 24V | COM | 0.5A | LM317MP*** |
| 78M05CKD | TO-202 | 5V | COM | 0.5A | LM78M05CP |
| 78M06CKD | TO-202 | 6V | COM | 0.5A | LM317MP*** |
| 78M08CKD | TO-202 | 8V | COM | 0.5A | LM317MP*** |
| 78M12CKD | TO-202 | 12V | COM | 0.5A | LM78M12CP |
| 78M15CKD | TO-202 | 15V | COM | 0.5A | LM78M15CP |
| 78M24CKD | TO-202 | 24V | COM | 0.5A | LM317MP*** |
| 7905C | TO-220 | -5V | COM | 1.5A | LM7905CT |
| 7952C | TO-220 | -5.2V | COM | 1.5A | LM3375*** |
| 7906C | TO-220 | -6V | COM | 1.5A | LM3375*** |
| 7908C | TO-220 | -8V | COM | 1.5A | LM3375*** |
| 7912C | TO-220 | -12V | COM | 1.5A | LM7912CT |
| 7915C | TO-220 | -15V | COM | 1.5A | LM7915CT |
| 7918C | TO-220 | -18V | COM | 1.5A | LM3375*** |
| 7924C | TO-220 | -24V | COM | 1.5A | LM3375*** |
| 79M05MLA/CLA | TO-39 | -5V | MIL/COM | 0.5A | LM120H / LM320H-5.0 |
| 79M06MLA/CLA | TO-39 | -6V | MIL/COM | 0.5A | LM137H / LM337H*** |
| 79M08MLA/CLA | TO-39 | -8V | MIL/COM | 0.5A | LM137H / LM337H*** |
| 79M12MLA/CLA | TO-39 | -12V | MIL/COM | 0.5A | LM120H / LM320H-12 |
| 79M15MLA/CLA | TO-39 | -15V | MIL/COM | 0.5A | LM120H / LM320H-15 |
| 79M24MLA/CLA | TO-39 | -24V | MIL/COM | 0.5A | LM137H / LM337H*** |
| 79M05CKC | TO-220 | -5V | COM | 0.5A | LM79M05CP** |
| 79M06CKC | TO-220 | -6V | COM | 0.5A | LM337MP*** |
| 79M08CKC | TO-220 | -8V | COM | 0.5A | LM337MP*** |
| 79M12CKC | TO-220 | -12V | COM | 0.5A | LM79M12CP** |
| 79M15CKC | TO-220 | -15V | COM | 0.5A | LM79M15CP** |
| 79M24CKC | TO-220 | -24V | COM | 0.5A | LM337MP*** |
| 79M05CKD | TO-202 | 5V | COM | 0.5A | LM79M05CP |
| 79M06CKD | TO-202 | 6V | COM | 0.5A | LM337MP*** |
| 79M08CKD | TO-202 | 8V | COM | 0.5A | LM337MP*** |
| 79M12CKD | TO-202 | 12V | COM | 0.5A | LM79M12CP |
| 79M15CKD | TO-202 | 15V | COM | 0.5A | LM79M15CP |
| 79M24CKD | TO-202 | 24V | COM | 0.5A | LM337MP*** |
| | | **FAIRCHILD** | | | |
| 7805KM | TO-3 | 5V | MIL | 1.5A | LM140K-5.0 |
| 7806KM | TO-3 | 6V | MIL | 1.5A | LM117K STEEL*** |
| 7808KM | TO-3 | 8V | MIL | 1.5A | LM117K STEEL*** |
| 7812KM | TO-3 | 12V | MIL | 1.5A | LM140K-12 |
| 7815KM | TO-3 | 15V | MIL | 1.5A | LM140K-15 |
| 7818KM | TO-3 | 18V | MIL | 1.5A | LM117K STEEL*** |
| 7824KM | TO-3 | 24V | MIL | 1.5A | |
| 7805KC | TO-3 aluminum | 5V | COM | 1.5A | LM8795KC |
| 7806KC | TO-3 aluminum | 6V | COM | 1.5A | LM317K STEEL*** |
| 7808KC | TO-3 aluminum | 8V | COM | 1.5A | LM317K STEEL*** |
| 7812KC | TO-3 aluminum | 12V | COM | 1.5A | LM7812KC |
| 7815KC | TO-3 aluminum | 15V | COM | 1.5A | LM7815KC |

*Pin compatible TO-202 package
**Lower output current – 100mA
***Not pin for pin equivalent

| Part # | Package | Voltage | Temp. | Max. Current | NSC Equiv. |
|---|---|---|---|---|---|
| | | **FAIRCHILD (cont.)** | | | |
| 7818KC | TO-3 aluminum | 18V | COM | 1.5A | LM317K STEEL*** |
| 7824KC | TO-3 aluminum | 24V | COM | 1.5A | LM317K STEEL*** |
| 7805UC | TO-220 | 5V | COM | 1.5A | LM7805CT |
| 7806UC | TO-220 | 6V | COM | 1.5A | LM317T*** |
| 7808UC | TO-220 | 8V | COM | 1.5A | LM317T*** |
| 7812UC | TO-220 | 12V | COM | 1.5A | LM7812CT |
| 7815UC | TO-220 | 15V | COM | 1.5A | LM7815CT |
| 7818UC | TO-220 | 18V | COM | 1.5A | LM317T*** |
| 7824UC | TO-220 | 24V | COM | 1.5A | LM317T*** |
| 78M05HM | TO-39 | 5V | MIL | 500mA | LM140LAH-5.0** |
| 78M06HM | TO-39 | 6V | MIL | 500mA | LM117H*** |
| 78M08HM | TO-39 | 8V | MIL | 500mA | LM117H*** |
| 78M12HM | TO-39 | 12V | MIL | 500mA | LM140LAH-12** |
| 78M15HM | TO-39 | 15V | MIL | 500mA | LM140LAH-15** |
| 78M18HM | TO-39 | 18V | MIL | 500mA | LM117H*** |
| 78M24HM | TO-39 | 24V | MIL | 500mA | LM117H*** |
| 78M05HC | TO-39 | 5V | COM | 500mA | LM340LAH-5.0** |
| 78M06HC | TO-39 | 6V | COM | 500mA | LM317H*** |
| 78M08HC | TO-39 | 8V | COM | 500mA | LM317H*** |
| 78M12HC | TO-39 | 12V | COM | 500mA | LM340LAH-12** |
| 78M15HC | TO-39 | 15V | COM | 500mA | LM340LAH-15** |
| 78M18HC | TO-39 | 18V | COM | 500mA | LM317H*** |
| 78M24HC | TO-39 | 24V | COM | 500mA | LM317H*** |
| 78M05UC | TO-220 | 5V | COM | 500mA | LM78M05CP* |
| 78M06UC | TO-220 | 6V | COM | 500mA | LM317MP*** |
| 78M08UC | TO-220 | 8V | COM | 500mA | LM317MP*** |
| 78M12UC | TO-220 | 12V | COM | 500mA | LM78M12CP* |
| 78M15UC | TO-220 | 15V | COM | 500mA | LM78M15CP* |
| 78M18UC | TO-220 | 18V | COM | 500mA | LM317MP*** |
| 78M24UC | TO-220 | 24V | COM | 500mA | LM317MP*** |
| 78L05HC | TO-39 | 5V | COM | 100mA | LM78L05ACH |
| 78L05WC | TO-92 | 5V | COM | 100mA | LM78L05ACZ |
| 78L05AHC | TO-39 | 5V | COM | 100mA | LM78L05ACH |
| 78L05AWC | TO-92 | 5V | COM | 100mA | LM78L05ACZ |
| 78L06WC | TO-39 | 6V | COM | 100mA | LM317H*** |
| 78L06AWC | TO-92 | 6V | COM | 100mA | LM317H*** |
| 78L12HC | TO-39 | 12V | COM | 100mA | LM78L12ACH |
| 78L12WC | TO-92 | 12V | COM | 100mA | LM78L12ACZ |
| 78L12AHC | TO-39 | 12V | COM | 100mA | LM78L12ACH |
| 78L12AWC | TO-92 | 12V | COM | 100mA | LM78L12ACZ |
| 78L15HC | TO-39 | 15V | COM | 100mA | LM78L15ACH |
| 78L15WC | TO-92 | 15V | COM | 100mA | LM78L15ACZ |
| 78L15AHC | TO-39 | 15V | COM | 100mA | LM78L15ACH |
| 78L15AWC | TO-92 | 15V | COM | 100mA | LM78L15ACZ |
| 78C05UC | TO-202 | 5V | COM | 0.5A | LM341P-5.0* |
| 78C12UC | TO-202 | 12V | COM | 0.5A | LM341P-12* |
| 78C15UC | TO-202 | 15V | COM | 0.5A | LM341P-15* |
| 78MUC | TO-202 | Adjustable | COM | 0.5A | LM317MP*** |
| 79MUC | TO-202 | Adjustable | COM | 0.5A | LM337MP*** |
| 78GUIC | TO-202 | Adjustable | COM | 1.5A | LM317T*** |
| 78GKC | TO-3 | Adjustable | COM | 1.5A | LM317K*** |
| 79GUIC | TO-202 | Adjustable | COM | 1.5A | LM337T*** |
| 79GKC | TO-3 | Adjustable | COM | 1.5A | LM337K*** |
| 78S | TO-3 | Adjustable | COM | 1.5A | LM3524*** |

*Pin compatible TO-202 package
**Lower output current – 100mA
***Not pin for pin equivalent

# Section 10.0
# Data Sheets



National Semiconductor

# Fixed or Adjustable Voltage Regulators

At National we see the trend moving toward the use of more adjustable regulators and we are broadening the adjustable line to satisfy this demand.

As you browse through this Voltage Regulator section you will notice many changes. We've expanded the adjustable regulator line and many voltage options on fixed regulators have been deleted.

The fixed voltage regulators, like the 7800 and 7900 series, resulted in customers having to stock and hold in inventory quantities of each voltage in order to always have on hand a specific device for a particular system. This proved to be very costly especially when production was stopped due to shortage of a particular voltage.

Adjustables combine versatility, performance, reliability and are leading to increased popularity.

## Versatility

- Satisfy output voltage requirements from 1.2V up to 47V
- Simplify inventory and purchasing since a single device satisfies many voltage requirements
- Allows precision application

## Performance

- Improves system performance by having line and load regulation a factor of 10 better
- Has improved overload protection thus allowing greater output current over operating temperature range

## Reliability

- Improves system reliability with each device being subjected to 100% thermal limit burn-in

As more and more applications use adjustable regulators, we believe that they will become the most popular regulators in the industry.

National Semiconductor

# LM109/LM209/LM309 5-Volt Regulator

## General Description

The LM109 series are complete 5 V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The devices are available in two standard transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1 A.

The regulators are essentially blowout proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

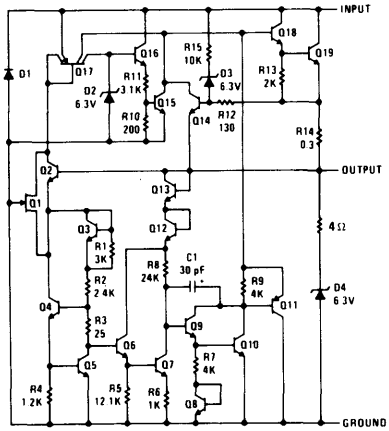
Considerable effort was expended to make these devices easy to use and to minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the LM109 series can be set to voltages above 5 V, as shown below. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

## Features

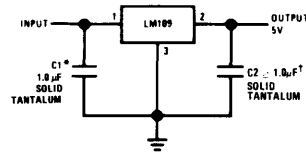
- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1 A
- Internal thermal overload protection
- No external components required

## Schematic Diagram




## Typical Application

**Fixed 5V Regulator**

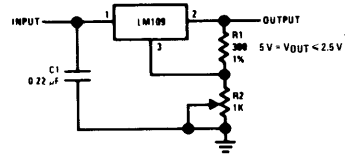



*Required if regulator is located more than 4" from power supply filter capacitor.

†Although no output capacitor is needed for stability, it does improve transient response. C2 should be used whenever long wires are used to connect to the load, or when transient response is critical.

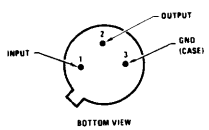
NOTE: Pin 3 electrically connected to case.

**Adjustable Output Regulator**

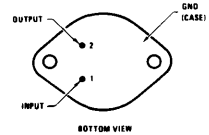



## Connection Diagrams

**Metal Can Packages**




Order Number LM109H, LM209H or LM309H
See Package H03A




Order Number LM109K STEEL, LM209K STEEL, LM309K STEEL or LM309K (Aluminum)
See Package K02A

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | 35 V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | |
| LM109 | −55°C to +150°C |
| LM209 | −25°C to +150°C |
| LM309 | 0°C to +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics

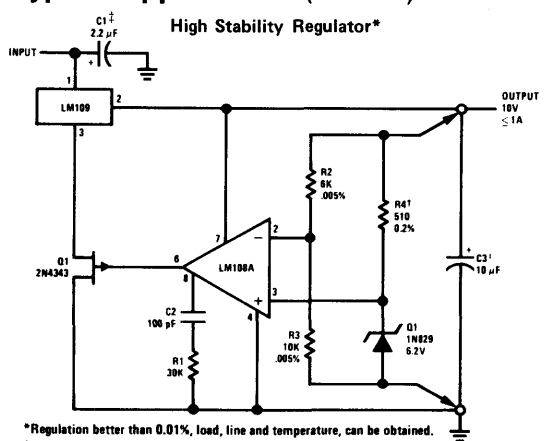
| PARAMETER | CONDITIONS | LM109/LM209 | | | LM309 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_j = 25°C$ | 4.7 | 5.05 | 5.3 | 4.8 | 5.05 | 5.2 | V |
| Line Regulation | $T_j = 25°C$, $7V \leq V_{IN} \leq 25V$ | | 4.0 | 50 | | 4.0 | 50 | mV |
| Load Regulation | $T_j = 25°C$ | | | | | | | |
| TO-5 Package | $5mA \leq I_{OUT} \leq 0.5A$ | | 15 | 50 | | 15 | 50 | mV |
| TO-3 Package | $5mA \leq I_{OUT} \leq 1.5A$ | | 15 | 100 | | 15 | 100 | mV |
| Output Voltage | $7V \leq V_{IN} \leq 25V$, $5mA \leq I_{OUT} \leq I_{MAX}$, $P < P_{MAX}$ | 4.6 | | 5.4 | 4.75 | | 5.25 | V |
| Quiescent Current | $7V \leq V_{IN} \leq 25V$ | | 5.2 | 10 | | 5.2 | 10 | mA |
| Quiescent Current Change | $7V \leq V_{IN} \leq 25V$ | | | 0.5 | | | 0.5 | mA |
| | $5mA \leq I_{OUT} \leq I_{MAX}$ | | | 0.8 | | | 0.8 | mA |
| Output Noise Voltage | $T_A = 25°C$, $10Hz \leq f \leq 100kHz$ | | 40 | | | 40 | | μV |
| Long Term Stability | | | | 10 | | | 20 | mV |
| Ripple Rejection | $T_j = 25°C$ | 50 | | | 50 | | | dB |
| Thermal Resistance, Junction to Case | (Note 2) | | | | | | | |
| TO-5 Package | | | 15 | | | 15 | | °C/W |
| TO-3 Package | | | 2.5 | | | 2.5 | | °C/W |

**Note 1:** Unless otherwise specified, these specifications apply for $-55°C \leq T_j \leq +150°C$ for the LM109, $-25°C \leq T_j \leq +150°C$ for the LM209, and $0°C \leq T_j \leq +125°C$ for the LM309; $V_{IN} = 10V$ and $I_{OUT} = 0.1A$ for the TO-5 package or $I_{OUT} = 0.5A$ for the TO-3 package. For the TO-5 package, $I_{MAX} = 0.2A$ and $P_{MAX} = 2.0W$. For the TO-3 package, $I_{MAX} = 1.0A$ and $P_{MAX} = 20W$.

**Note 2:** Without a heat sink, the thermal resistance of the TO-5 package is about 150°C/W, while that of the TO-3 package is approximately 35°C/W. With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

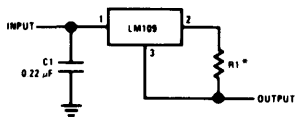
## Typical Applications (cont'd.)

**High Stability Regulator***




*Regulation better than 0.01%, load, line and temperature, can be obtained.
†Determines zener current. May be adjusted to minimize thermal drift.
‡Solid tantalum.

**Current Regulator**




*Determines output current. If wirewound resistor is used, bypass with 0.1 μF.

## Application Hints

a. **Bypass the input** of the LM109 to ground with $\geq 0.2\ \mu F$ ceramic or solid tantalum capacitor if main filter capacitor is more than 4 inches away.

b. **Use steel package** instead of aluminum if more than 5,000 thermal cycles are expected. ($\Delta T \geq 50^{\circ}C$)

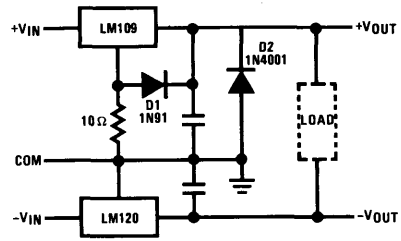
c. **Avoid insertion of regulator into "live" socket** if input voltage is greater than 10 V. The output will rise to within 2 V of the unregulated input if the ground pin does not make contact, possibly damaging the load. The LM109 may also be damaged if a large output capacitor is charged up, then discharged through the internal clamp zener when the ground pin makes contact.

d. **The output clamp zener** is designed to absorb transients only. It will not clamp the output effectively if a failure occurs in the internal power transistor structure. Zener dynamic impedance is $\approx 4\ \Omega$. Continuous RMS current into the zener should not exceed 0.5 A.

e. **Paralleling of LM109s** for higher output current is not recommended. Current sharing will be almost nonexistent, leading to a current limit mode operation for devices with the highest initial output voltage. The current limit devices may also heat up to the thermal shutdown point ($\approx 175^{\circ}C$). Long term reliability cannot be guaranteed under these conditions.

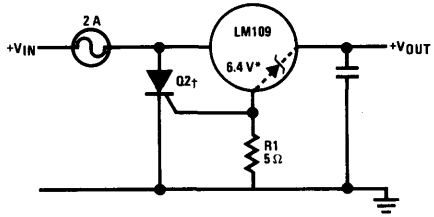
f. **Preventing latchoff** for loads connected to negative voltage:

If the output of the LM109 is pulled negative by a high current supply so that the output pin is more than 0.5 V negative with respect to the ground pin, the LM109 can latch off. This can be prevented by clamping the ground pin to the output pin with a germanium or Schottky diode as shown. A silicon diode (1N4001) at the output is also needed to keep the positive output from being pulled too far negative. The $10\ \Omega$ resistor will raise $+V_{OUT}$ by $\approx 0.05$ V.

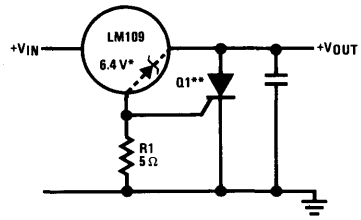



## Crowbar Overvoltage Protection

**INPUT CROWBAR**




**OUTPUT CROWBAR**




*Zener is internal to LM109.

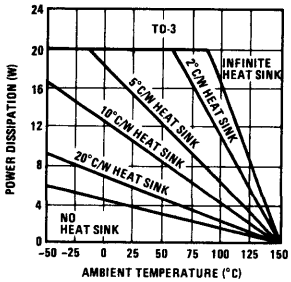
**Q1 must be able to withstand 7 A continuous current if fusing is not used at regulator input. LM109 bond wires will fuse at currents above 7 A.

†Q2 is selected for surge capability. Consideration must be given to filter capacitor size, transformer impedance, and fuse blowing time.

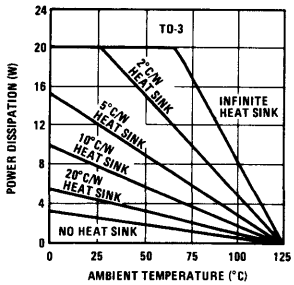
††Trip point is ≈ 7.5 V.

# Typical Performance Characteristics

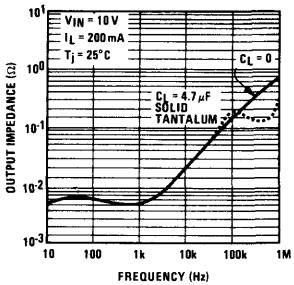
MAXIMUM AVERAGE POWER DISSIPATION (LM109K)



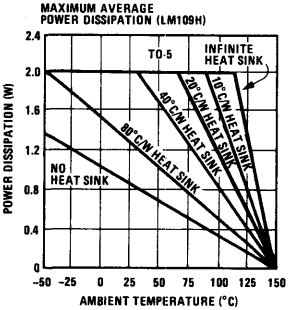

MAXIMUM AVERAGE POWER DISSIPATION (LM309K)



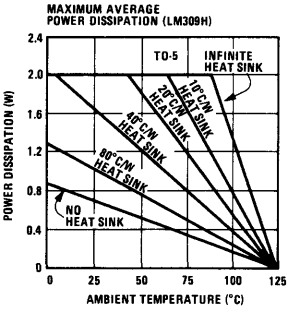

OUTPUT IMPEDANCE



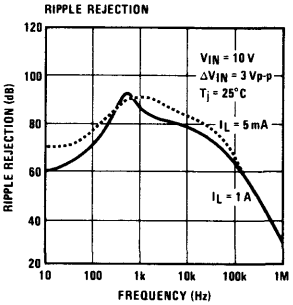

MAXIMUM AVERAGE POWER DISSIPATION (LM109H)



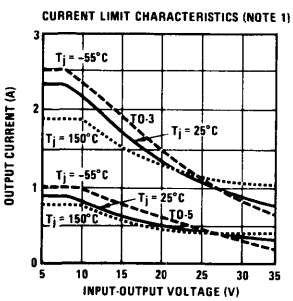

MAXIMUM AVERAGE POWER DISSIPATION (LM309H)




RIPPLE REJECTION

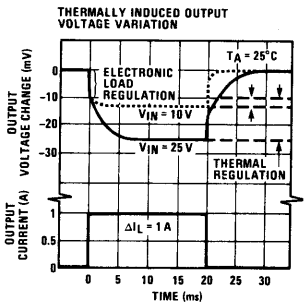



CURRENT LIMIT CHARACTERISTICS (NOTE 1)

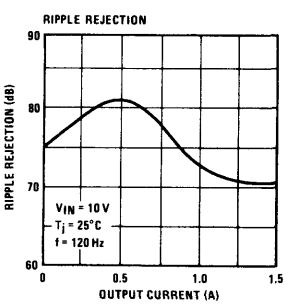



Note 1: Current limiting foldback characteristics are determined by input-output differential, not by output voltage.

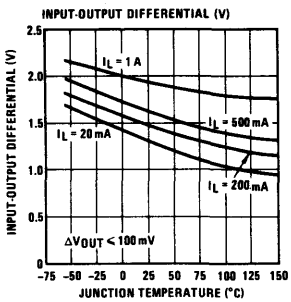
THERMALLY INDUCED OUTPUT VOLTAGE VARIATION

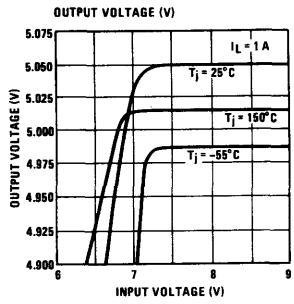


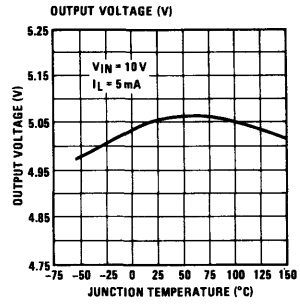

RIPPLE REJECTION

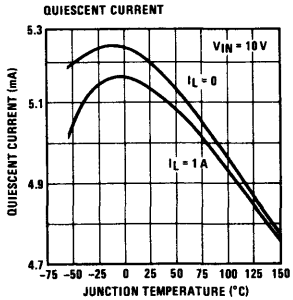


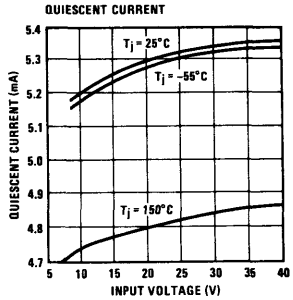
# Typical Performance Characteristics (cont'd)

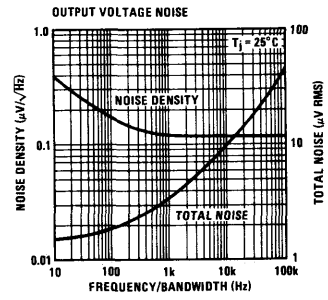


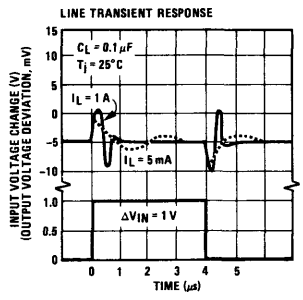



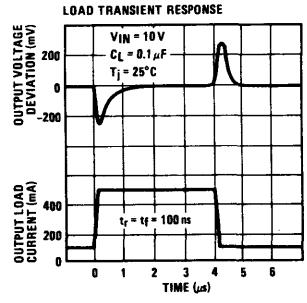



National Semiconductor

# LM117/LM217/LM317 3-Terminal Adjustable Regulator

## General Description

The LM117/LM217/LM317 are adjustable 3-terminal positive voltage regulators capable of supplying in excess of 1.5A over a 1.2V to 37V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 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 disconnected.

## Features

- Adjustable output down to 1.2V
- Guaranteed 1.5A output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- **100% electrical burn-in**
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection

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, the LM117 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.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM117 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 LM117K, LM217K and LM317K are packaged in standard TO-3 transistor packages while the LM117H, LM217H and LM317H are packaged in a solid Kovar base TO-5 transistor package. The LM117 is rated for operation from −55°C to +150°C, the LM217 from −25°C to +150°C and the LM317 from 0°C to +125°C. The LM317T and LM317MP, rated for operation over a 0°C to +125°C range, are available in a TO-220 plastic package and a TO-202 package, respectively.

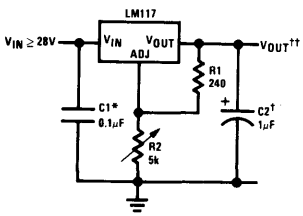
For applications requiring greater output current in excess of 3A and 5A, see LM150 series and LM138 series data sheets, respectively. For the negative complement, see LM137 series data sheet.

**LM117 Series Packages and Power Capability**

| DEVICE | PACKAGE | RATED POWER DISSIPATION | DESIGN LOAD CURRENT |
|---|---|---|---|
| LM117 | TO-3 | 20W | 1.5A |
| LM217<br>LM317 | TO-5 | 2W | 0.5A |
| LM317T | TO-220 | 15W | 1.5A |
| LM317M | TO-202 | 7.5W | 0.5A |

## Typical Applications

**1.2V–25V Adjustable Regulator**

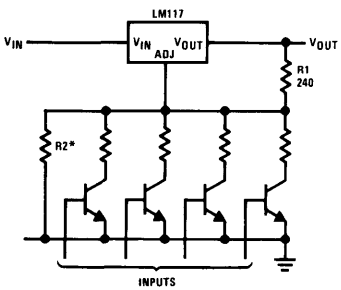



†Optional—improves transient response

*Needed if device is far from filter capacitors

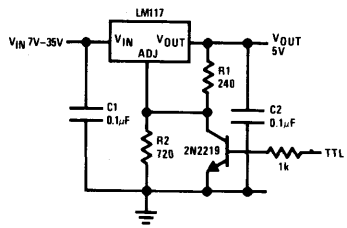
††$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right)$

**Digitally Selected Outputs**




*Sets maximum $V_{OUT}$

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




*Min output ≈ 1.2V

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 40V |
| Operating Junction Temperature Range | |
| LM117 | −55°C to +150°C |
| LM217 | −25°C to +150°C |
| LM317 | 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** | **100% All Devices** |

## Electrical Characteristics (Note 1)

| PARAMETER | CONDITIONS | LM117/217 | | | LM317 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Line Regulation | $T_A = 25°C$, $3V \le V_{IN} - V_{OUT} \le 40V$ (Note 2) | | 0.01 | 0.02 | | 0.01 | 0.04 | %/V |
| Load Regulation | $T_A = 25°C$, $10\ mA \le I_{OUT} \le I_{MAX}$ | | | | | | | |
| | $V_{OUT} \le 5V$, (Note 2) | | 5 | 15 | | 5 | 25 | mV |
| | $V_{OUT} \ge 5V$, (Note 2) | | 0.1 | 0.3 | | 0.1 | 0.5 | % |
| Thermal Regulation | $T_A = 25°C$, 20 ms Pulse | | 0.03 | 0.07 | | 0.04 | 0.07 | %/W |
| Adjustment Pin Current | | | 50 | 100 | | 50 | 100 | μA |
| Adjustment Pin Current Change | $10\ mA \le I_L \le I_{MAX}$ $2.5V \le (V_{IN}-V_{OUT}) \le 40V$ | | 0.2 | 5 | | 0.2 | 5 | μA |
| Reference Voltage | $3 \le (V_{IN}-V_{OUT}) \le 40V$, (Note 3) $10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$ | 1.20 | 1.25 | 1.30 | 1.20 | 1.25 | 1.30 | V |
| Line Regulation | $3V \le V_{IN} - V_{OUT} \le 40V$, (Note 2) | | 0.02 | 0.05 | | 0.02 | 0.07 | %/V |
| Load Regulation | $10\ mA \le I_{OUT} \le I_{MAX}$, (Note 2) | | | | | | | |
| | $V_{OUT} \le 5V$ | | 20 | 50 | | 20 | 70 | mV |
| | $V_{OUT} \ge 5V$ | | 0.3 | 1 | | 0.3 | 1.5 | % |
| Temperature Stability | $T_{MIN} \le T_j \le T_{MAX}$ | | 1 | | | 1 | | % |
| Minimum Load Current | $V_{IN}-V_{OUT} = 40V$ | | 3.5 | 5 | | 3.5 | 10 | mA |
| Current Limit | $V_{IN}-V_{OUT} \le 15V$ | | | | | | | |
| | K and T Package | 1.5 | 2.2 | | 1.5 | 2.2 | | A |
| | H and P Package | 0.5 | 0.8 | | 0.5 | 0.8 | | A |
| | $V_{IN}-V_{OUT} = 40V$ | | | | | | | |
| | K and T Package | | 0.4 | | | 0.4 | | A |
| | H and P Package | | 0.07 | | | 0.07 | | A |
| RMS Output Noise, % of $V_{OUT}$ | $T_A = 25°C$, 10 Hz ≤ f ≤ 10 kHz | | 0.003 | | | 0.003 | | % |
| Ripple Rejection Ratio | $V_{OUT} = 10V$, f = 120 Hz | | 65 | | | 65 | | dB |
| | $C_{ADJ} = 10\mu F$ | 66 | 80 | | 66 | 80 | | dB |
| Long-Term Stability | $T_A = 125°C$ | | 0.3 | 1 | | 0.3 | 1 | % |
| Thermal Resistance, Junction to Case | H Package | | 12 | 15 | | 12 | 15 | °C/W |
| | K Package | | 2.3 | 3 | | 2.3 | 3 | °C/W |
| | T Package | | | | | 4 | | °C/W |
| | P Package | | | | | 12 | | °C/W |

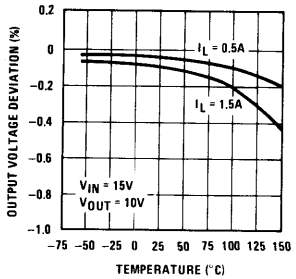
**Note 1:** Unless otherwise specified, these specifications apply: $-55°C \le T_j \le +150°C$ for the LM117, $-25°C \le T_j \le +150°C$ for the LM217 and $0°C \le T_j \le +125°C$ for the LM317; $V_{IN}-V_{OUT} = 5V$ and $I_{OUT} = 0.1A$ for the TO-5 and TO-202 packages and $I_{OUT} = 0.5A$ for the TO-3 package and TO-220 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-5 and TO-202 and 20W for the TO-3 and TO-220. $I_{MAX}$ is 1.5A for the TO-3 and TO-220 package and 0.5A for the TO-5 and TO-202 package.

**Note 2:** Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

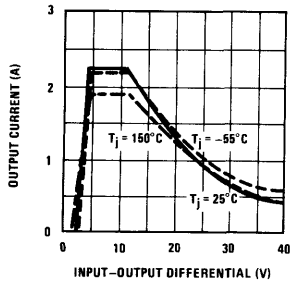
**Note 3:** Selected devices with tightend tolerance reference voltage available.

# Typical Performance Characteristics (K and T Packages)

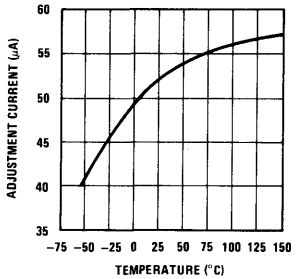
**Load Regulation**



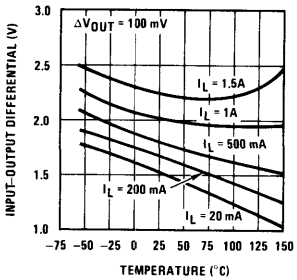

**Current Limit**



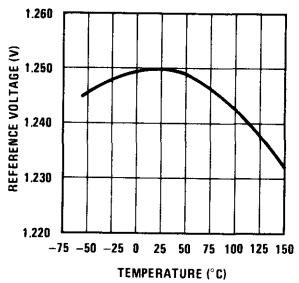

**Adjustment Current**



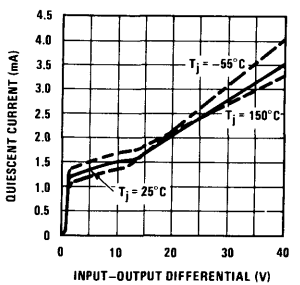

**Dropout Voltage**



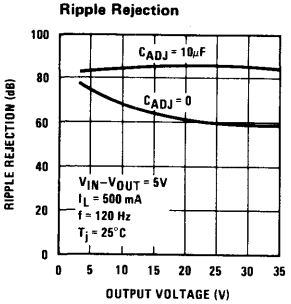

**Temperature Stability**



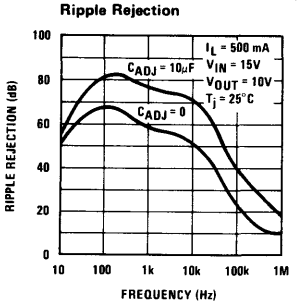

**Minimum Operating Current**



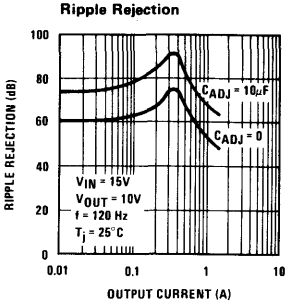

**Ripple Rejection**



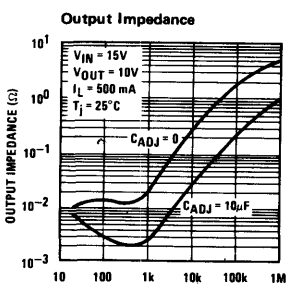

**Ripple Rejection**



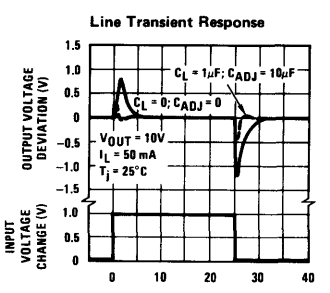

**Ripple Rejection**



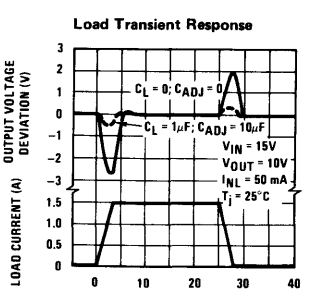

**Output Impedance**




**Line Transient Response**




**Load Transient Response**



## Application Hints

In operation, the LM117 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

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

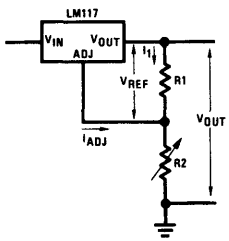



**FIGURE 1.**

Since the 100μA current from the adjustment terminal represents an error term, the LM117 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 0.1μF disc or 1μF 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 LM117 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10μF bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10μF 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 25μF in aluminum electrolytic to equal 1μF 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, 0.01μF disc may seem to work better than a 0.1μF disc as a bypass.

Although the LM117 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 1μF solid tantalum (or 25μF aluminum electrolytic) on the output swamps this effect and insures stability.

### Load Regulation

The LM117 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 effectvely 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.

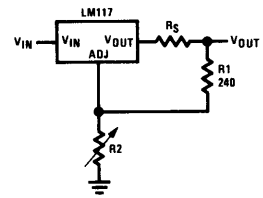



**FIGURE 2. Regulator with Line Resistance in Output Lead**

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. 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 10μF 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

## Application Hints (cont'd.)

current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of $V_{IN}$. In the LM117, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25μF 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 LM117 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10μF capacitance. *Figure 3* shows an LM117 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

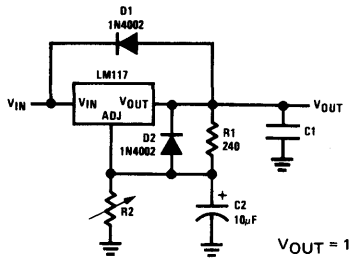
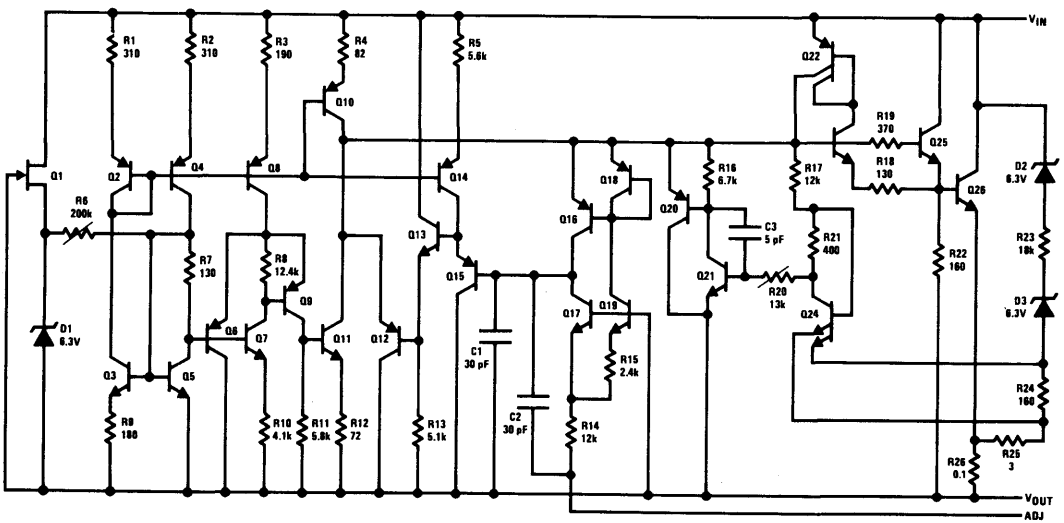


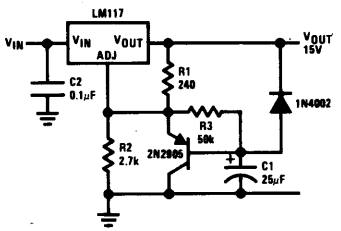

**FIGURE 3. Regulator with Protection Diodes**

## Schematic Diagram

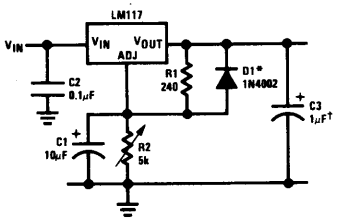


# Typical Applications (cont'd.)

### Slow Turn-On 15V Regulator

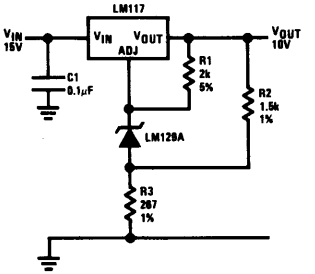



### Adjustable Regulator with Improved Ripple Rejection

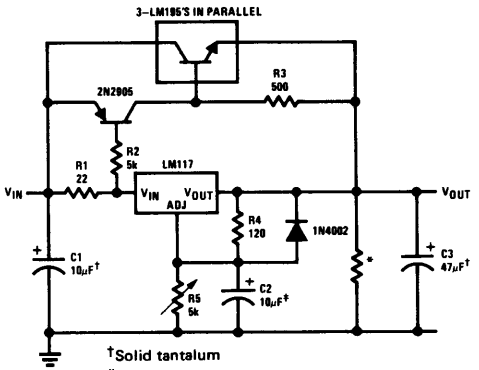



†Solid tantalum
*Discharges C1 if output is shorted to ground

### High Stability 10V Regulator

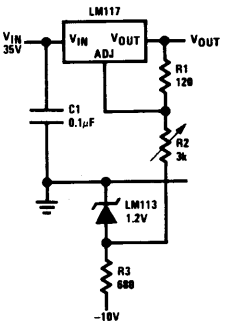



### High Current Adjustable Regulator

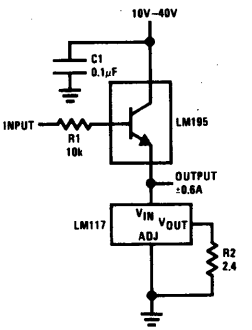



†Solid tantalum
*Minimum load current = 30 mA
‡Optional—improves ripple rejection

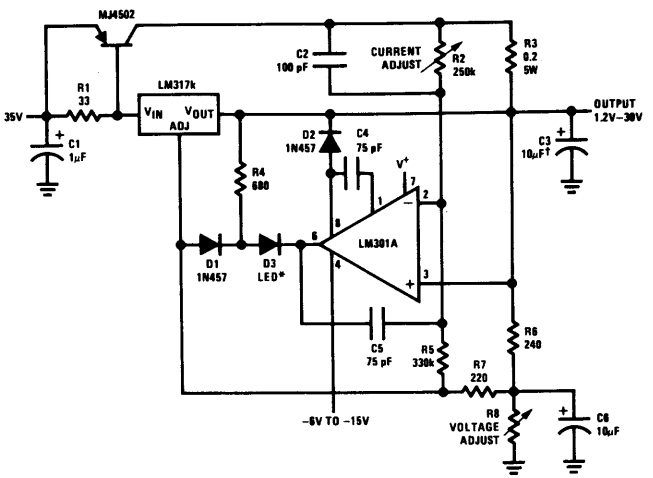
### 0 to 30V Regulator




### Power Follower

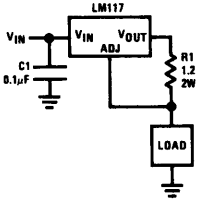



### 5A Constant Voltage/Constant Current Regulator

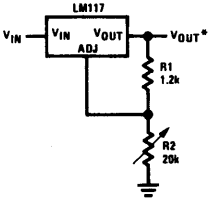



†Solid tantalum
*Lights in constant current mode

### 1A Current Regulator



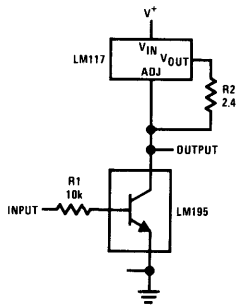

### 1.2V–20V Regulator with Minimum Program Current



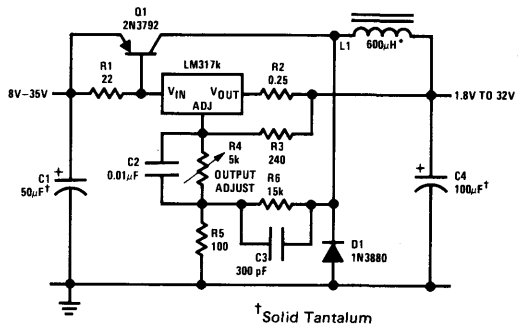

*Minimum load current ≈ 4 mA

# Typical Applications (cont'd.)

**High Gain Amplifier**



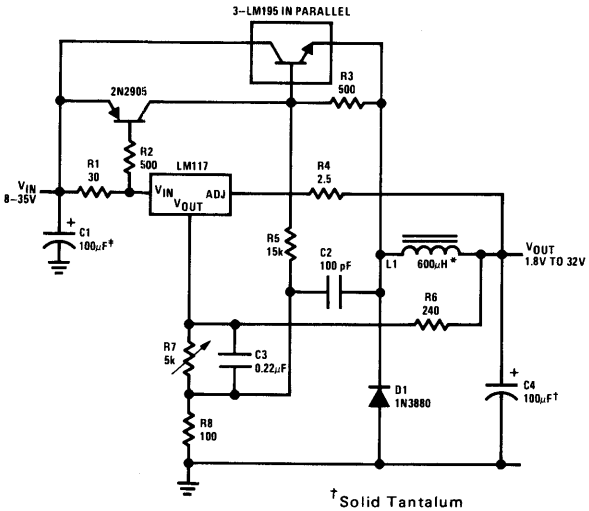

**Low Cost 3A Switching Regulator**




†Solid Tantalum

*Core–Arnold A-254168-2 60 turns

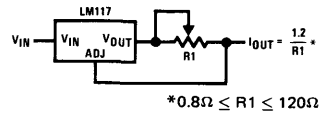
**4A Switching Regulator with Overload Protection**




†Solid Tantalum

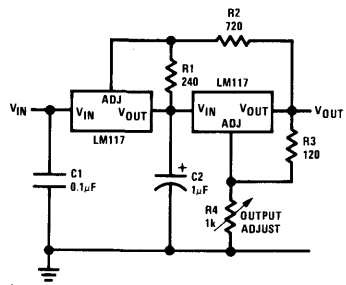
*Core Arnold A-254168-2 60 turns

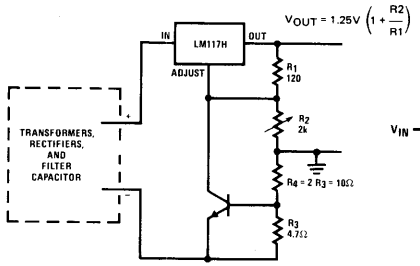
**Precision Current Limiter**



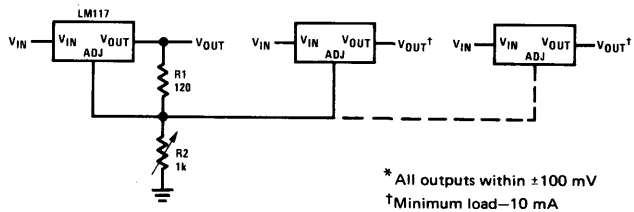

*0.8Ω ≤ R1 ≤ 120Ω

**Tracking Preregulator**




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




*All outputs within ±100 mV

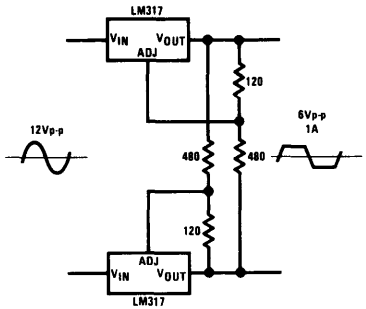
†Minimum load–10 mA

— Short circuit current is approximately $\frac{600mV}{R_3}$, or 120mA (compared to LM117H's 1 ampere current limit)

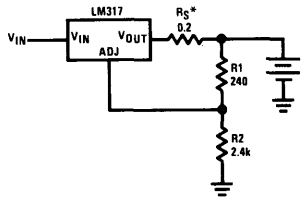
— (At 50mA output only ¾ volt of drop occurs in $R_3$ and $R_4$).

## Typical Applications (cont'd.)

**AC Voltage Regulator**

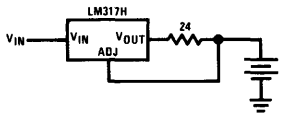



**12V Battery Charger**

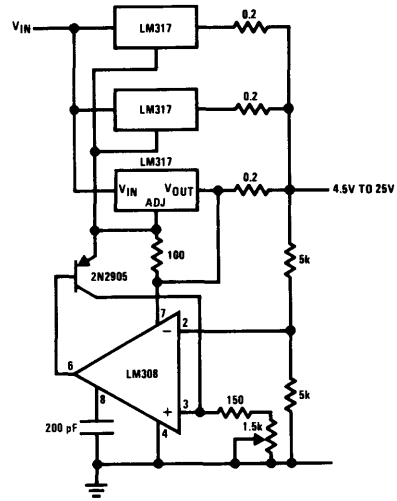



*$R_S$—sets output impedance of charger $Z_{OUT} = R_S\left(1+\frac{R2}{R1}\right)$
Use of $R_S$ allows low charging rates with fully charged battery.

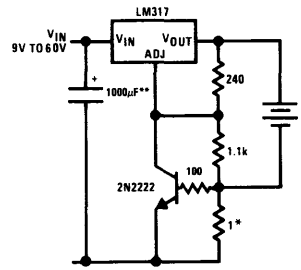
**50 mA Constant Current Battery Charger**




**Adjustable 4A Regulator**




**Current Limited 6V Charger**

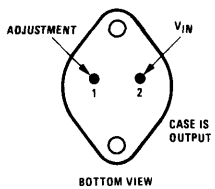



*Sets peak current (0.6A for 1Ω)

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

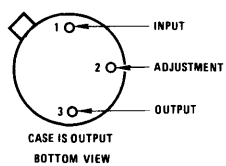
## Connection Diagrams

**(TO-3 STEEL)**
**Metal Can Package**



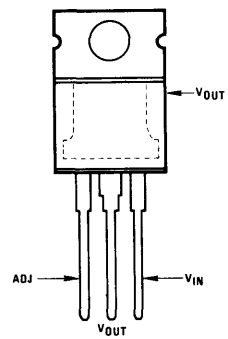

**Order Number:**
**LM117K STEEL**
**LM217K STEEL**
**LM317K STEEL**
**See Package K02A**

**(TO-39)**
**Metal Can Package**



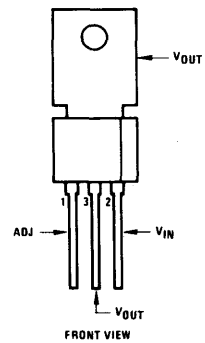

**Order Number:**
**LM117H**
**LM217H**
**LM317H**
**See Package H03A**

**(TO-220)**
**Plastic Package**




**Order Number:**
**LM317T**
**See Package T03B**

**(TO-202)**
**Plastic Package**




**Order Number:**
**LM317MP**
**See Package P03A**
**Tab Formed Devices**
**LM317MP TB**
**See Package P03E**

National Semiconductor



# LM117HV/LM217HV/LM317HV 3-Terminal Adjustable Regulator

## General Description

The LM117HV/LM217HV/LM317HV are adjustable 3-terminal positive voltage regulators capable of supplying in excess of 1.5A over a 1.2V to 57V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117HV is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117HV 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 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, the LM117HV 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.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM117HV 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.

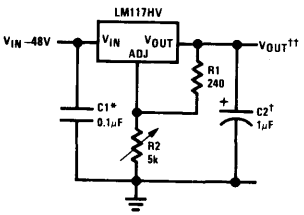
The LM117HVK STEEL, LM217HVK STEEL, and LM317HVK STEEL are packaged in standard TO-3 transistor packages while the LM117HVH, LM217HVH and LM317HVH are packaged in a solid Kovar base TO-5 transistor package. The LM117HV is rated for operation from −55°C to +150°C, the LM217HV from −25°C to +150°C and the LM317HV from 0°C to +125°C.

## Features

- Adjustable output down to 1.2V
- Guaranteed 1.5A output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- **100% electrical burn-in**
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection

## Typical Applications

**1.2V–45V Adjustable Regulator**

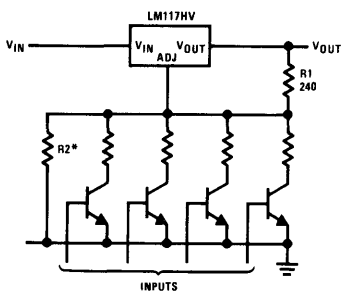



†Optional—improves transient response

*Needed if device is far from filter capacitors

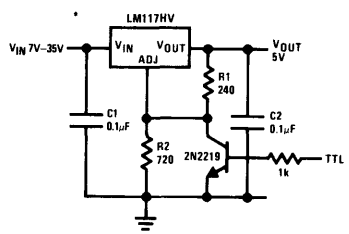
††$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right)$

**Digitally Selected Outputs**




*Sets maximum $V_{OUT}$

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




*Min output ≈ 1.2V

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 60V |
| Operating Junction Temperature Range | |
| LM117HV | −55°C to +150°C |
| LM217HV | −25°C to +150°C |
| LM317HV | 0°C to +125°C |
| Storage Temperature | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (Note 1)

| PARAMETER | CONDITIONS | LM117HV/LM217HV | | | LM317HV | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Line Regulation | $T_A = 25°C$, $3V \le V_{IN} - V_{OUT} \le 60V$ (Note 2) | | 0.01 | 0.02 | | 0.01 | 0.04 | %/V |
| Load Regulation | $T_A = 25°C$, $10\ mA \le I_{OUT} \le I_{MAX}$ | | | | | | | |
| | $V_{OUT} \le 5V$, (Note 2) | | 5 | 15 | | 5 | 25 | mV |
| | $V_{OUT} \ge 5V$, (Note 2) | | 0.1 | 0.3 | | 0.1 | 0.5 | % |
| Thermal Regulation | T = 10ns | | | | | | | %/W |
| Adjustment Pin Current | | | 50 | 100 | | 50 | 100 | μA |
| Adjustment Pin Current Change | $10\ mA \le I_L \le I_{MAX}$<br>$3.0V \le (V_{IN}-V_{OUT}) \le 60V$ | | 0.2 | 5 | | 0.2 | 5 | μA |
| Reference Voltage | $3 \le (V_{IN}-V_{OUT}) \le 60V$, (Note 3)<br>$10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$ | 1.20 | 1.25 | 1.30 | 1.20 | 1.25 | 1.30 | V |
| Line Regulation | $3V \le V_{IN} - V_{OUT} \le 60V$, (Note 2) | | 0.02 | 0.05 | | 0.02 | 0.07 | %/V |
| Load Regulation | $10\ mA \le I_{OUT} \le I_{MAX}$, (Note 2) | | | | | | | |
| | $V_{OUT} \le 5V$ | | 20 | 50 | | 20 | 70 | mV |
| | $V_{OUT} \ge 5V$ | | 0.3 | 1 | | 0.3 | 1.5 | % |
| Temperature Stability | $T_{MIN} \le T_j \le T_{MAX}$ | | 1 | | | 1 | | % |
| Minimum Load Current | $V_{IN}-V_{OUT} = 60V$ | | 3.5 | 7 | | 3.5 | 12 | mA |
| Current Limit | $V_{IN}-V_{OUT} \le 15V$ | | | | | | | |
| | K Package | 1.5 | 2.2 | | 1.5 | 2.2 | | A |
| | H Package | 0.5 | 0.8 | | 0.5 | 0.8 | | A |
| | $V_{IN}-V_{OUT} = 60V$ | | | | | | | |
| | K Package | | 0.1 | | | 0.1 | | A |
| | H Package | | 0.03 | | | 0.03 | | 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 | | 65 | | | 65 | | dB |
| | $C_{ADJ} = 10\mu F$ | 66 | 80 | | 66 | 80 | | dB |
| Long-Term Stability | $T_A = 125°C$ | | 0.3 | 1 | | 0.3 | 1 | % |
| Thermal Resistance, Junction to Case | H Package | | 12 | 15 | | 12 | 15 | °C/W |
| | K Package | | 2.3 | 3 | | 2.3 | 3 | °C/W |

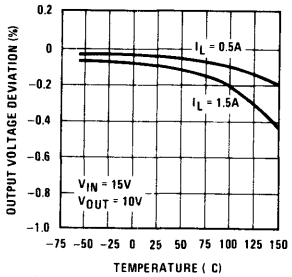
**Note 1:** Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM117HV, $-25°C \le T_j \le +150°C$ for the LM217HV and $0°C \le T_j \le +125°C$ for the LM317HV; $V_{IN} - V_{OUT} = 5V$ and $I_{OUT} = 0.1\ A$ for the TO-5 package and $I_{OUT} = 0.5\ A$ for the TO-3 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-5 and 20W for the TO-TO-3. $I_{MAX}$ is 1.5A for the TO-3 and 0.5A for the TO-5 package.

**Note 2:** Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

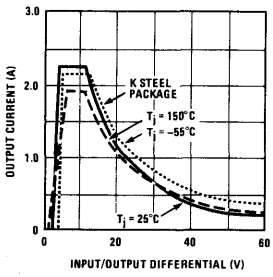
**Note 3:** Selected devices with tightened tolerance reference voltage available.

# Typical Performance Characteristics (K and T Packages)

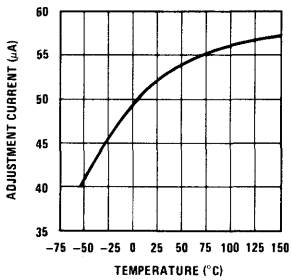
**Load Regulation**



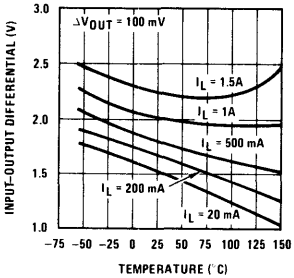

**Current Limit**



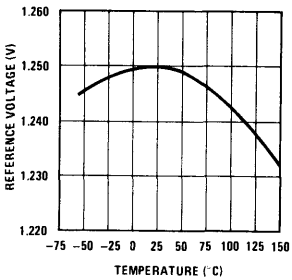

**Adjustment Current**



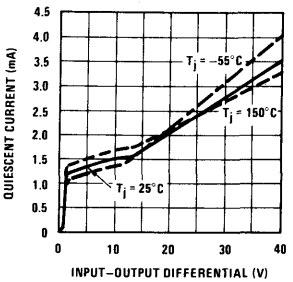

**Dropout Voltage**



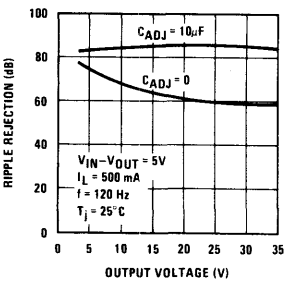

**Temperature Stability**



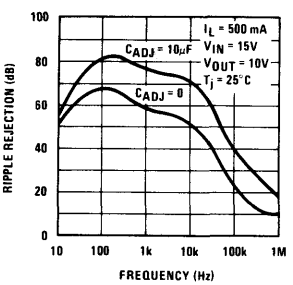

**Minimum Operating Current**



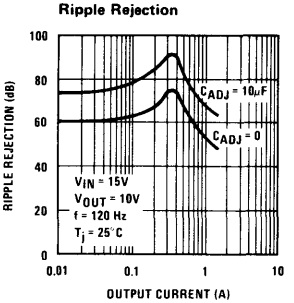

**Ripple Rejection**



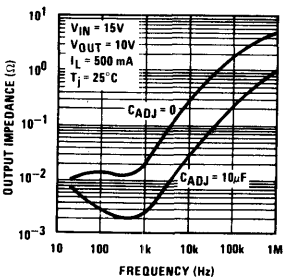

**Ripple Rejection**



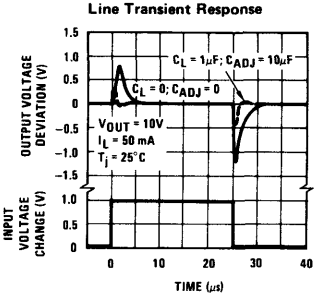

**Ripple Rejection**



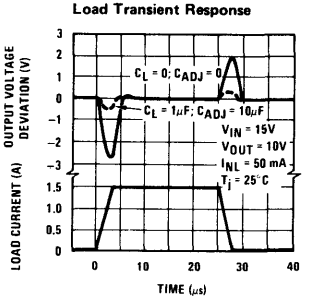

**Output Impedance**




**Line Transient Response**




**Load Transient Response**



## Application Hints

In operation, the LM117HV 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

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

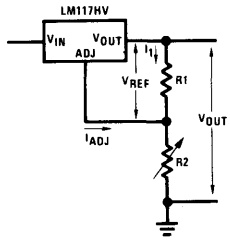



**FIGURE 1.**

Since the 100μA current from the adjustment terminal represents an error term, the LM117HV 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 0.1μF disc or 1μF 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 LM117HV to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10μF bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10μF 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 25μF in aluminum electrolytic to equal 1μF 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, 0.01μF disc may seem to work better than a 0.1μF disc as a bypass.

Although the LM117HV 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 1μF solid tantalum (or 25μF aluminum electrolytic) on the output swamps this effect and insures stability.

### Load Regulation

The LM117HV 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 effectvely 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.

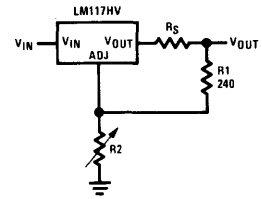



**FIGURE 2. Regulator with Line Resistance in Output Lead**

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

### Protection Diodes

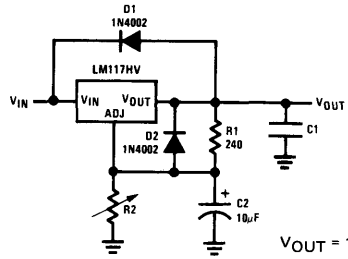
When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although 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

## Application Hints (cont'd.)

current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of $V_{IN}$. In the LM117HV, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25μF 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 LM117HV is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10μF capacitance. *Figure 3* shows an LM117HV with protection diodes included for use with outputs greater than 25V and high values of output capacitance.



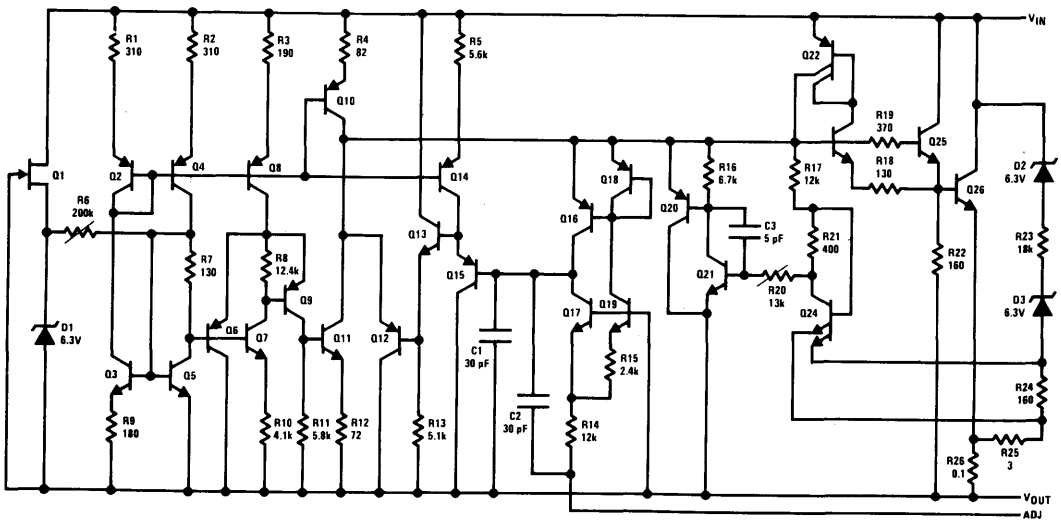

$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right) + R2 I_{ADJ}$$

D1 protects against C1

D2 protects against C2

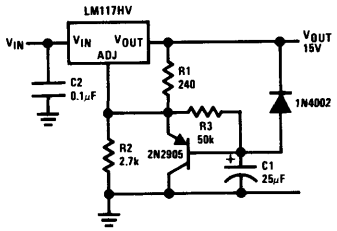
**FIGURE 3. Regulator with Protection Diodes**

## Schematic Diagram

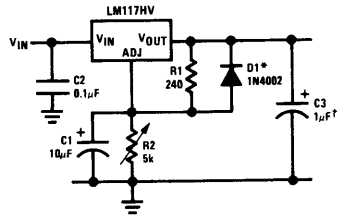


## Typical Applications (cont'd.)

### Slow Turn-On 15V Regulator

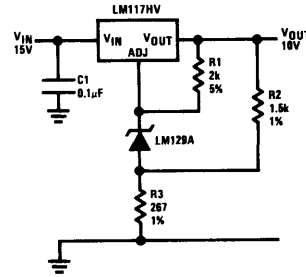



### Adjustable Regulator with Improved Ripple Rejection

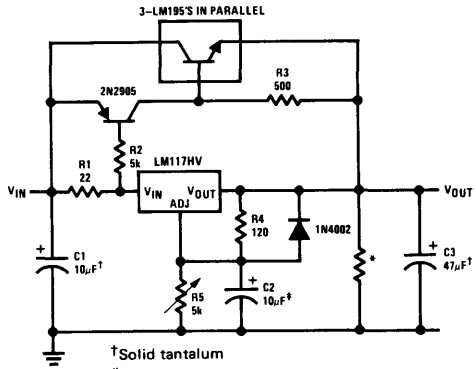



†Solid tantalum
*Discharges C1 if output is shorted to ground

### High Stability 10V Regulator

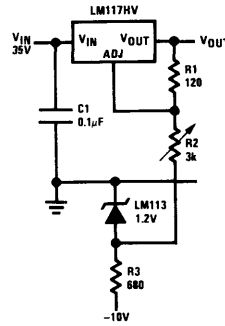



### High Current Adjustable Regulator

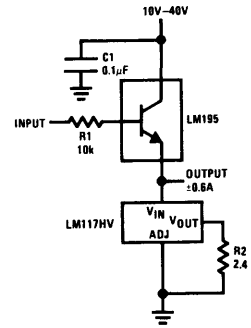



†Solid tantalum
*Minimum load current = 30 mA
‡Optional—improves ripple rejection

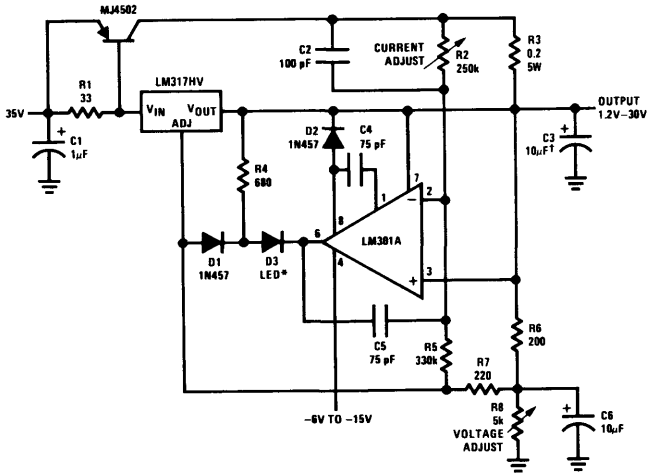
### 0 to 30V Regulator




### Power Follower

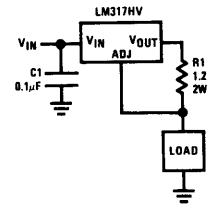



### 5A Constant Voltage/Constant Current Regulator

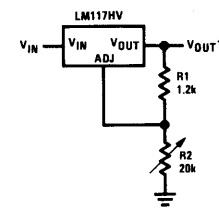



†Solid tantalum
*Lights in constant current mode

### 1A Current Regulator



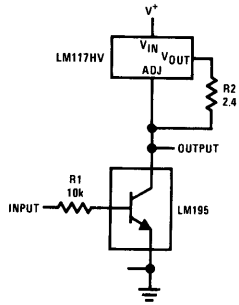

### 1.2V–20V Regulator with Minimum Program Current



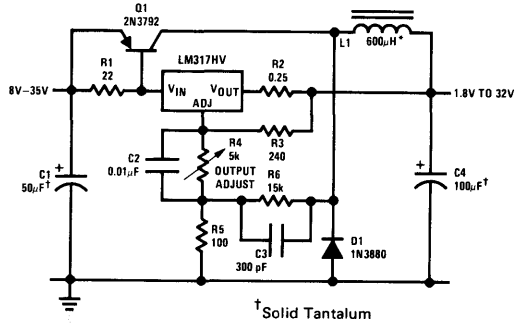

*Minimum load current ≈ 4 mA

## Typical Applications (cont'd.)

**High Gain Amplifier**



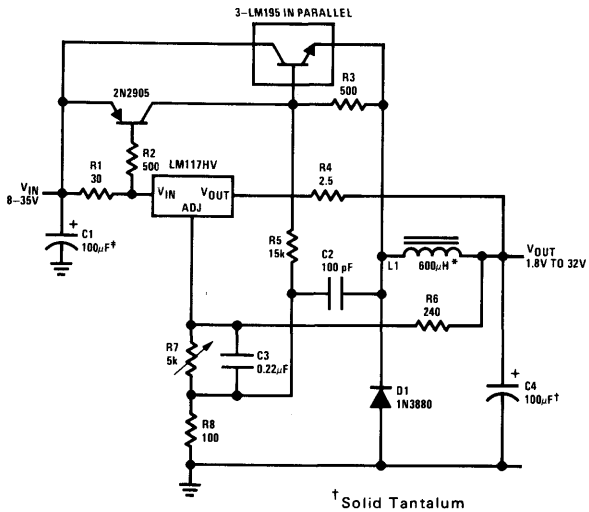

**Low Cost 3A Switching Regulator**




†Solid Tantalum

*Core–Arnold A-254168-2 60 turns

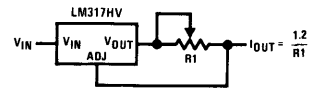
**4A Switching Regulator with Overload Protection**




†Solid Tantalum

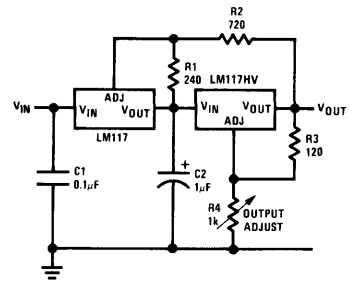
*Core Arnold A-254168-2 60 turns

**Precision Current Limiter**

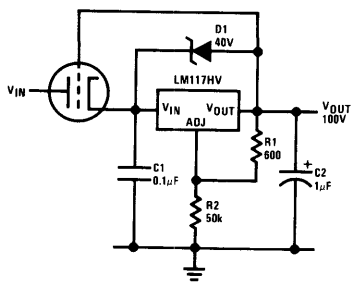



*0.8Ω ≤ R1 ≤ 120Ω

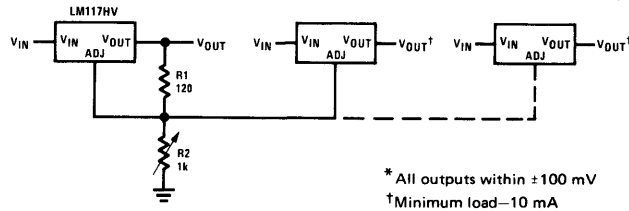
**Tracking Preregulator**




**High Voltage Regulator**




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

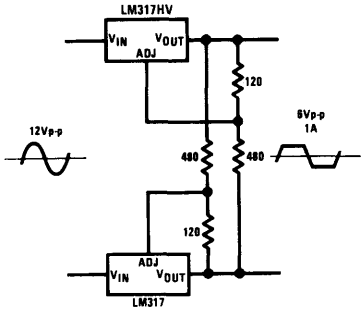



*All outputs within ±100 mV

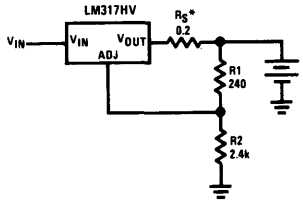
†Minimum load–10 mA

## Typical Applications (cont'd.)

**AC Voltage Regulator**

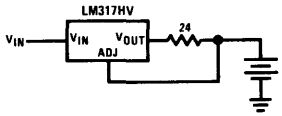



**12V Battery Charger**

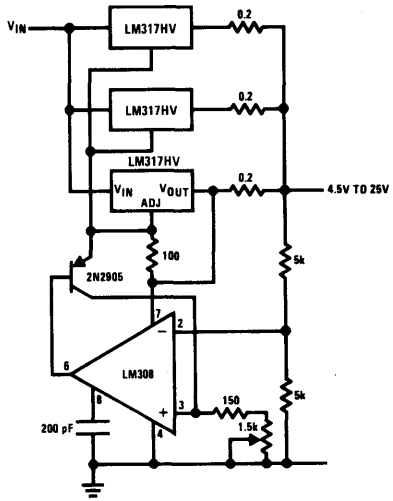



*$R_S$—sets output impedance of charger $Z_{OUT} = R_S\left(1+\frac{R2}{R1}\right)$
Use of $R_S$ allows low charging rates with fully charged battery.

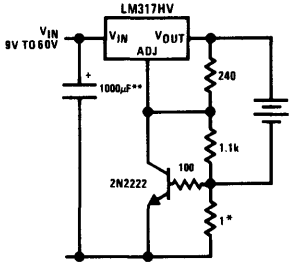
**50 mA Constant Current Battery Charger**




**Adjustable 4A Regulator**



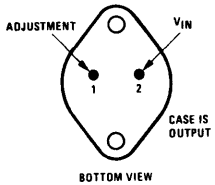

**Current Limited 6V Charger**




*Sets peak current (0.6A for 1Ω)
**The 1000 μF is recommended to filter out input transients

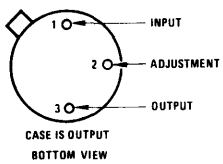
## Connection Diagrams

**(TO-3 Steel)**
**Metal Can Package**




**Order Number LM117HVK STEEL, LM217HVK STEEL, or LM317HVK STEEL**
**See Package K02A**

**(TO-39)**
**Metal Can Package**




**Order Number LM117HVH, LM217HVH, or LM317HVH**
**See Package H03A**

National Semiconductor

# Voltage Regulators

# LM120 Series 3-Terminal Negative Regulators

## General Description

The LM120 series are three-terminal negative regulators with a fixed output voltage of -5V, -12V, and -15V, and up to 1.5A load current capability. Where other voltages are required, the LM137 series provides an output voltage range of -1.2V to -47V.

The LM120 need only one external component-a compensation capacitor at the output, making them easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM120 Series immune to overload conditions. The regulators have current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM120 Series may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain current of the devices allows this technique to be used with good regulation.

## Features

- Preset output voltage error less than ±3%
- Preset current limit
- Internal thermal shutdown
- Operates with input-output voltage differential down to 1V
- Excellent ripple rejection
- Low temperature drift
- Easily adjustable to higher output voltage

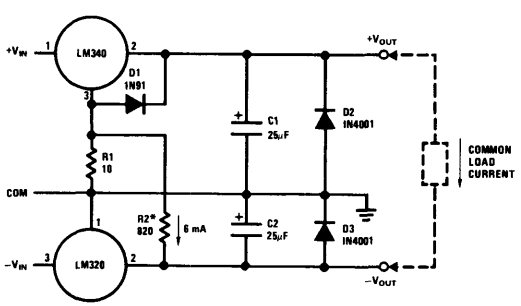
**LM120 Series Packages and Power Capability**

| DEVICE | PACKAGE | RATED POWER DISSIPATION | DESIGN LOAD CURRENT |
|---|---|---|---|
| LM120 | TO-3 | 20W | 1.5A |
| LM320 | TO-5 | 2W | 0.5A |
| LM320T | TO-220 | 15W | 1.5A |
| LM320M | TO-202 | 7.5W | 0.5A |
| LM320ML* | TO-202 | 7.5W | 0.25A |
| LM320L* | TO-92+ | 1.2W | 0.1A |

*Electrical specifications shown on separate data sheet

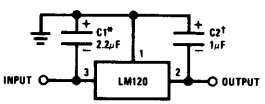
## Typical Applications

**Preventing Positive Regulator Latch-Up**




R1 & D1 allow the positive regulator to "start-up" when $+V_{IN}$ is delayed relative to $-V_{IN}$ and a heavy load is drawn between the outputs. Without R1 & D1, most three-terminal regulators will not start with heavy (0.1A–1A) load current flowing to the negative regulator, even though the positive output is clamped by D2.
*R2 is optional. Ground pin current from the positive regulator flowing through R1 will increase $+V_{OUT}$ ≈ 60 mV if R2 is omitted.

**Fixed Regulator**

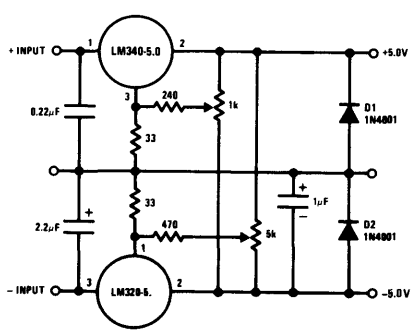



*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may substituted. Values given may be increased without limit.

For output capacitance in excess of 100μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

**Dual Trimmed Supply**



## −5 VOLT REGULATORS (Note 3)

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally Limited |
| Input Voltage | −25V |
| Input-Output Voltage Differential | 25V |
| Junction Temperatures | See Note 1 |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics

| ORDER NUMBERS | | METAL CAN PACKAGE | | | | | | | | | | | | POWER PLASTIC PACKAGE | | | | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LM120K-5.0 (TO-3) | | | LM320K-5.0 (TO-3) | | | LM120H-5.0 (TO-5) | | | LM320H-5.0 (TO-5) | | | LM320T-5.0 (TO-220) | | | LM320MP-5.0 (TO-202) | | | |
| DESIGN OUTPUT CURRENT ($I_D$) DEVICE DISSIPATION ($P_D$) | | 1.5A 20W | | | 1.5A 20W | | | 0.5A 2W | | | 0.5A 2W | | | 1.5A 15W | | | 0.5A 7.5W | | | |
| PARAMETER | CONDITIONS (NOTE 1) | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_J = 25°C$, $V_{IN} = 10V$, $I_{LOAD} = 5$ mA | −5.1 | −5 | −4.9 | −5.2 | −5 | −4.8 | −5.1 | −5.0 | −4.9 | −5.2 | −5.0 | −4.8 | −5.2 | −5.0 | −4.8 | −5.2 | −5.0 | −4.8 | V |
| *Line Regulation* | $T_J = 25°C$, $I_{LOAD} = 5$ mA, $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 10 | 25 | | 10 | 40 | | 10 | 25 | | 10 | 40 | | 10 | 40 | | 10 | 40 | mV |
| Input Voltage | | −25 | | −7 | −25 | | −7 | −25 | | −7 | −25 | | −7 | −25 | | −7.5 | −25 | | −7.5 | V |
| Ripple Rejection | f = 120 Hz | 54 | 64 | | 54 | 64 | | 54 | 64 | | 54 | 64 | | 54 | 64 | | 54 | 64 | | dB |
| Load Regulation, (Note 2) | $T_J = 25°C$, $V_{IN} = 10V$, $5\text{ mA} \leq I_{LOAD} \leq I_D$ | | 50 | 75 | | 50 | 100 | | 30 | 50 | | 30 | 50 | | 50 | 100 | | 40 | 100 | mV |
| Output Voltage, (Note 1) | $-7.5V \leq V_{IN} \leq V_{MAX}$, $5\text{ mA} \leq I_{LOAD} \leq I_D$, $P \leq P_D$ | −5.20 | | −4.80 | −5.25 | | −4.75 | −5.20 | | −4.80 | −5.25 | | −4.75 | −5.25 | | −4.75 | −5.25 | −5.0 | −4.75 | V |
| Quiescent Current | $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 1 | 2 | | 1 | 2 | | 1 | 2 | | 1 | 2 | | 1 | 2 | | 1 | 2 | mA |
| Quiescent Current Change | $T_J = 25°C$ | | | | | | | | | | | | | | | | | | | |
| | $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.4 | | 0.05 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.3 | mA |
| | $5\text{ mA} \leq I_{LOAD} \leq I_D$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.04 | 0.4 | | 0.04 | 0.4 | | 0.1 | 0.4 | | 0.04 | 0.25 | mA |
| Output Noise Voltage | $T_A = 25°C$, $C_L = 1\mu F$, $I_L = 5$ mA, $V_{IN} = 10V$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$ | | 150 | | | 150 | | | 150 | | | 150 | | | 150 | | | 150 | | $\mu V$ |
| Long Term Stability | | | 5 | 50 | | 5 | 50 | | 5 | 50 | | 5 | 50 | | 10 | | | 10 | | mV |
| Thermal Resistance | | | | | | | | | | | | | | | | | | | | |
| Junction to Case | | | | 3 | | | 3 | | | 15 | | | 15 | | 4 | | | 12 | | °C/W |
| Junction to Ambient | | | | 35 | | | 35 | | | 150 | | | 150 | | 50 | | | 70 | | °C/W |

**Note 1:** This specification applies over $-55°C \leq T_J \leq +150°C$ for the LM120 and $0°C \leq T_J \leq +125°C$ for the LM320.

**Note 2:** Regulation is measured at constant junction temperature. *Changes in output voltage* due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to $P_D$.

**Note 3:** For −5V 3 amp regulators, see LM145 data sheet.

## −12 VOLT REGULATORS

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally Limited |
| Input Voltage | −35V |
| Input-Output Voltage Differential | 30V |
| Junction Temperatures | See Note 1 |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics

| ORDER NUMBERS | | METAL CAN PACKAGE | | | | | | | | | | | | POWER PLASTIC PACKAGE | | | | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LM120K-12 (TO-3) | | | LM320K-12 (TO-3) | | | LM120H-12 (TO-5) | | | LM320H-12 (TO-5) | | | LM320T-12 (TO-220) | | | LM320MP-12 (TO-202) | | | |
| DESIGN OUTPUT CURRENT ($I_D$) DEVICE DISSIPATION ($P_D$) | | 1A 20W | | | 1A 20W | | | 0.2A 2W | | | 0.2A 2W | | | 1A 15W | | | 0.5A 7.5W | | | |
| PARAMETER | CONDITIONS (NOTE 1) | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_J = 25°C$, $V_{IN} = 17V$, $I_{LOAD} = 5$ mA | −12.3 | −12 | −11.7 | −12.4 | −12 | −11.6 | −12.3 | −12 | −11.7 | −12.4 | −12 | −11.6 | −12.4 | −12 | −11.6 | −12.5 | −12 | −11.5 | V |
| Line Regulation | $T_J = 25°C$, $I_{LOAD} = 5$ mA, $V_{MIN} \le V_{IN} \le V_{MAX}$ | | 4 | 10 | | 4 | 20 | | 4 | 10 | | 4 | 20 | | 4 | 20 | | 4 | 24 | mV |
| Input Voltage | | −32 | | −14 | −32 | | −14 | −32 | | −14 | −32 | | −14 | −32 | | −14.5 | −32 | | −14.5 | V |
| Ripple Rejection | f = 120 Hz | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | dB |
| Load Regulation, (Note 2) | $T_J = 25°C$, $V_{IN} = 17V$, $5\text{ mA} \le I_{LOAD} \le I_D$ | | 30 | 80 | | 30 | 80 | | 10 | 25 | | 10 | 40 | | 30 | 80 | | 40 | 100 | mV |
| Output Voltage, (Note 1) | $14.5V \le V_{IN} \le V_{MAX}$, $5\text{ mA} \le I_{LOAD} \le I_D$, $P \le P_D$ | −12.5 | | −11.5 | −12.6 | | −11.4 | −12.5 | | −11.5 | −12.6 | | −11.4 | −12.6 | | −11.4 | −12.6 | | −11.4 | V |
| Quiescent Current | $V_{MIN} \le V_{IN} \le V_{MAX}$ | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | mA |
| Quiescent Current Change | $T_J = 25°C$ | | | | | | | | | | | | | | | | | | | |
| | $V_{MIN} \le V_{IN} \le V_{MAX}$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.4 | | 0.05 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.3 | mA |
| | $5\text{ mA} \le I_{LOAD} \le I_D$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.03 | 0.4 | | 0.03 | 0.4 | | 0.1 | 0.4 | | 0.04 | 0.25 | mA |
| Output Noise Voltage | $T_A = 25°C$, $C_L = 1\mu F$, $I_L = 5$ mA, $V_{IN} = 17V$, $10\text{ Hz} \le f \le 100\text{ kHz}$ | | 400 | | | 400 | | | 400 | | | 400 | | | 400 | | | 400 | | μV |
| Long Term Stability | | | 12 | 120 | | 12 | 120 | | 12 | 120 | | 12 | 120 | | 24 | | | 24 | | mV |
| Thermal Resistance | | | | | | | | | | | | | | | | | | | | |
| Junction to Case | | | | 3 | | | 3 | | | 15 | | | 15 | | 4 | | | 12 | | °C/W |
| Junction to Ambient | | | | 35 | | | 35 | | | 150 | | | 150 | | 50 | | | 70 | | °C/W |

**Note 1:** This specification applies over $-55°C \le T_J \le +150°C$ for the LM120 and $0°C \le T_J \le +125°C$ for the LM320.

**Note 2:** Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to $P_D$.

## −15 VOLT REGULATORS

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally Limited |
| Input Voltage | |
| LM120/LM320 | −40V |
| LM320T/LM320MP | −35V |
| Input-Output Voltage Differential | 30V |
| Junction Temperatures | See Note 1 |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics

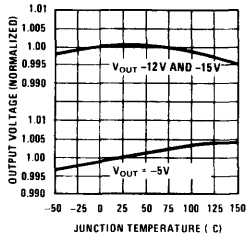
| ORDER NUMBERS | | METAL CAN PACKAGE | | | | | | | | | | | | POWER PLASTIC PACKAGE | | | | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LM120K-15 (TO-3) | | | LM320K-15 (TO-3) | | | LM120H-15 (TO-5) | | | LM320H-15 (TO-5) | | | LM320T-15 (TO-220) | | | LM320MP-15 (TO-202) | | | |
| DESIGN OUTPUT CURRENT ($I_D$) | | 1A | | | 1A | | | 0.2A | | | 0.2A | | | 1A | | | 0.5A | | | |
| DEVICE DISSIPATION ($P_D$) | | 20W | | | 20W | | | 2W | | | 2W | | | 15W | | | 7.5W | | | |
| PARAMETER | CONDITIONS (NOTE 1) | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_J = 25°C$, $V_{IN} = 20V$, $I_{LOAD} = 5$ mA | −15.3 | −15 | −14.7 | −15.4 | −15 | −14.6 | −15.3 | −15 | −14.7 | −15.4 | −15 | −14.6 | −15.5 | −15 | −14.5 | −15.6 | −15 | −14.4 | V |
| Line Regulation | $T_J = 25°C$, $I_{LOAD} = 5$ mA, $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 5 | 10 | | 5 | 20 | | 5 | 10 | | 5 | 20 | | 5 | 20 | | 5 | 30 | mV |
| Input Voltage | | −35 | | −17 | −35 | | −17 | −35 | | −17 | −35 | | −17 | −35 | | −17.5 | −35 | | −17.5 | V |
| Ripple Rejection | f = 120 Hz | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | 56 | 80 | | dB |
| Load Regulation, (Note 2) | $T_J = 25°C$, $V_{IN} = 20V$, 5 mA $\leq I_{LOAD} \leq I_D$ | | 30 | 80 | | 30 | 80 | | 10 | 25 | | 10 | 40 | | 30 | 80 | | 40 | 100 | mV |
| Output Voltage, (Note 1) | $17.5V < V_{IN} \leq V_{MAX}$, 5 mA $\leq I_{LOAD} \leq I_D$, $P \leq P_D$ | −15.5 | | −14.5 | −15.6 | | −14.4 | −15.5 | | −14.5 | −15.6 | | −14.4 | −15.7 | | −14.3 | −15.7 | | −14.3 | V |
| Quiescent Current | $V_{MIN} < V_{IN} \leq V_{MAX}$ | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | | 2 | 4 | mA |
| Quiescent Current Change | $T_J = 25°C$ | | | | | | | | | | | | | | | | | | | |
| | $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.4 | | 0.05 | 0.4 | | 0.1 | 0.4 | | 0.05 | 0.3 | mA |
| | 5 mA $\leq I_{LOAD} \leq I_D$ | | 0.1 | 0.4 | | 0.1 | 0.4 | | 0.03 | 0.4 | | 0.03 | 0.4 | | 0.1 | 0.4 | | 0.04 | 0.25 | mA |
| Output Noise Voltage | $T_A = 25°C$, $C_L = 1\mu F$, $I_L = 5$ mA, $V_{IN} = 20V$, 10 Hz $\leq f \leq$ 100 kHz | | 400 | | | 400 | | | 400 | | | 400 | | | 400 | | | 400 | | $\mu V$ |
| Long Term Stability | | | 15 | 150 | | 15 | 150 | | 15 | 150 | | 15 | 150 | | 30 | | | 30 | | mV |
| Thermal Resistance | | | | | | | | | | | | | | | | | | | | |
| Junction to Case | | | | 3 | | | 3 | | | 15 | | | 15 | | 4 | | | 12 | | °C/W |
| Junction to Ambient | | | | 35 | | | 35 | | | 150 | | | 150 | | 50 | | | 70 | | °C/W |

**Note 1:** This specification applies over $-55°C \leq T_J \leq +150°C$ for the LM120 and $0°C \leq T_J \leq +125°C$ for the LM320.

**Note 2:** Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to $P_D$.

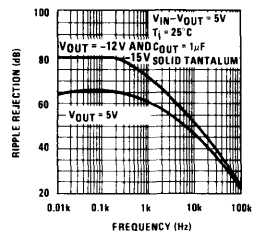
# Typical Performance Characteristics

**Output Voltage vs Temperature**

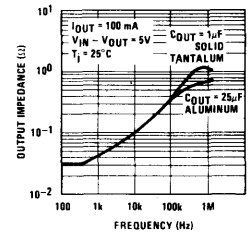



**Note:** Shaded portion refers to LM320 series regulators.

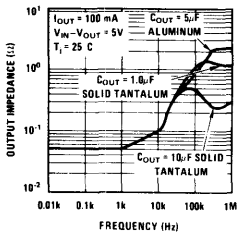
**Ripple Rejection (All Types)**



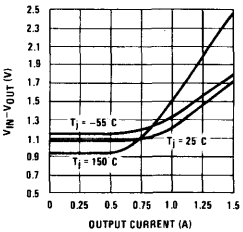

**Output Impedance TO-3 and TO-220 Packages**



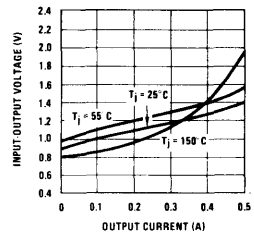

**Output Impedance TO-5 and TO-202 Packages**



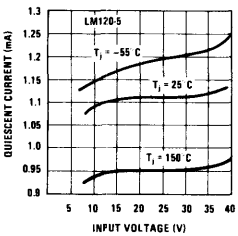

**Minimum Input-Output Differential TO-3 and TO-220 Packages**



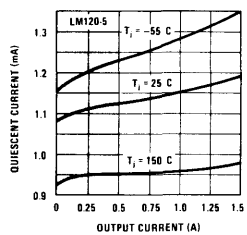

**Minimum Input-Output Differential TO-5 and TO-202 Packages**




**Quiescent Current vs Input Voltage**

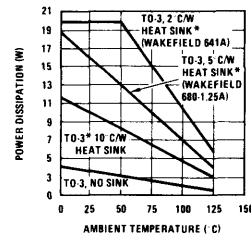



**Quiescent Current vs Load Current**



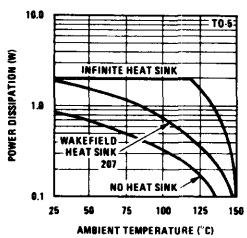

**Note:** Shaded area shows operating range of TO-5 and TO-202 packages.

**Maximum Average Power Dissipation (TO-3)**

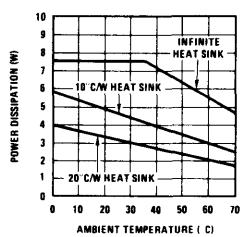



*These curves for LM120 and LM220. Derate 25°C further for LM320.

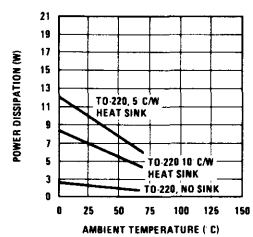
**Maximum Average Power Dissipation (TO-5)**



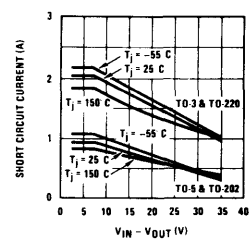

**Maximum Average Power Dissipation (TO-202)**




**Maximum Average Power Dissipation (TO-220)**

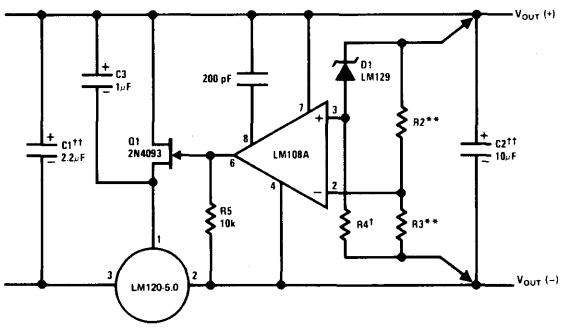



**Short Circuit Current**



# Typical Applications (cont'd.)

### High Stability 1 Amp Regulator




Load and line regulation · 0.01% temperature stability < 0.2%

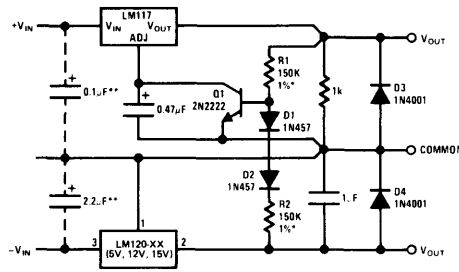
†Determines Zener current.

††Solid tantalum.

An LM120-12 or LM120-15 may be used to permit higher input voltages, but the regulated output voltage must be at least −15V when using the LM120-12 and −18V for the LM120-15.

**Select resistors to set output voltage. 2 ppm/ C tracking suggested.

### Wide Range Tracking Regulator

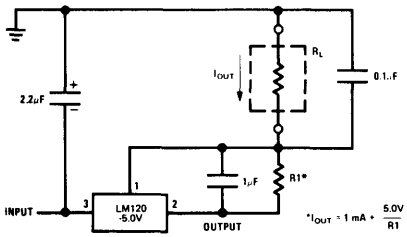



*Resistor tolerance of R1 and R2 determine matching of (+) and (−) inputs.

**Necessary only if raw supply capacitors are more than 3" from regulators

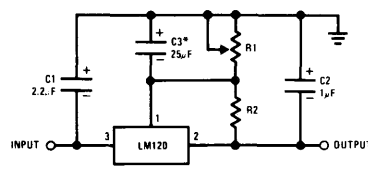
An LM3086N array may substitute for Q1, D1 and D2 for better stability and tracking. In the array diode transistors Q5 and Q4 (in parallel) make up D2; similarly, Q1 and Q2 become D1 and D3 replaces the 2N2222.

### Current Source




*$I_{OUT}$ = 1 mA + $\frac{5.0V}{R1}$

### Variable Output



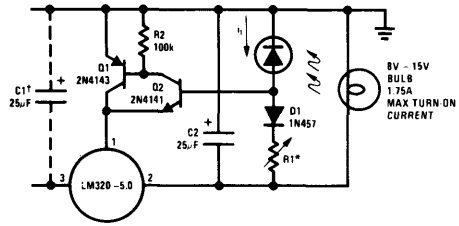

*Optional: improves transient response and ripple rejection.

$V_{OUT} = V_{SET} \frac{R1 + R2}{R2}$

**SELECT R2 AS FOLLOWS**

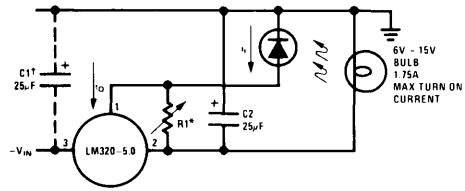
| | |
|---|---|
| **LM120-5** | **300Ω** |
| **LM120-12** | **750Ω** |
| **LM120-15** | **1K** |

### Light Controllers Using Silicon Photo Cells




*Lamp brightness increases until $I_1$ = 5V/R1 ($I_1$ can be set as low as 1μA).

†Necessary only if raw supply filter capacitor is more than 2" from LM320MP.

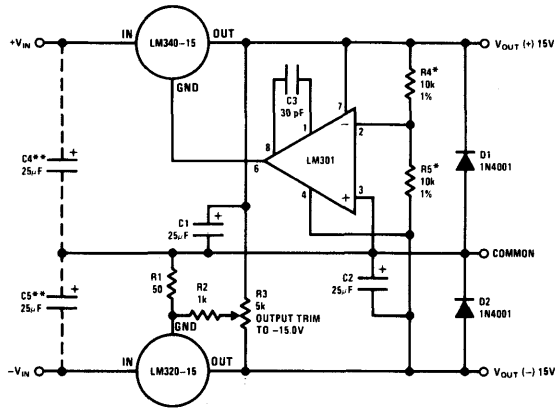



*Lamp brightness increases until $I_1 = I_O$ ( 1 mA) + 5V/R1.

†Necessary only if raw supply filter capacitor is more than 2" from LM320.

## Typical Applications (cont'd.)

**±15V, 1 Amp Tracking Regulators**

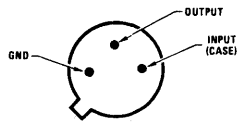



**Performance (Typical)**

| | | |
|---|---|---|
| Load Regulation at $\Delta I_L$ = 1A | 10 mV | 1 mV |
| Output Ripple, $C_{PM}$ = 3000μF, $I_L$ = 1A | 190μVrms | 190μVrms |
| Temperature Stability | +50 mV | +50 mV |
| Output Noise 10 Hz ≤ f ≤ 10 kHz | 150μVrms | 150μVrms |

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.
**Necessary only if raw supply filter capacitors are more than 2" from regulators.

## Connection Diagrams

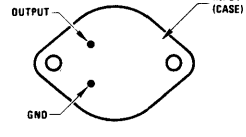



BOTTOM VIEW

**Metal Can Package (TO-39) (H)**
**Order Numbers:**

LM120H-5.0 LM120H-12 LM120H-15
LM320H-5.0 LM320H-12 LM320H-15

**See Package H03A**

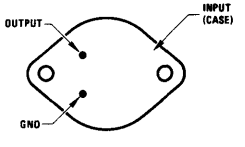



BOTTOM VIEW

**Steel Metal Can Package TO-3 (K)**
**Order Numbers:**

LM120K-5.0 LM120K-12 LM120K-15
LM320H-5.0 LM320K-12 LM320K-15

**See Package K02A**

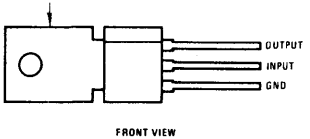



BOTTOM VIEW

**Aluminum Metal Can Package TO-3 (KC)**
**Order Numbers:**

LM320KC-5.0 LM320KC-12
LM320KC-15

**See Package KC02A**



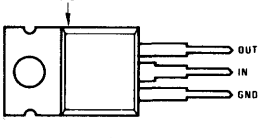

FRONT VIEW

**Power Package TO-202 (P)**
**Order Numbers:**

LM320MP-5.0
LM320MP-12
LM320MP-15

**See Package P03A**

**For Tab Formed TO-202**
**Order Numbers:**
LM320MP-5.0TB
LM320MP-12TB
LM320MP-15TB
**See Package P03E**




TOP VIEW

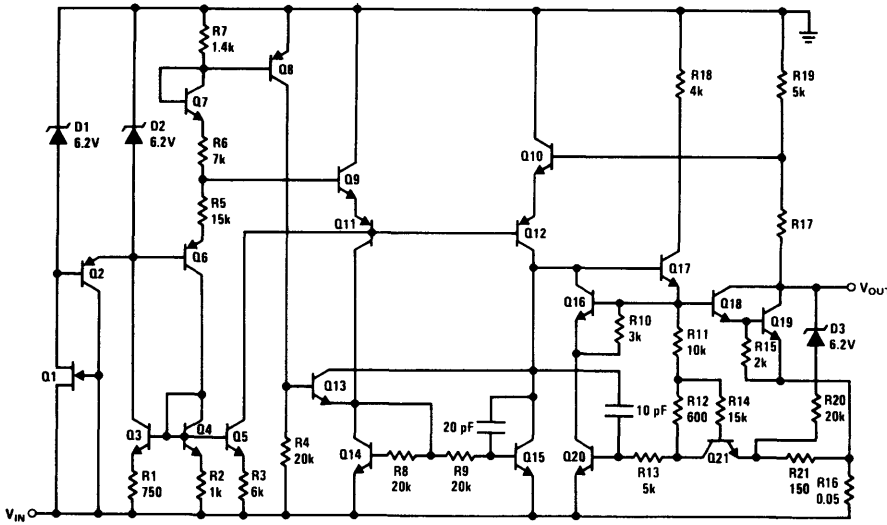
**Power Package TO-220 (T)**
**Order Numbers:**

LM320T-5.0
LM320T-12
LM320T-15

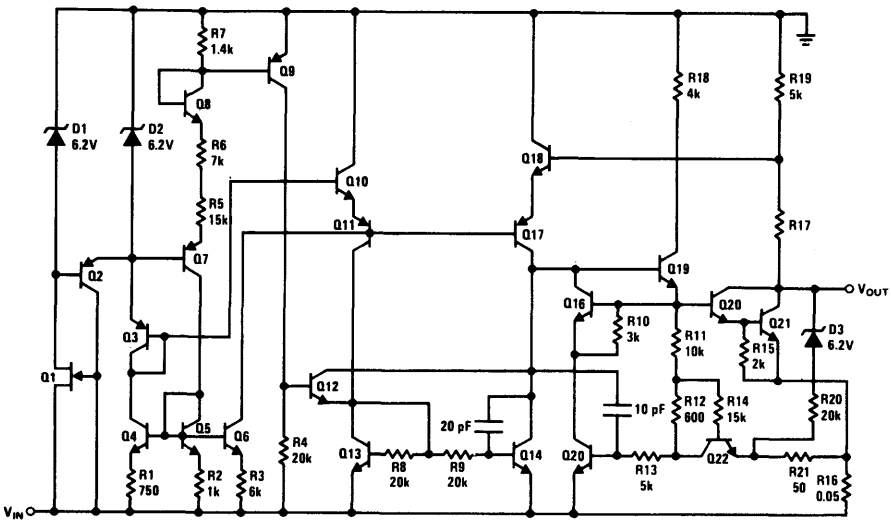
**See Package T03B**

## Schematic Diagrams

-5V




-12V and -15V



National Semiconductor

# Voltage Regulators

# LM123/LM223/LM323 3 Amp, 5 Volt Positive Regulator

## General Description

The LM123 is a three-terminal positive regulator with a preset 5V output and a load driving capability of 3 amps. New circuit design and processing techniques are used to provide the high output current without sacrificing the regulation characteristics of lower current devices.

The 3 amp regulator is virtually blowout proof. Current limiting, power limiting, and thermal shutdown provide the same high level of reliability obtained with these techniques in the LM109 1 amp regulator.

No external components are required for operation of the LM123. If the device is more than 4 inches from the filter capacitor, however, a 1μF solid tantalum capacitor should be used on the input. A 0.1μF or larger capacitor may be used on the output to reduce load transient spikes created by fast switching digital logic, or to swamp out stray load capacitance.

An overall worst case specification for the combined effects of input voltage, load currents, ambient temperature, and power dissipation ensure that the LM123 will perform satisfactorily as a system element.

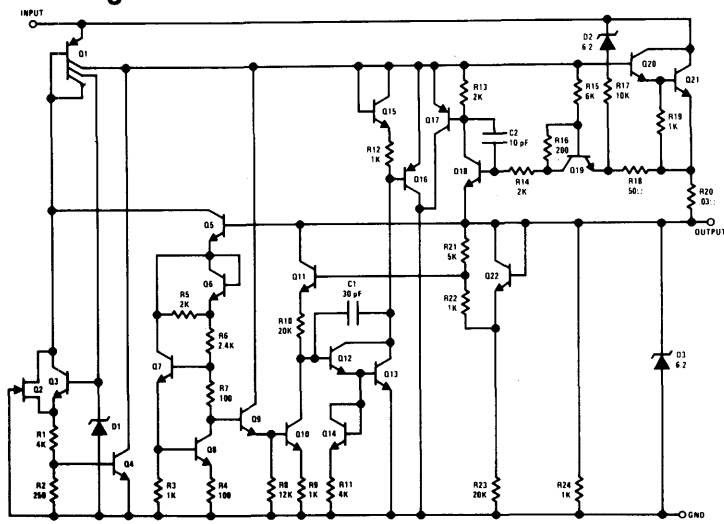
For applications requiring other voltages, see LM150 series data sheet.

Operation is guaranteed over the junction temperature range −55°C to +150°C. An electrically identical LM223 operates from −25°C to +150°C and the LM323 is specified from 0°C to +125°C junction temperature. A hermetic TO-3 package is used for high reliability and low thermal resistance.

## Features

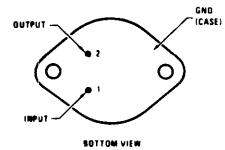
- 3 amp output current
- Internal current and thermal limiting
- 0.01Ω typical output impedance
- 7.5 minimum input voltage
- 30W power dissipation
- 100% electrical burn-in

## Schematic Diagram




## Connection Diagram

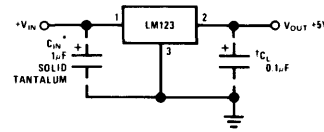
**Metal Can Package**




**Order Number LM123K STEEL, LM223K STEEL or LM323K STEEL**
**See Package K02A**

## Typical Applications

**Basic 3 Amp Regulator**




*Required if LM123 is more than 4" from filter capacitor.
†Regulator is stable with no load capacitor into resistive loads.

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | 20V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | |
| LM123 | −55°C to +150°C |
| LM223 | −25°C to +150°C |
| LM323 | 0°C to +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 sec) | 300°C |

## Preconditioning

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

## Electrical Characteristics (Note 1)

| PARAMETER | CONDITIONS | LM123/LM223 | | | LM323 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_j = 25°C$<br>$V_{IN} = 7.5V$, $I_{OUT} = 0$ | 4.7 | 5 | 5.3 | 4.8 | 5 | 5.2 | V |
| Output Voltage | $7.5V \leq V_{IN} \leq 15V$<br>$0 \leq I_{OUT} \leq 3A$, $P \leq 30W$ | 4.6 | | 5.4 | 4.75 | | 5.25 | V |
| Line Regulation (Note 3) | $T_j = 25°C$<br>$7.5V \leq V_{IN} \leq 15V$ | | 5 | 25 | | 5 | 25 | mV |
| Load Regulation (Note 3) | $T_j = 25°C$, $V_{IN} = 7.5V$,<br>$0 \leq I_{OUT} \leq 3A$ | | 25 | 100 | | 25 | 100 | mV |
| Quiescent Current | $7.5V \leq V_{IN} \leq 15V$,<br>$0 \leq I_{OUT} \leq 3A$ | | 12 | 20 | | 12 | 20 | mA |
| Output Noise Voltage | $T_j = 25°C$<br>$10 Hz \leq f \leq 100 kHz$ | | 40 | | | 40 | | μVrms |
| Short Circuit Current Limit | $T_j = 25°C$<br>$V_{IN} = 15V$<br>$V_{IN} = 7.5V$ | | 3<br>4 | 4.5<br>5 | | 3<br>4 | 4.5<br>5 | A<br>A |
| Long Term Stability | | | | 35 | | | 35 | mV |
| Thermal Resistance Junction to Case (Note 2) | | | 2 | | | 2 | | °C/W |

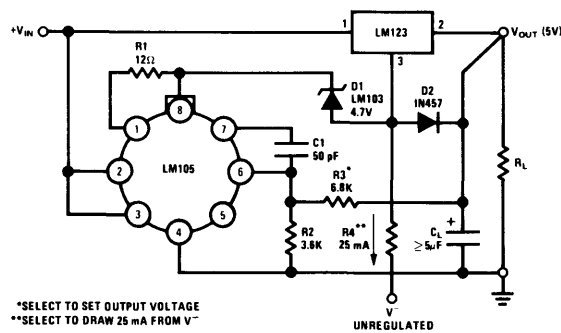
**Note 1:** Unless otherwise noted, specifications apply for $-55°C \leq T_j \leq +150°C$ for the LM123, $-25°C \leq T_j \leq +150°C$ for the LM223, and $0°C \leq T_j \leq +125°C$ for the LM323. Although power dissipation is internally limited, specifications apply only for $P \leq 30W$.

**Note 2:** Without a heat sink, the thermal resistance of the TO-3 package is about 35°C/W. With a heat sink, the effective thermal resistance can only approach the specified values of 2°C/W, depending on the efficiency of the heat sink.

**Note 3:** Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width ≤ 1 ms and a duty cycle ≤ 5%.

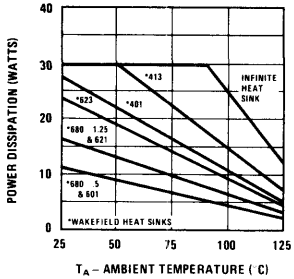
## Typical Applications (cont'd.)

**Adjustable Output 5V – 10V 0.1% Regulation**

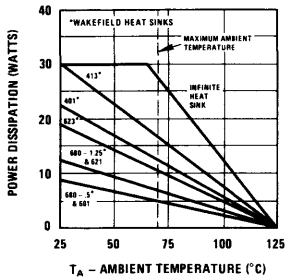


# Typical Performance Characteristics

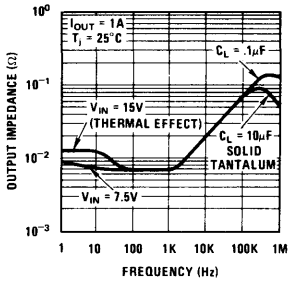
**Maximum Average Power Dissipation For LM123; LM223**



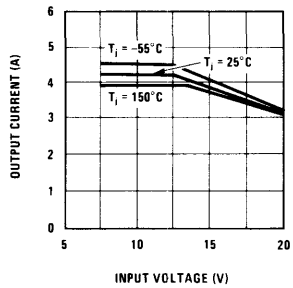

**Maximum Average Power Dissipation For LM323**



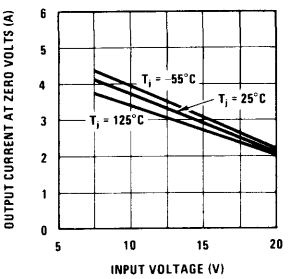

**Output Impedance**



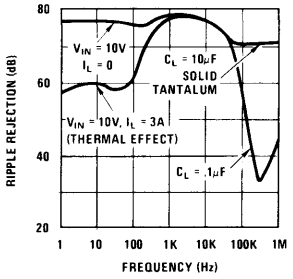

**Peak Available Output Current**



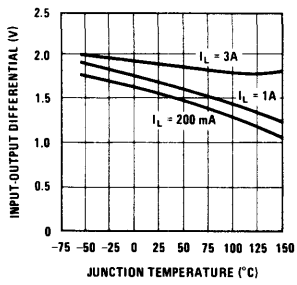

**Short Circuit Current**



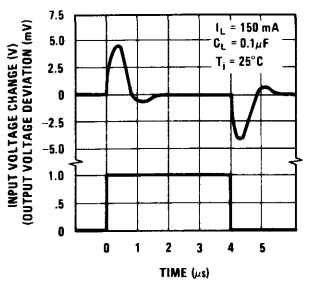

**Ripple Rejection**



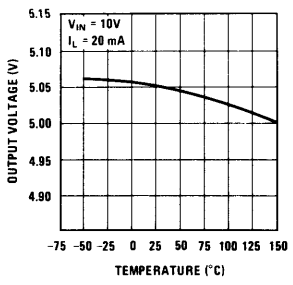

**Dropout Voltage**



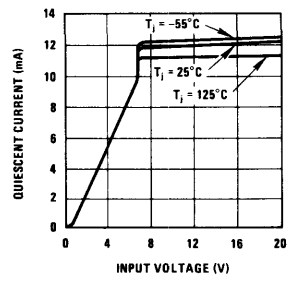

**Line Transient Response**



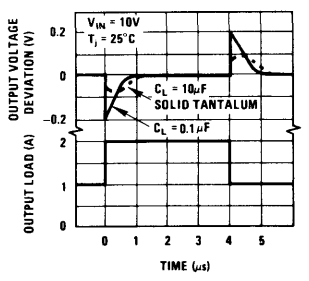

**Output Voltage**



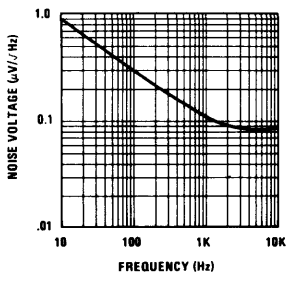

**Quiescent Current**




**Load Transient Response**

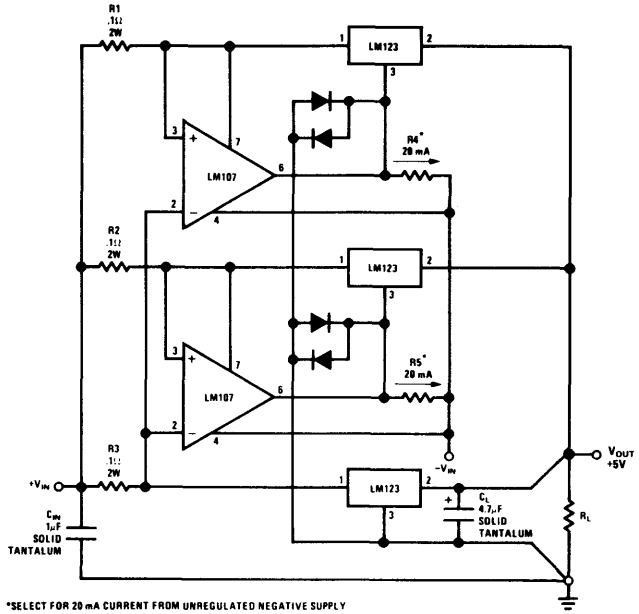



**Output Noise Voltage**



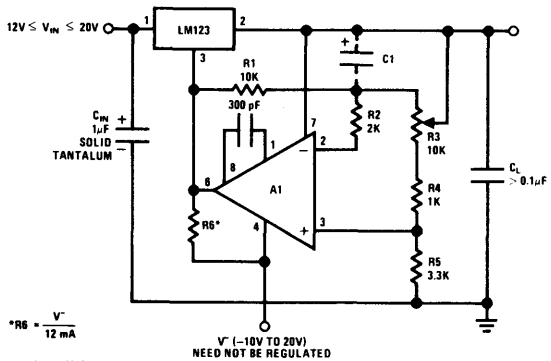
## Typical Applications (cont'd.)

**10 Amp Regulator With Complete Overload Protection**




*SELECT FOR 20 mA CURRENT FROM UNREGULATED NEGATIVE SUPPLY

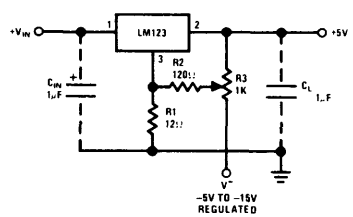
**Adjustable Regulator 0–10V @ 3A**




$A_1$ – LM101A

$C_1$ – 2μF OPTIONAL – IMPROVES RIPPLE REJECTION, NOISE, AND TRANSIENT RESPONSE

**Trimming Output to 5V**



National Semiconductor



# LM125/LM225/LM325/LM325A, LM126/LM326 Voltage Regulators

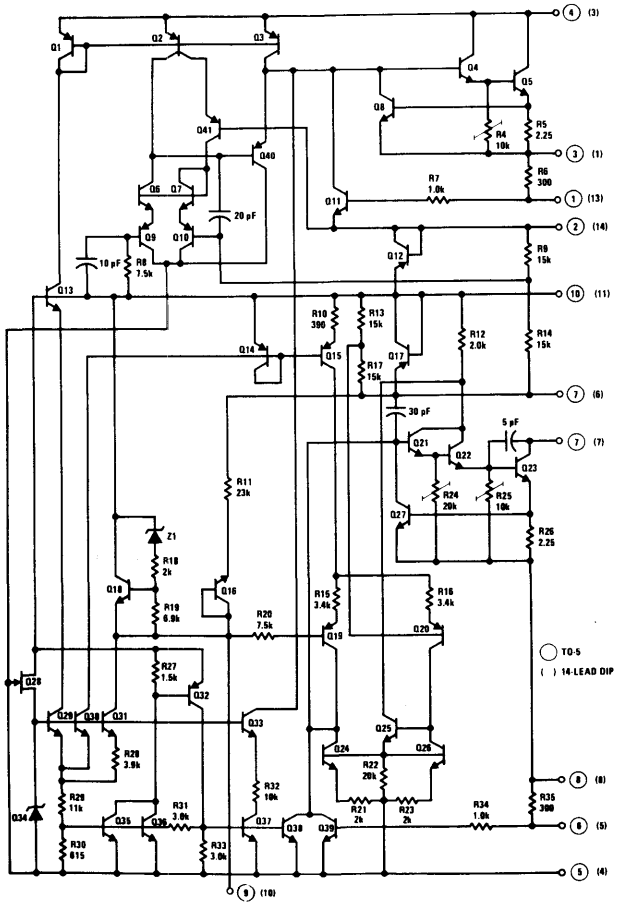
## General Description

These are dual polarity tracking regulators designed to provide balanced positive and negative output voltages at current up to 100 mA, the devices are set for ±15 V and ±12 V outputs respectively. Input voltages up to ±30 V can be used and there is provision for adjustable current limiting. These devices are available in three package types to accomodate various power requirements and temperature ranges.

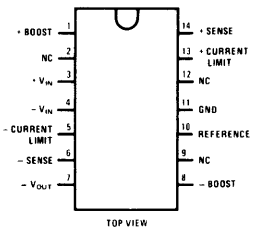
## Features

- ±15V and ±12V tracking outputs
- Output current to 100 mA
- Output voltages balanced to within 1% (LM125, LM126, LM325A)
- Line and load regulation of 0.06%
- Internal thermal overload protection
- Standby current drain of 3 mA
- Externally adjustable current limit
- Internal current limit

## Schematic and Connection Diagrams

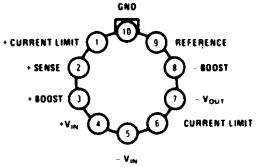



Dual-In-Line Package




**Order Number LM325AN, LM325N, or LM326N**
**See Package N14A**

Metal Can Package




**Order Number LM125H, LM325H, LM126H, or LM326H**
**See Package H10C**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | ±30V |
| Forced $V_O^+$ (min) (Note 1) | −0.5V |
| Forced $V_O^-$ (max) (Note 1) | +0.5V |
| Power Dissipation (Note 2) | $P_{MAX}$ |
| Output Short-Circuit Duration (Note 3) | Indefinite |

## Operating Conditions

| | |
|---|---|
| Operating Temperature Range | |
| LM125 | −55°C to +125°C |
| LM325, LM325A | 0°C to +70°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics LM125/LM325/LM325A (Note 2)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| Output Voltage | $T_j$ = 25°C | | | | |
| **LM125/LM325A** | | 14.8 | 15 | 15.2 | V |
| LM325 | | 14.5 | 15 | 15.5 | V |
| Input-Output Differential | | 2.0 | | | V |
| Line Regulation | $V_{IN}$ = 18V to 30V, $I_L$ = 20 mA, $T_j$ = 25°C | | 2.0 | 10 | mV |
| Line Regulation Over Temperature Range | $V_{IN}$ = 18V to 30V, $I_L$ = 20 mA | | 2.0 | 20 | mV |
| Load Regulation | $I_L$ = 0 to 50 mA, $V_{IN}$ = ±30V, | | | | |
| $V_O$+ | $T_j$ = 25°C | | 3.0 | 10 | mV |
| $V_O$− | | | 5.0 | 10 | mV |
| Load Regulation Over Temperature Range | $I_L$ = 0 to 50 mA, $V_{IN}$ = ±30V | | | | |
| $V_O$+ | | | 4.0 | 20 | mV |
| $V_O$− | | | 7.0 | 20 | mV |
| Output Voltage Balance | $T_j$ = 25°C | | | | |
| **LM125, LM325A** | | | | ±150 | mV |
| LM325 | | | | ±300 | mV |
| Output Voltage Over Temperature Range | $P \leq P_{MAX}$, $0 \leq I_O \leq 50$ mA, $18V \leq \lvert V_{IN} \rvert \leq 30$ | | | | |
| LM125/LM325A | | 14.65 | | 15.35 | V |
| **LM325** | | 14.27 | | 15.73 | V |
| Temperature Stability of $V_O$ | | | ±0.3 | | % |
| Short Circuit Current Limit | $T_j$ = 25°C | | 260 | | mA |
| Output Noise Voltage | $T_j$ = 25°C, BW = 100 − 10 kHz | | 150 | | μVrms |
| Positive Standby Current | $T_j$ = 25°C | | 1.75 | 3.0 | mA |
| Negative Standby Current | $T_j$ = 25°C | | 3.1 | 5.0 | mA |
| Long Term Stability | | | 0.2 | | %/kHr |
| Thermal Resistance Junction to Case (Note 4) | | | | | |
| **LM125H, LM325H** | | | 45 | | °C/W |
| Junction to Ambient | | | | | |
| LM325AN, LM325N | | | 150 | | °C/W |

**Note 1:** That voltage to which the output may be forced without damage to the device.

**Note 2:** Unless otherwise specified these specifications apply for $T_j$=55°C to +150°C on LM125, $T_j$=0°C to +125°C on LM325A, $T_j$=0°C to +125°C on LM325, $V_{IN}$=±20V, $I_L$=0 mA, $I_{MAX}$=100 mA, $P_{MAX}$=2.0W for the TO-5 H Package. $I_{MAX}$=100 mA. $I_{MAX}$=100 mA, $P_{MAX}$=1.0W for the DIP N Package.

**Note 3:** If the junction temperature exceeds 150°C, the output short circuit duration is 60 seconds.

**Note 4:** Without a heat sink, the thermal resistance junction to ambient of the TO-5 Package is about 150°C/W. With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending of the efficiency of the sink.

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | ±30V |
| Forced $V_O^+$ (Min) (Note 1) | −0.5V |
| Forced $V_O^-$ (Max) (Note 1) | +0.5V |
| Power Dissipation (Note 2) | Internally Limited |
| Output Short-Circuit Duration (Note 3) | Indefinite |
| Operating Temperature Range | |
| LM126 | −55°C to +125°C |
| LM326 | 0°C to +70°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics LM126/LM226/LM326 (Note 2)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| Output Voltage | $T_j$ = 25°C | | | | |
| LM126, LM326 | | 11.8 | 12 | 12.2 | V |
| | | 11.5 | | 12.5 | V |
| Input-Output Differential | | 2.0 | | | V |
| Line Regulation | $V_{IN}$ = 15V to 30V<br>$I_L$ = 20 mA, $T_j$ = 25°C | | 2.0 | 10 | mV |
| Line Regulation Over Temperature Range | $V_{IN}$ = 15V to 30V, $I_L$ = 20 mA | | 2.0 | 20 | mV |
| Load Regulation | $I_L$ = 0 to 50 mA, $V_{IN}$ = ±30V, | | | | |
| $V_O^+$ | $T_j$ = 25°C | | 3.0 | 10 | mV |
| $V_O^-$ | | | 5.0 | 10 | mV |
| Load Regulation Over Temperature Range | $I_L$ = 0 to 50 mA, $V_{IN}$ = ±30V | | | | |
| $V_O^+$ | | | 4.0 | 20 | mV |
| $V_O^-$ | | | 7.0 | 20 | mV |
| Output Voltage Balance | $T_j$ = 25°C | | | | |
| LM126, LM326 | | | | ±125 | mV |
| | | | | ±250 | mV |
| Output Voltage Over Temperature Range | $P \leq P_{MAX}$, $0 \leq I_O \leq 50$ mA | | | | |
| LM126 | $15V \leq \lvert V_{IN} \rvert \leq 30V$ | 11.68 | | 12.32 | V |
| LM326 | | 11.32 | | 12.68 | V |
| Temperature Stability of $V_O$ | | | ±0.3 | | % |
| Short Circuit Current Limit | $T_j$ = 25°C | | 260 | | mA |
| Output Noise Voltage | $T_j$ = 25°C, BW = 100 ~ 10 kHz | | 100 | | μVrms |
| Positive Standby Current | $T_j$ = 25°C, $I_L$ = 0 | | 1.75 | 3.0 | mA |
| Negative Standby Current | $T_j$ = 25°C, $I_L$ = 0 | | 3.1 | 5.0 | mA |
| Long Term Stability | | | 0.2 | | %/kHr |
| Thermal Resistance Junction to Case (Note 4) | | | | | |
| LM126/LM326H | | | 45 | | °C/W |
| Junction to Ambient LM326N | | | 150 | | °C/W |

**Note 1:** That voltage to which the output may be forced without damage to the device.

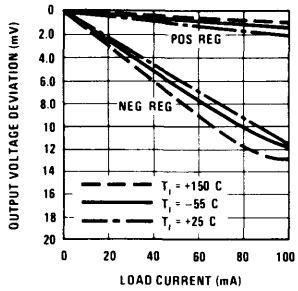
**Note 2:** Unless otherwise specified, these specifications apply for $T_j$=55°C to +150°C on LM126, $T_j$=0°C to +125°C on LM326, $V_{IN}$=±20V, $I_L$=0 mA, $I_{MAX}$=100 mA, $P_{MAX}$=2.0W for the TO-5 H Package $I_{MAX}$=100 mA. $I_{MAX}$=100 mA, $P_{MAX}$=1.0W for the DIP N Package.

**Note 3:** If the junction temperature exceeds 150°C the output short circuit duration is 60 seconds.

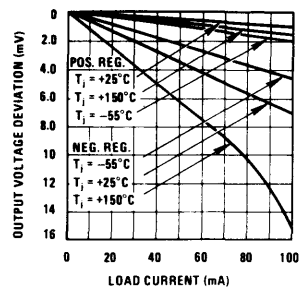
**Note 4:** Without a heat sink, the thermal resistance junction to ambient of the TO-5 Package is about 150° C/W. With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending on the efficiency of the sink.

## Typical Performance Characteristics ($V_{IN}$ = ±20V, $I_L$ = 0 mA, $T_j$ = 25°C, unless otherwise noted.)

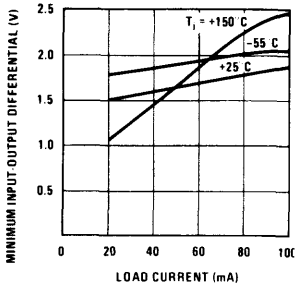
**LM125 Load Regulation**



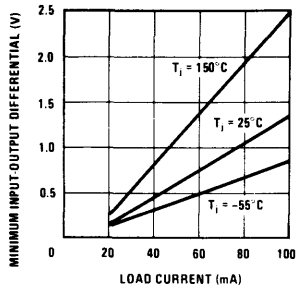

**LM126 Load Regulation**



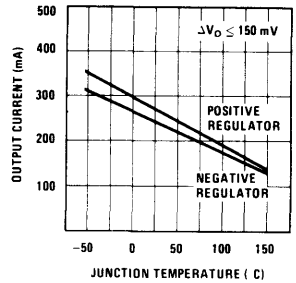

**LM125/126 Regulator Dropout Voltage for Positive Regulator**



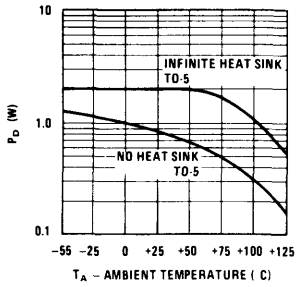

**LM125/126 Regulator Dropout Voltage for Negative Regulator**



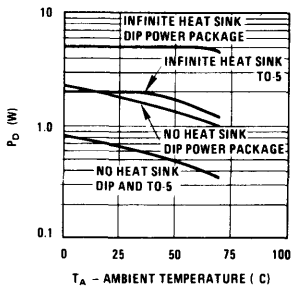

**LM125/126 Peak Output Current vs Junction Temperature**



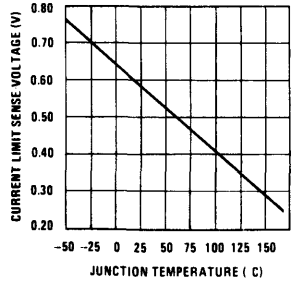

**LM125/126 Maximum Average Power Dissipation vs Ambient Temperature**



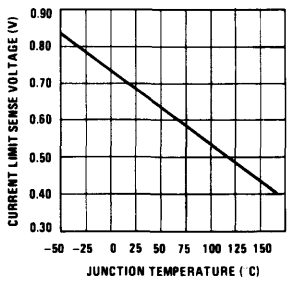

**LM325/326 Maximum Average Power Dissipation vs Ambient Temperature**



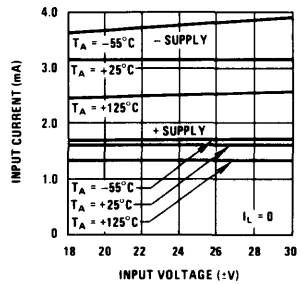

**LM125/126 Current Limit Sense Voltage vs Temperature for Negative Regulator**




**LM125/126 Current Limit Sense Voltage vs Temperature for Positive Regulator**

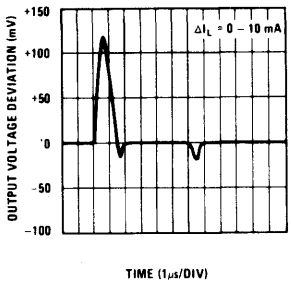



**LM125/126 Standby Current Drain**

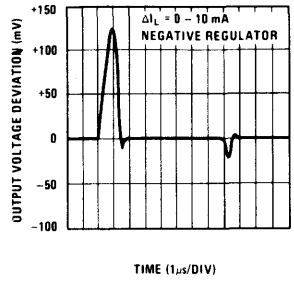


## Typical Performance Characteristics (cont'd.)

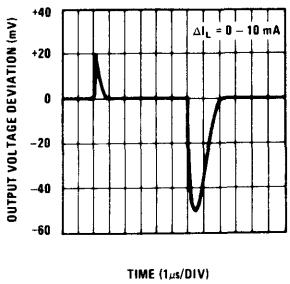
**LM125**
**Load Transient Response for Negative Regulator**



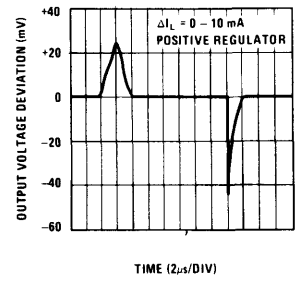

**LM126**
**Load Transient Response**



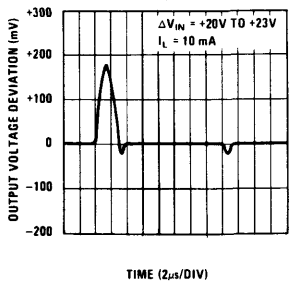

**LM125**
**Load Transient Response for Positive Regulator**



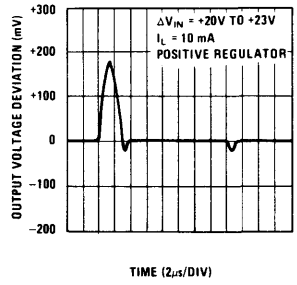

**LM126**
**Load Transient Response**



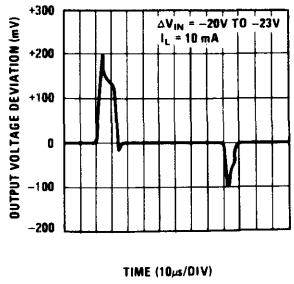

**LM125**
**Line Transient Response for Positive Regulator**



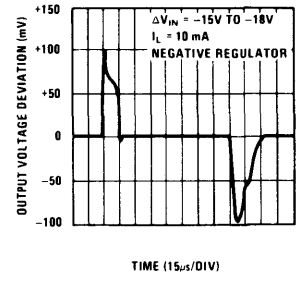

**LM126**
**Line Transient Response**




**LM125**
**Line Transient Response for Negative Regulator**

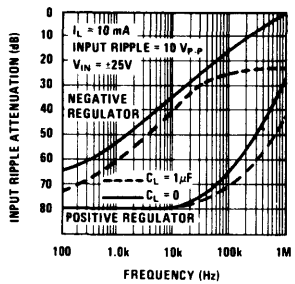



**LM126**
**Line Transient Response**

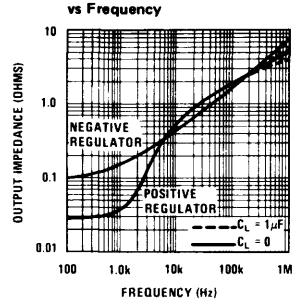


## Typical Performance Characteristics (cont'd.)

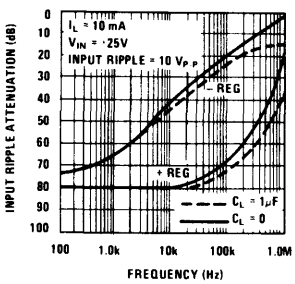
**LM125**
**Ripple Rejection**



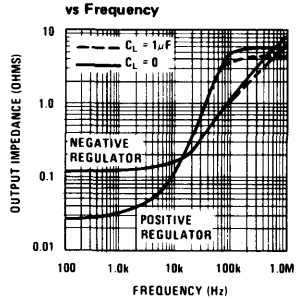

**LM125**
**Output Impedance**
**vs Frequency**




**LM126**
**Ripple Rejection**



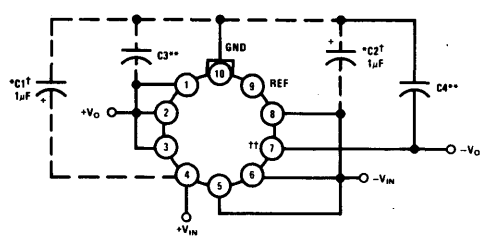

**LM126**
**Output Impedance**
**vs Frequency**



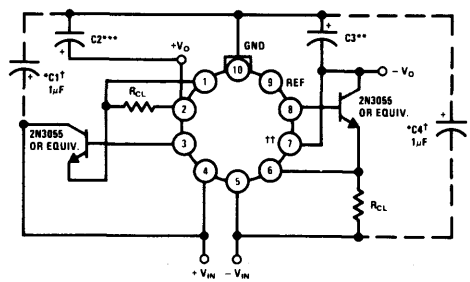

## Typical Applications

Note. Metal can (H) packages shown.

**Basic Regulator†††**




**2.0 Amp Boosted Regulator With Current Limit**




$$I_{CL} = \frac{\text{CURRENT LIMIT SENSE VOLTAGE (SEE CURVE)}}{R_{CL}}$$

†SOLID TANTALUM

††SHORT PINS 6 AND 7 ON DIP

†††$R_{CL}$ CAN BE ADDED TO THE BASIC REGULATOR BETWEEN PINS 6 AND 5, 1 AND 2 TO REDUCE CURRENT LIMIT.

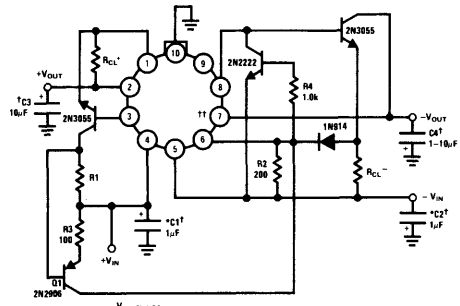
*REQUIRED IF REGULATOR IS LOCATED AN APPRECIABLE DISTANCE FROM POWER SUPPLY FILTER.

**ALTHOUGH NO CAPACITOR IS NEEDED FOR STABILITY, IT DOES HELP TRANSIENT RESPONSE. (IF NEEDED USE 1μF ELECTROLYTIC).

***ALTHOUGH NO CAPACITOR IS NEEDED FOR STABILITY, IT DOES HELP TRANSIENT RESPONSE. (IF NEEDED USE 10μF ELECTROLYTIC).

# Typical Applications (cont'd.)

### Positive Current Dependent Simultaneous Current Limiting

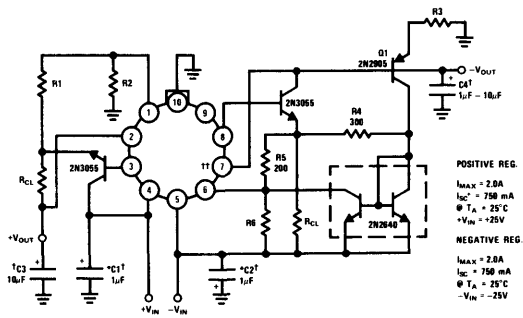



$$I_{CL}^{+} = \frac{V_{SENSE\ NEG} + V_{BEQ1}}{R1} \qquad R_{CL}^{+} = \frac{V_{SENSE}^{+}}{1.1\ I_{CL}^{+}}$$

$$I_{CL}^{-} = \frac{V_{SENSE\ NEG} + V_{DIODE}}{R_{CL}^{-}}$$

$I_{CL}^{+}$ CONTROLS BOTH SIDES OF THE REGULATOR.

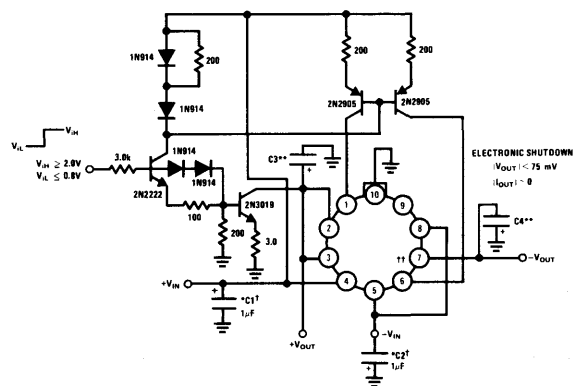
### Boosted Regulator With Foldback Current Limit




**Resistor Values**

| | 125 | 126 |
|---|---|---|
| R1 | 18 | 20 |
| R2 | 310 | 180 |
| R3 | 2.4k | 1.35k |
| R6 | 300 | 290 |
| $R_{CL}$ | 0.7 | 0.9 |

### Electric Shutdown




†SOLID TANTALUM

††SHORT PINS 8 AND 7 ON DIP

*REQUIRED IF REGULATOR IS LOCATED AN APPRECIABLE DISTANCE FROM POWER SUPPLY FILTER.

**ALTHOUGH NO CAPACITOR IS NEEDED FOR STABILITY, IT DOES HELP TRANSIENT RESPONSE. (IF NEEDED USE 1μF ELECTROLYTIC.)

National Semiconductor

# LM129/LM329 Precision Reference

## General Description

The LM129 and LM329 family are precision multi-current temperature compensated 6.9V zener references with dynamic impedances a factor of 10 to 100 less than discrete diodes. Constructed in a single silicon chip, the LM129 uses active circuitry to buffer the internal zener allowing the device to operate over a 0.5 mA to 15 mA range with virtually no change in performance. The LM129 and LM329 are available with selected temperature coefficients of 0.001, 0.002, 0.005 and 0.01%/°C. These new references also have excellent long term stability and low noise.

A new subsurface breakdown zener used in the LM129 gives lower noise and better long term stability than conventional IC zeners. Further the zener and temperature compensating transistor are made by a planar process so they are immune to problems that plague ordinary zeners. For example, there is virtually no voltage shifts in zener voltage due to temperature cycling and the device is insensitive to stress on the leads.

The LM129 can be used in place of conventional zeners with improved performance. The low dynamic impedance simplifies biasing and the wide operating current allows the replacement of many zener types.

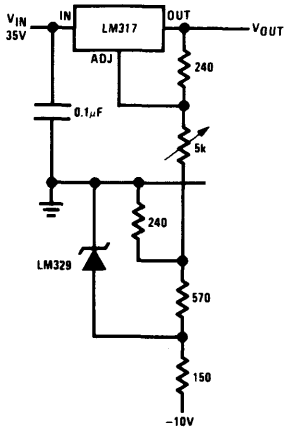
The LM129 is packaged in a 2-lead TO-46 package and is rated for operation over a −55°C to +125°C temperature range. The LM329 for operation over 0–70°C is available in both a hermetic TO-46 package and a TO-92 epoxy package.

## Features

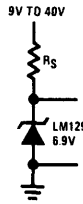
- 0.6 mA to 15 mA operating current
- 0.6Ω dynamic impedance at any current
- Available with temperature coefficients of 0.001%/°C
- 7μV wideband noise
- 5% initial tolerance
- 0.002% long term stability
- Low cost
- Subsurface zener

## Typical Applications

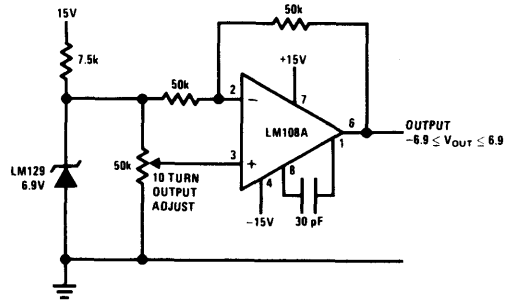
**Low Cost 0–25V Regulator**




**Simple Reference**




**Adjustable Bipolar Output Reference**



## Absolute Maximum Ratings

| | |
|---|---|
| Reverse Breakdown Current | 30 mA |
| Forward Current | 2 mA |
| Operating Temperature Range | |
| LM129 | −55°C to +125°C |
| LM329 | 0°C to +70°C |
| Storage Temperature Range | −55°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

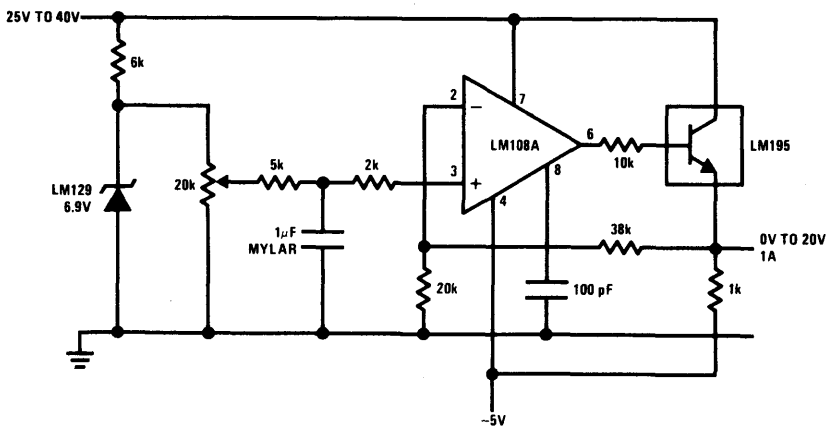
## Electrical Characteristics (Note 1)

| PARAMETER | CONDITIONS | LM129A, B, C | | | LM329B, C, D | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Reverse Breakdown Voltage | $T_A = 25°C$, $0.6\ mA \leq I_R \leq 15\ mA$ | 6.7 | 6.9 | 7.2 | 6.6 | 6.9 | 7.25 | V |
| Reverse Breakdown Change with Current | $T_A = 25°C$, $0.6\ mA \leq I_R \leq 15\ mA$ | | 9 | 14 | | 9 | 20 | mV |
| Reverse Dynamic Impedance | $T_A = 25°C$, $I_R = 1\ mA$ | | 0.6 | 1 | | 0.8 | 2 | Ω |
| RMS Noise | $T_A = 25°C$, $10\ Hz \leq F \leq 10\ kHz$ | | 7 | 20 | | 7 | 100 | μV |
| Long Term Stability | $T_A = 45°C \pm 0.1°C$, $I_R = 1\ mA \pm 0.3\%$ | | 20 | | | 20 | | ppm |
| Temperature Coefficient | $I_R = 1\ mA$ | | | | | | | |
| LM129A, LM329A | | | 6 | 10 | | | | ppm/°C |
| LM129B, LM329B | | | 15 | 20 | | 15 | 20 | ppm/°C |
| LM129C, LM329C | | | 30 | 50 | | 30 | 50 | ppm/°C |
| LM329D | | | | | | 50 | 100 | ppm/°C |
| Change In Reverse Breakdown Temperature Coefficient | $1\ mA \leq I_R \leq 15\ mA$ | | 1 | | | 1 | | ppm/°C |
| Reverse Breakdown Change with Current | $1\ mA \leq I_R \leq 15\ mA$ | | 12 | | | 12 | | mV |
| Reverse Dynamic Impedance | $1\ mA \leq I_R \leq 15\ mA$ | | 0.8 | | | 1 | | Ω |

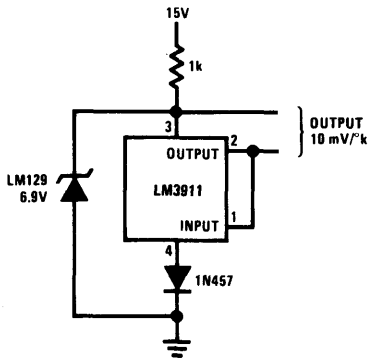
**Note 1:** These specifications apply for $-55°C \leq T_A \leq +125°C$ for the LM129 and $0°C \leq T_A \leq +70°C$ for the LM329 unless otherwise specified. The maximum junction temperature for an LM129 is 150°C and LM329 is 100°C. For operating at elevated temperature, devices in TO-46 package must be derated based on a thermal resistance of 440°C/W junction to ambient or 80°C/W junction to case. For the TO-92 package, the derating is based on 180°C/W junction to ambient with 0.4" leads from a PC board and 160°C/W junction to ambient with 0.125" lead length to a PC board.

## Typical Applications (cont'd.)

**0V to 20V Power Reference**

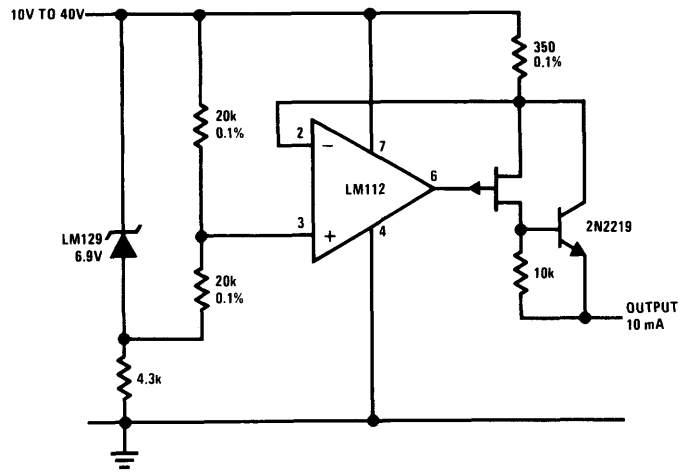



**External Reference for Temperature Transducer**

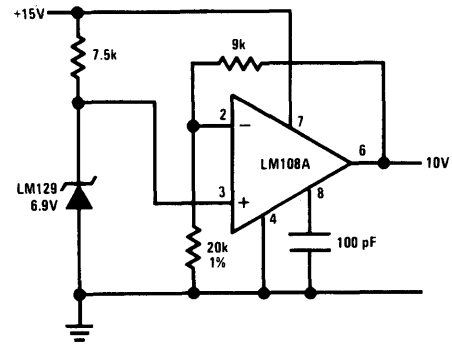


## Typical Applications (cont'd.)

**Positive Current Source**

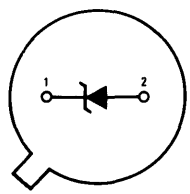



**Buffered Reference with Single Supply**




## Connection Diagrams

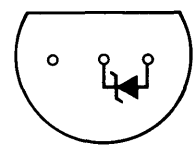
**Metal Can Package**




BOTTOM VIEW

**Order Number LM129AH, LM129BH**
**LM129CH, LM329BH, LM329CH, LM329AH**
**or LM329DH**
**See Package H02A**

**Plastic Package**

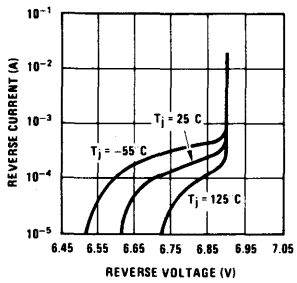


BOTTOM VIEW

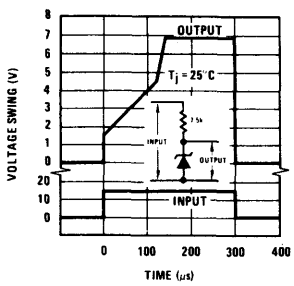
**Order Number LM329BZ, LM329CZ**
**or LM329DZ**
**See Package Z03A**

# Typical Performance Characteristics

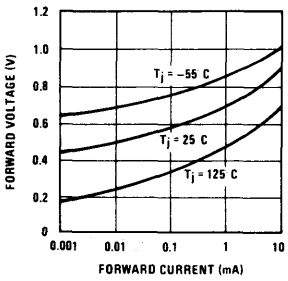
**Reverse Characteristics**



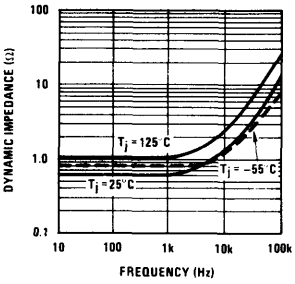

**Response Time**



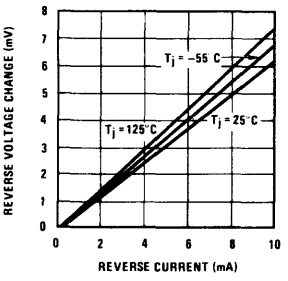

**Forward Characteristics**



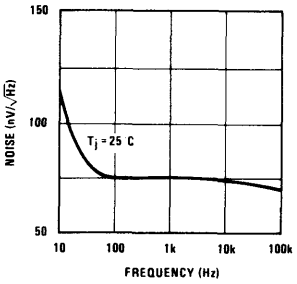

**Dynamic Impedance**



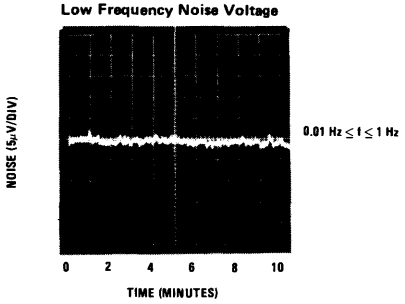

**Reverse Voltage Change**




**Zener Noise Voltage**




**Low Frequency Noise Voltage**



National Semiconductor

# Voltage Regulators
PRELIMINARY

# LM130/LM330 3-Terminal Positive Regulators

## General Description

The LM130 series of 3-terminal positive voltage regulators feature an ability to source full output current with an input-output differential of 0.5V or less. Familiar regulator features such as current limit and thermal overload protection are also provided.

The low in-out differential voltage makes the LM130 useful for certain battery applications since this feature allows a longer battery discharge before the output falls out of regulation. For example, a 9V battery supplying the regulator input voltage discharges to below 5½V before any change is noted in the output. Supporting this feature, the LM130 protects both itself and regulated systems from negative voltage inputs resulting from reverse installations of batteries.

Other protection features include line transient protection up to 50V, when the output actually shuts down to avoid damaging internal and external circuits. Also, the LM330 regulator in the TO-202 package cannot be harmed by a temporary mirror-image insertion.

A fixed output of 5V is available in the 3-lead hermetic metal can and the plastic TO-202 power package (LM330 only).

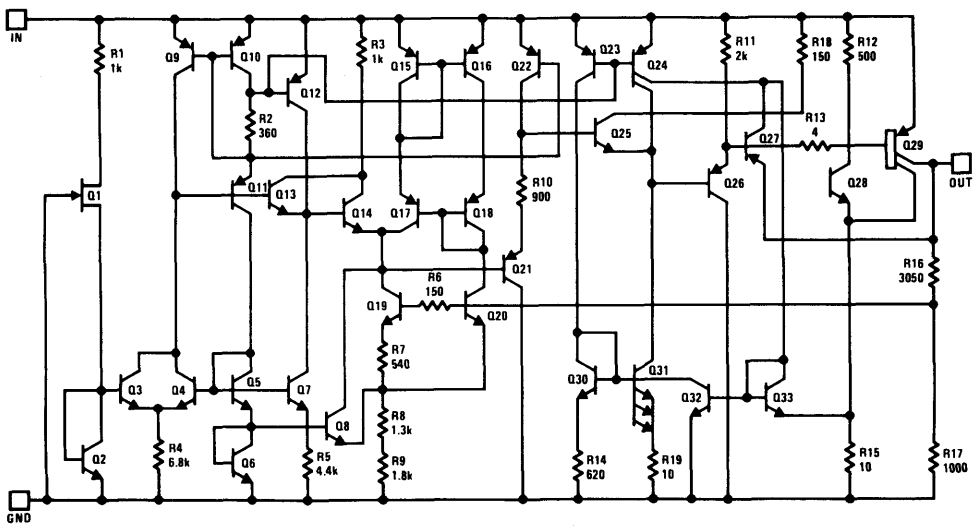
## Features

- Input-output differential less than 0.5V
- Output current of 150mA
- Reverse battery protection
- Line transient protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection
- Available in plastic TO-202 (LM330)

## Voltage Range

| | |
|---|---|
| LM130H-5.0 | 5V |
| LM330H-5.0 | 5V |
| LM330P-5.0 | 5V |

## Schematic



## Absolute Maximum Ratings

| | LM130 | LM330 |
|---|---|---|
| Input Voltage | | |
| Operating Range | 30V | 26V |
| Line Transient Protection (1000 ms) | 50V | 26V |
| Internal Power Dissipation | Internally Limited | Internally Limited |
| Operating Temperature Range | −55°C to +125°C | 0°C to +70°C |
| Maximum Junction Temperature | +150°C | +125°C |
| Storage Temperature Range | −65°C to +150°C | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | +300°C | +300°C |

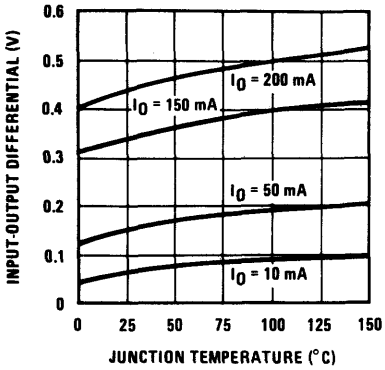
## Electrical Characteristics (Note 1)

| Parameter | | Conditions | LM130 | | | LM330 | | | Units |
|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Typ | Max | Min | Typ | Max | |
| $V_O$ | Output Voltage | $T_j = 25°C$ | 4.8 | 5 | 5.2 | 4.8 | 5 | 5.2 | V |
| | Output Voltage Over Temp | $5 < I_O < 150mA$<br>$6 < V_{IN} < 26V$ | 4.75 | | 5.25 | 4.75 | | 5.25 | |
| $\Delta V_O$ | Line Regulation | $9 < V_{IN} < 16V$, $I_O = 5mA$ | | 7 | 15 | | 7 | 25 | mV |
| | | $6 < V_{IN} < 26V$, $I_O = 5mA$ | | 30 | 45 | | 30 | 60 | |
| | Load Regulation | $5 < I_O < 150mA$ | | 14 | 25 | | 14 | 50 | |
| | Long Term Stability | | | 20 | | | 20 | | mV/1000 hrs |
| $I_Q$ | Quiescent Current | $I_O = 10mA$ | | 3.5 | 5 | | 3.5 | 7 | mA |
| | | $I_O = 50mA$ | | 5 | 7 | | 5 | 9 | |
| | | $I_O = 150mA$ | | 18 | 30 | | 18 | 40 | |
| | Line Transient | $V_{IN} = 40V$, $R_L = 100\Omega$, 1 sec | | 25 | 40 | | 25 | | |
| | Reverse Polarity | $V_{IN} = -6V$, $R_L = 100\Omega$ | | −80 | | | −80 | | |
| $\Delta I_Q$ | Quiescent Current Change | $6 < V_{IN} < 26V$ | | 10 | | | 10 | | % |
| $V_{IN}$ | Max Operational Input Voltage | | 30 | 35 | | 26 | 35 | | V |
| | Max Line Transient | 100 ms $V_O \leq 5.5V$ | 50 | 60 | | | 60 | | |
| | | 1 sec $V_O \leq 5.5V$ | 40 | 50 | | | 50 | | |
| | Reverse Polarity Input Voltage | 100 ms $V_O > -0.3V$ $R_L = 100\Omega$ | | −30 | −15 | | −30 | | |
| | | DC $V_O > -0.3V$ $R_L = 100\Omega$ | | −12 | −6 | | −12 | | |
| | Output Noise Voltage | 10 Hz–100 kHz | | 50 | | | 50 | | μV |
| | Output Impedance | $I_O = 100$ mADC + 10 mArms | | 200 | | | 200 | | mΩ |
| | Ripple Rejection | | | 56 | | | 56 | | dB |
| | Current Limit | | 150 | 400 | 700 | 150 | 400 | 700 | mA |
| | Dropout Voltage | $I_O = 150mA$ | | 0.4 | 0.5 | | 0.4 | 0.6 | V |
| | Thermal Resistance | Junction to Case | | | | | | | °C/W |
| | | TO-39 | | 40 | | | 40 | | |
| | | TO-202 | | — | | | 12 | | |
| | | Junction to Ambient | | | | | | | |
| | | TO-39 | | 140 | | | 140 | | |
| | | TO-202 | | — | | | 70 | | |

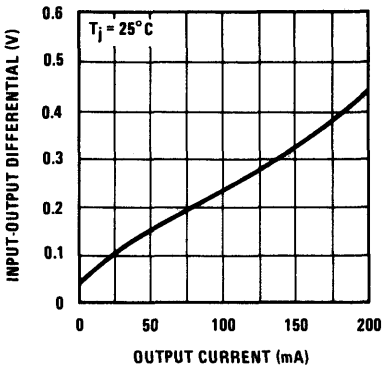
**Note 1:** Unless otherwise specified: $V_{IN} = 14V$, $I_O = 200$ mA, $T_j = 25°C$, $C1 = 0.1\mu F$, $C2 = 10\mu F$. All characteristics except noise voltage and ripple rejection are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

## Typical Performance Characteristics

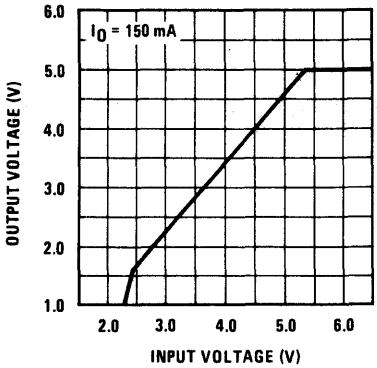
**Dropout Voltage**



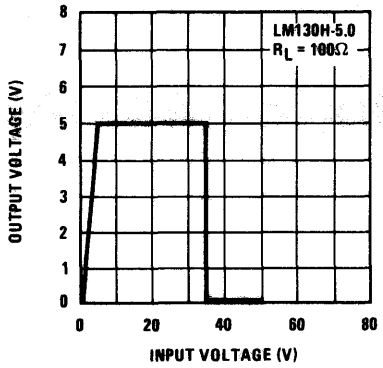

**Dropout Voltage**



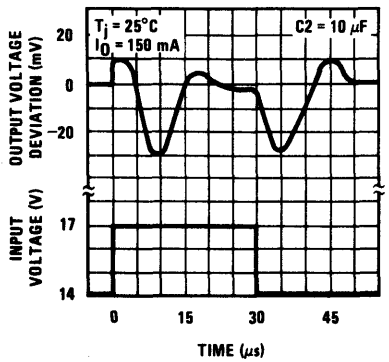

**Low Voltage Behavior**



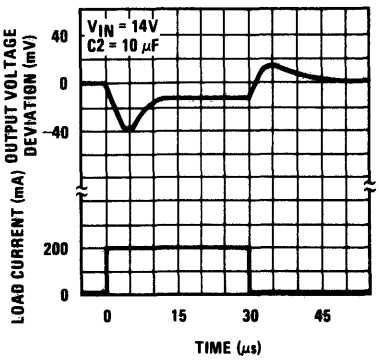

**High Voltage Behavior**




**Line Transient Response**

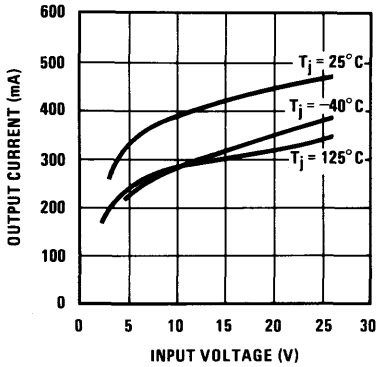



**Load Transient Response**

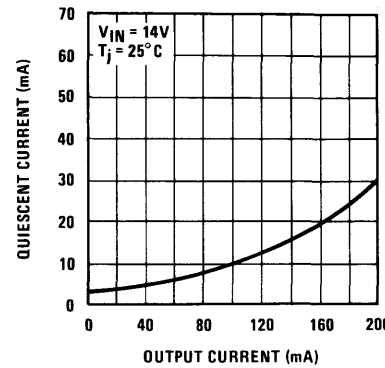


## Typical Performance Characteristics (Continued)

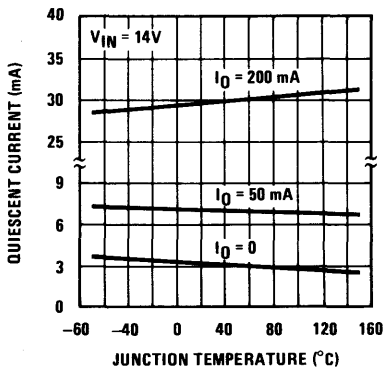
**Peak Output Current**



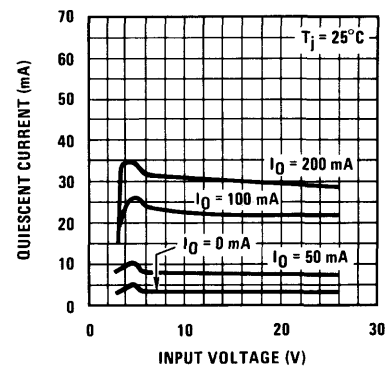

**Quiescent Current**



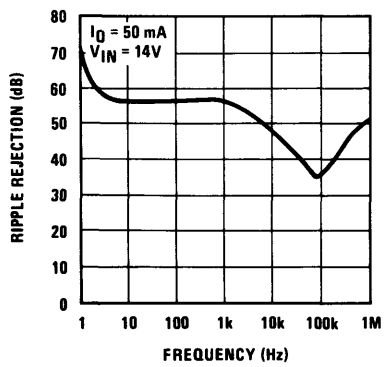

**Quiescent Current**



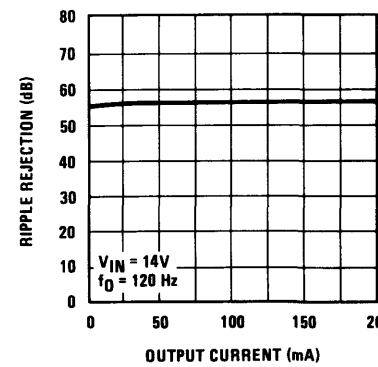

**Quiescent Current**




**Ripple Rejection**

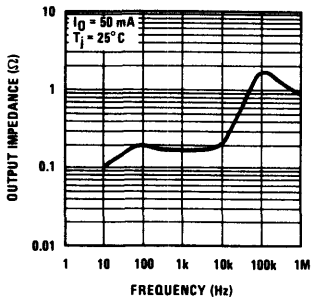



**Ripple Rejection**

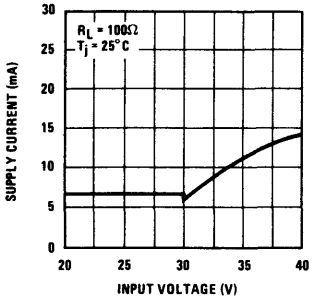


## Typical Performance Characteristics (Continued)

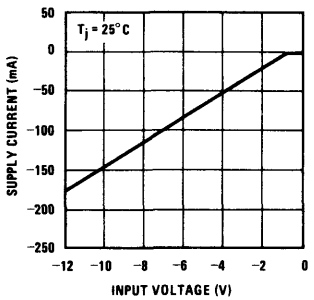
**Output Impedance**



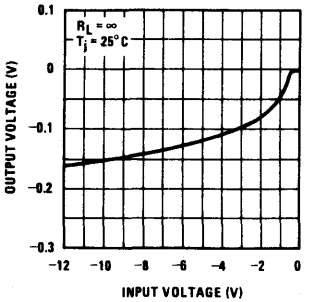

**Overvoltage Supply Current**



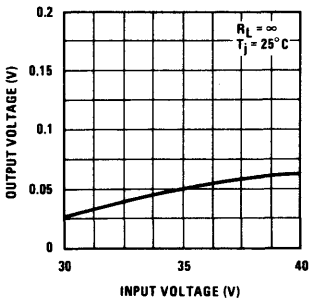

**Reverse Supply Current**



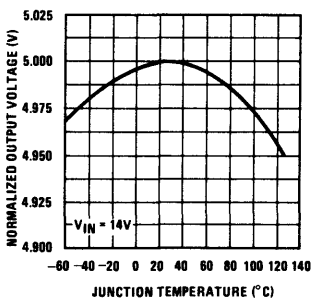

**Output at Reverse Supply**



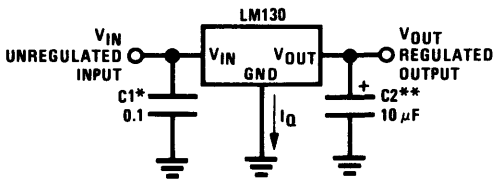

**Output at Overvoltage**




**Output Voltage (Normalized to 5V at $T_j$ = 25°C)**




## Typical Application




* Required if regulator is located far from power supply filter

** C2 must be at least 10 μF to maintain stability. May be increased without bound. Locate as close as possible to regulator.

## Definition of Terms

**Dropout Voltage:** The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

**Input Voltage:** The DC voltage applied to the input terminals with respect to ground.

**Input-Output Differential:** The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

**Line Regulation:** The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

**Load Regulation:** The change in output voltage for a change in load current at constant chip temperature.

**Long Term Stability:** Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

**Output Noise Voltage:** The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

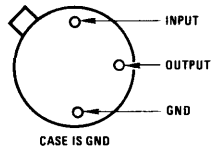
**Quiescent Current:** That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

**Ripple Rejection:** The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

**Temperature Stability of $V_O$:** The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

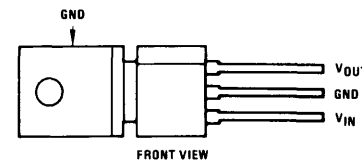
## Connection Diagrams

**(TO-39)**
**Metal Can Package**




**Order Number**
**LM130H-5.0**
**LM330H-5.0**
**See Package H03B**

**(TO-202)**
**Plastic Package**




**Order Number**
**LM330P-5.0 TB**
**See Package P03E**

National Semiconductor

# LM136/LM236/LM336 2.5V Reference Diode

## General Description

The LM136/LM236 and LM336 integrated circuits are precision 2.5V shunt regulator diodes. These monolithic IC voltage references operate as a low temperature coefficient 2.5V zener with 0.2Ω dynamic impedance. A third terminal on the LM136 allows the reference voltage and temperature coefficient to be trimmed easily.

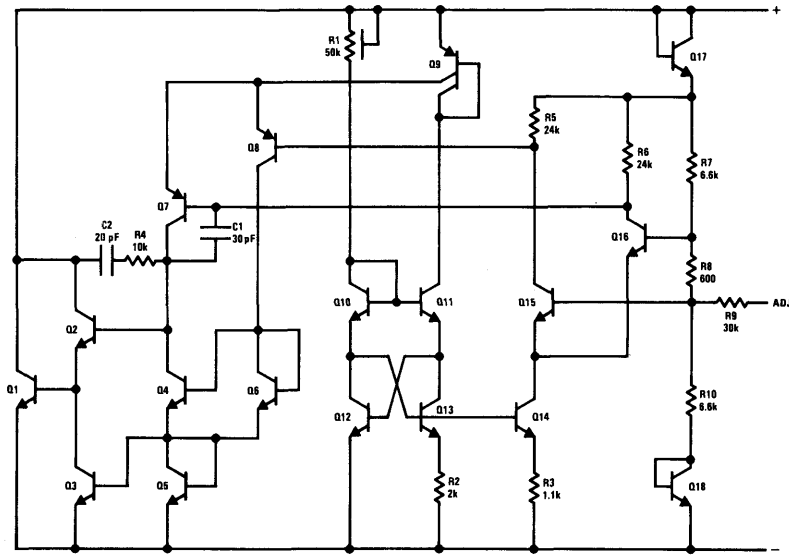
The LM136 series is useful as a precision 2.5V low voltage reference for digital voltmeters, power supplies or op amp circuitry. The 2.5V make it convenient to obtain a stable reference from 5V logic supplies. Further, since the LM136 operates as a shunt regulator, it can be used as either a positive or negative voltage reference.

The LM136 is rated for operation over −55°C to +125°C while the LM236 is rated over a −25°C to +85°C temperature range. Both are packaged in a TO-46 package. The LM336 is rated for operation over a 0°C to +70°C temperature range and is available in either a three lead TO-46 package or a TO-92 plastic package.

## Features

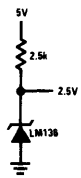
- Low temperature coefficient
- Wide operating current of 300 μA to 10 mA
- 0.2Ω dynamic impedance
- ±1% initial tolerance available
- Guaranteed temperature stability
- Easily trimmed for minimum temperature drift
- Fast turn-on
- Three lead transistor package

## Schematic Diagram

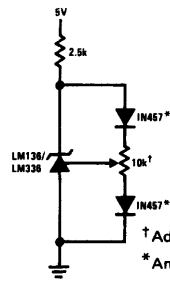



## Typical Applications

**2.5V Reference**



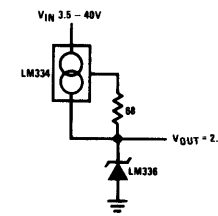

**2.5V Reference with Minimum Temperature Coefficient**




†Adjust to 2.490V

*Any silicon signal diode

**Wide Input Range Reference**



## Absolute Maximum Ratings

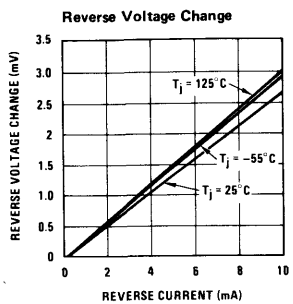
| | |
|---|---|
| Reverse Current | 15 mA |
| Forward Current | 10 mA |
| Storage Temperature | −60°C to +150°C |
| Operating Temperature | |
| LM136 | −55°C to +150°C |
| LM236 | −25°C to +85°C |
| LM336 | 0°C to +70°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

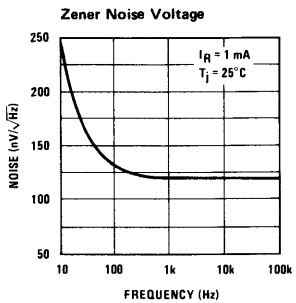
## Electrical Characteristics (Note 1)

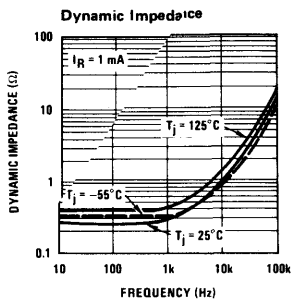
| PARAMETER | CONDITIONS | LM136A/LM236A LM136/LM236 | | | LM336B LM336 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Reverse Breakdown Voltage | $T_A = 25°C$, $I_R = 1$ mA | | | | | | | |
| | LM136/LM236/LM336 | 2.440 | 2.490 | 2.540 | 2.390 | 2.490 | 2.590 | V |
| | LM136A/LM236A, LM336B | 2.465 | 2.490 | 2.515 | 2.440 | 2.490 | 2.540 | V |
| Reverse Breakdown Change With Current | $T_A = 25°C$, $400\ \mu A \leq I_R \leq 10$ mA | | 2.6 | 6 | | 2.6 | 10 | mV |
| Reverse Dynamic Impedance | $T_A = 25°C$, $I_R = 1$ mA | | 0.2 | 0.6 | | 0.2 | 1 | Ω |
| Temperature Stability | $V_R$ Adjusted to 2.490V, $I_R = 1$ mA, *(Figure 2)* | | | | | | | |
| | $0°C \leq T_A \leq 70°C$ (LM336) | | | | | 1.8 | 6 | mV |
| | $-25°C \leq T_A \leq +85°C$ (LM236) | | 3.5 | 9 | | | | mV |
| | $-55°C \leq T_A \leq +125°C$ (LM136) | | 12 | 18 | | | | mV |
| Reverse Breakdown Change With Current | $400\ \mu A \leq I_R \leq 10$ mA | | 3 | 10 | | 3 | 12 | mV |
| Reverse Dynamic Impedance | $I_R = 1$ mA | | 0.4 | 1 | | 0.4 | 1.4 | Ω |
| Long Term Stability | $T_A = 25°C \pm 0.1°C$, $I_R = 1$ mA | | 20 | | | 20 | | ppm |

**Note 1:** Unless otherwise specified, the LM136 is specified from $-55°C \leq T_A \leq +125°C$, the LM236 from $-25°C \leq T_A \leq +85°C$ and the LM336 from $0°C \leq T_A \leq +70°C$. The maximum junction temperature of the LM136 is 150°C, LM236 is 125°C and the LM336 is 100°C. For elevated junction temperature, devices in the TO-46 package should be derated based on a thermal resistance of 440°C/W junction to ambient or 30°C/W junction to case. For the TO-92 package, the derating is based on 180°C/W junction to ambient with 0.4" leads from a PC board and 160°C/W junction to ambient with 0.125" lead length to a PC board.

## Typical Performance Characteristics

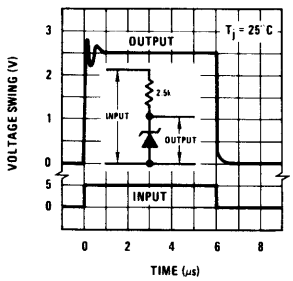


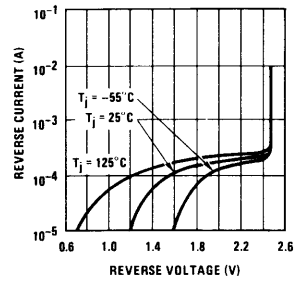



## Typical Performance Characteristics (Continued)

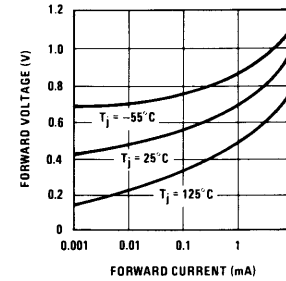
Response Time



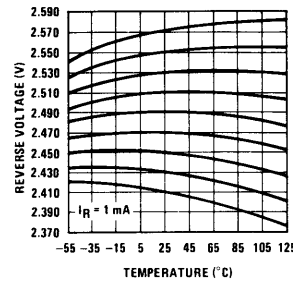

Reverse Characteristics




Forward Characteristics




Temperature Drift




## Application Hints

The LM136 series voltage references are much easier to use than ordinary zener diodes. Their low impedance and wide operating current range simplify biasing in almost any circuit. Further, either the breakdown voltage or the temperature coefficient can be adjusted to optimize circuit performance.

*Figure 1* shows an LM136 with a 10k potentiometer for adjusting the reverse breakdown voltage. With the addrion of R1 the breakdown voltage can be adjusted without affecting the temperature coefficient of the device. The adjustment range is usually sufficient to adjust for both the initial device tolerance and inaccuracies in buffer circuitry.

If minimum temperature coefficient is desired, two diodes can be added in series with the adjustment potentiometer as shown in *Figure 2*. When the device is adjusted to 2.490V the temperature coefficient is minimized. Almost any silicon signal diode can be used for this purpose such as a 1N914, 1N4148 or a 1N457. For proper temperature compensation the diodes should be in the same thermal environment as the LM136. It is usually sufficient to mount the diodes near the LM136 on the printed circuit board. The absolute resistance of R1 is not critical and any value from 2k to 20k will work.

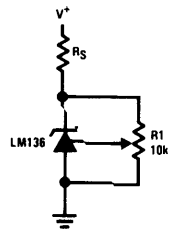



FIGURE 1. LM136 With Pot for Adjustment of Breakdown Voltage

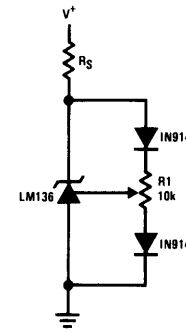
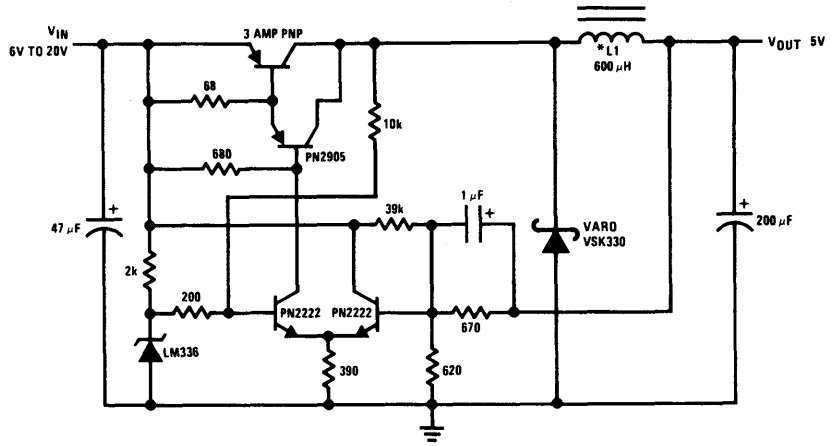



FIGURE 2. Temperature Coefficient Adjustment

## Typical Applications (Continued)

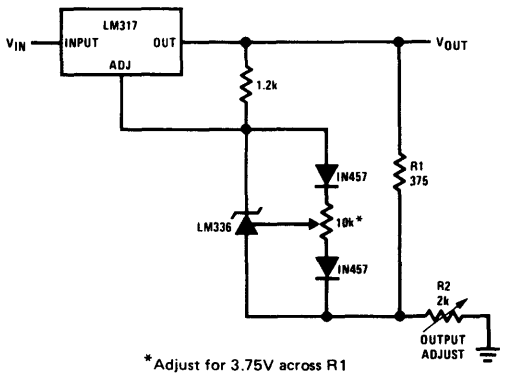
**Low Cost 2 Amp Switching Regulator†**




*L1 60 turns #16 wire on Arnold Core A-254168-2

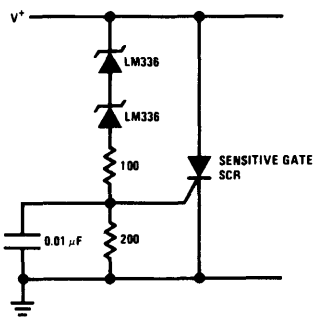
†Efficiency ≈ 80%

**Precision Power Regulator with Low Temperature Coefficient**

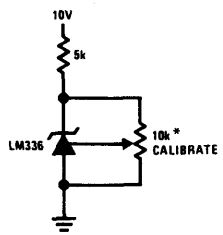



*Adjust for 3.75V across R1

**5V Crowbar**



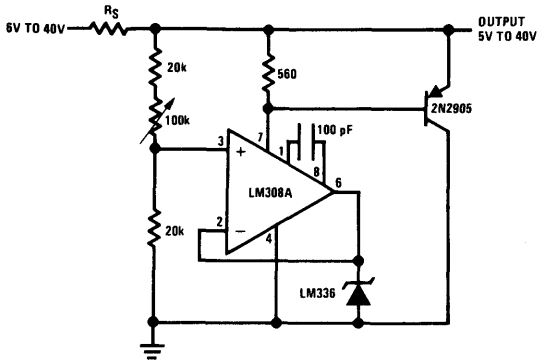

**Trimmed 2.5V Reference with Temperature Coefficient Independent of Breakdown Voltage**



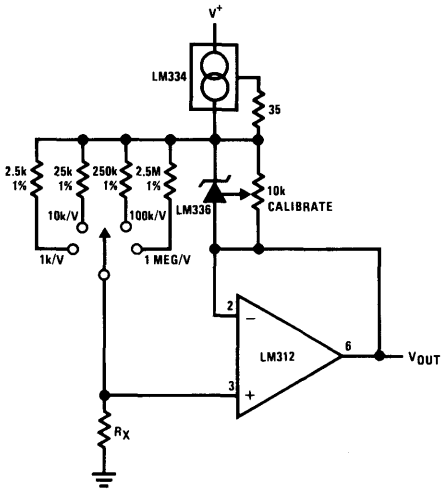

*Does not affect temperature coefficient

## Typical Applications (Continued)

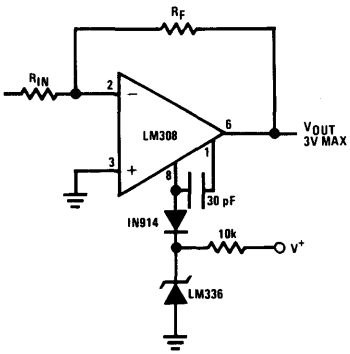
Adjustable Shunt Regulator



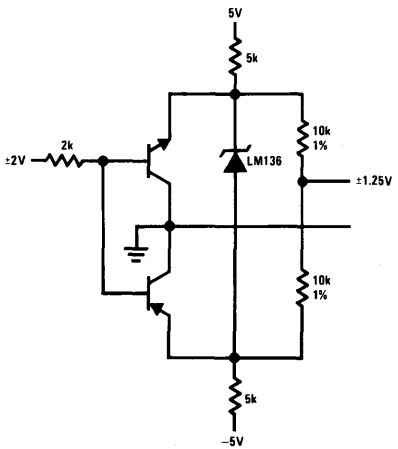

Linear Ohmmeter



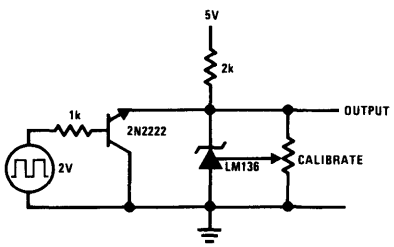

Op Amp with Output Clamped




Bipolar Output Reference

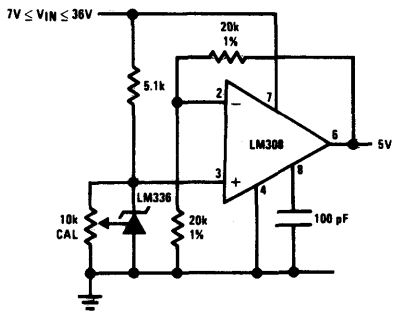



2.5V Square Wave Calibrator

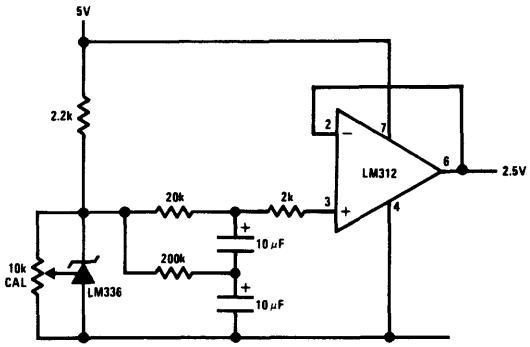


## Typical Applications (Continued)

**5V Buffered Reference**

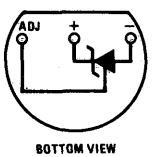



**Low Noise Buffered Reference**




## Connection Diagrams

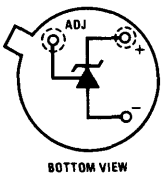
**TO-92**
**Plastic Package**




BOTTOM VIEW

**Order Number**
**LM336Z or LM336BZ**
**See Package Z03A**

**TO-46**
**Metal Can Package**




BOTTOM VIEW

**Order Number**
**LM136H, LM236H, LM336H, LM136AH,**
**LM236AH or LM336BH**
**See Package H03H**

National Semiconductor

# LM137/LM237/LM337 3-Terminal Adjustable Negative Regulators

## General Description

The LM137/LM237/LM337 are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −1.5A over an output voltage range of −1.2V to −37V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137 series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

The LM137/LM237/LM337 serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137/LM237/LM337 are ideal complements to the LM117/LM217/LM317 adjustable positive regulators.

## Features

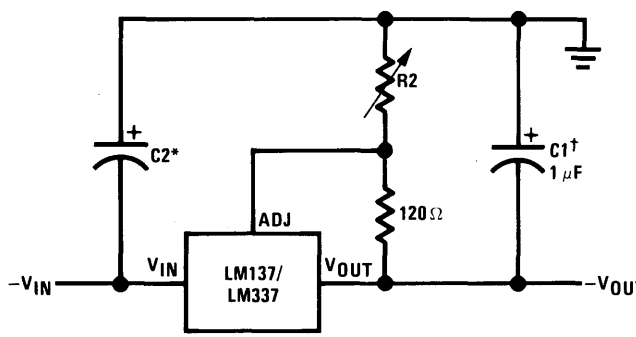
- Output voltage adjustable from −1.2V to −37V
- 1.5A output current guaranteed, −55°C to +150°C
- Line regulation typically 0.01%/V
- Load regulation typically 0.3%
- Excellent thermal regulation, 0.002%/W
- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/°C temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- 100% electrical burn-in
- Standard 3-lead transistor package

**LM137 Series Packages and Power Capability**

| DEVICE | PACKAGE | RATED POWER DISSIPATION | DESIGN LOAD CURRENT |
|---|---|---|---|
| LM137 | TO-3 | 20W | 1.5A |
| LM237<br>LM337 | TO-5 | 2W | 0.5A |
| LM337T | TO-220 | 15W | 1.5A |
| LM337M | TO-202 | 7.5W | 0.5A |

## Typical Applications

**Adjustable Negative Voltage Regulator**




$$-V_{OUT} = -1.25V\left(1 + \frac{R2}{120\Omega}\right)$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability
*C2 = 1 μF solid tantalum is required only if regulator is more than 4" from power-supply filter capacitor

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 40V |
| Operating Junction Temperature Range | |
| LM137 | −55°C to +150°C |
| LM237 | −25°C to +150°C |
| LM337 | 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** **100% All Devices**

## Electrical Characteristics (Note 1)

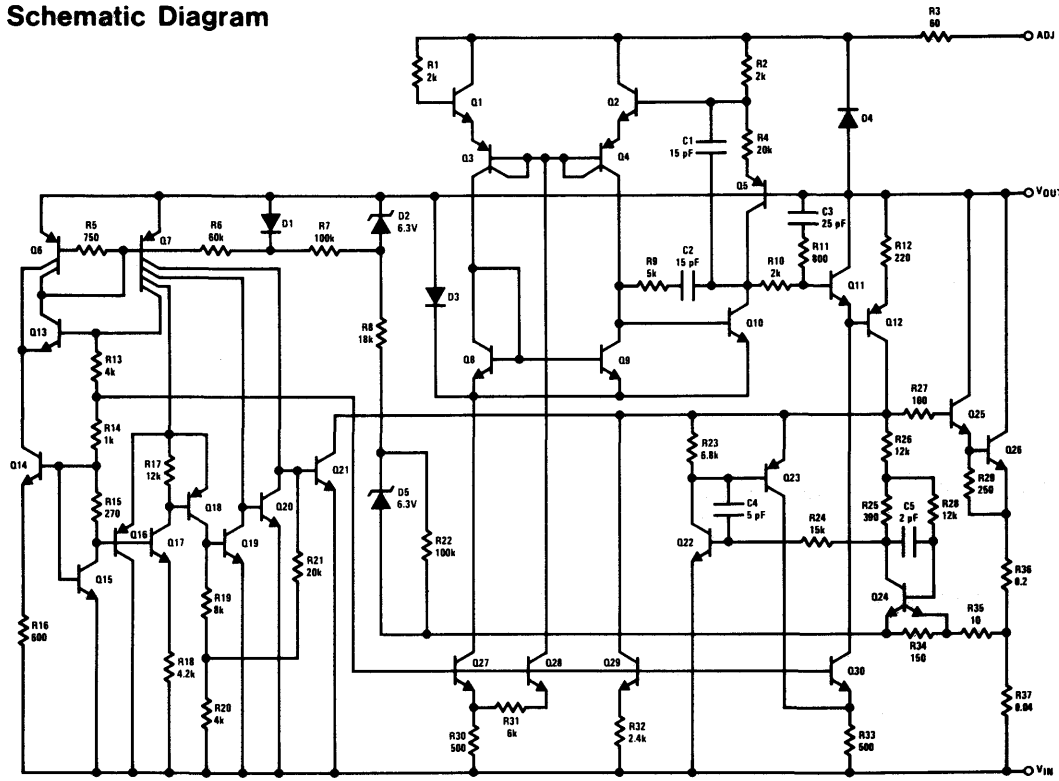
| PARAMETER | CONDITIONS | LM137/LM237 | | | LM337 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Line Regulation | $T_A = 25°C$, $3V \le \lvert V_{IN}-V_{OUT}\rvert \le 40V$ (Note 2) | | 0.01 | 0.02 | | 0.01 | 0.04 | %/V |
| Load Regulation | $T_A = 25°C$, $10\ mA \le I_{OUT} \le I_{MAX}$ | | | | | | | |
| | $\lvert V_{OUT}\rvert \le 5V$, (Note 2) | | 15 | 25 | | 15 | 50 | mV |
| | $\lvert V_{OUT}\rvert \ge 5V$, (Note 2) | | 0.3 | 0.5 | | 0.3 | 1.0 | % |
| Thermal Regulation | $T_A = 25°C$, 10 ms Pulse | | 0.002 | 0.02 | | 0.003 | 0.04 | %/W |
| Adjustment Pin Current | | | 65 | 100 | | 65 | 100 | μA |
| Adjustment Pin Current Change | $10\ mA \le I_L \le I_{MAX}$ $2.5V \le \lvert V_{IN}-V_{OUT}\rvert \le 40V$, $T_A = 25°C$ | | 2 | 5 | | 2 | 5 | μA |
| Reference Voltage | $T_A = 25°C$ (Note 3) | −1.225 | −1.250 | −1.275 | −1.213 | −1.250 | −1.287 | V |
| | $3 \le \lvert V_{IN}-V_{OUT}\rvert \le 40V$, (Note 3) | −1.200 | −1.250 | −1.300 | −1.200 | −1.250 | −1.300 | V |
| | $10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$ | | | | | | | |
| Line Regulation | $3V \le \lvert V_{IN}-V_{OUT}\rvert \le 40V$, (Note 2) | | 0.02 | 0.05 | | 0.02 | 0.07 | %/V |
| Load Regulation | $10\ mA \le I_{OUT} \le I_{MAX}$, (Note 2) | | | | | | | |
| | $\lvert V_{OUT}\rvert \le 5V$ | | 20 | 50 | | 20 | 70 | mV |
| | $\lvert V_{OUT}\rvert \ge 5V$ | | 0.3 | 1 | | 0.3 | 1.5 | % |
| Temperature Stability | $T_{MIN} \le T_j \le T_{MAX}$ | | 0.6 | | | 0.6 | | % |
| Minimum Load Current | $\lvert V_{IN}-V_{OUT}\rvert \le 40V$ | | 2.5 | 5 | | 2.5 | 10 | mA |
| | $\lvert V_{IN}-V_{OUT}\rvert \le 10V$ | | 1.2 | 3 | | 1.5 | 6 | mA |
| Current Limit | $\lvert V_{IN}-V_{OUT}\rvert \le 15V$ | | | | | | | |
| | K and T Package | 1.5 | 2.2 | | 1.5 | 2.2 | | A |
| | H and P Package | 0.5 | 0.8 | | 0.5 | 0.8 | | A |
| | $\lvert V_{IN}-V_{OUT}\rvert = 40V$ | | | | | | | |
| | K and T Package | | 0.4 | | | 0.4 | | A |
| | H and P Package | | 0.17 | | | 0.17 | | 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 |
| | $C_{ADJ} = 10\ \mu F$ | 66 | 77 | | 66 | 77 | | dB |
| Long-Term Stability | $T_A = 125°C$, 1000 Hours | | 0.3 | 1 | | 0.3 | 1 | % |
| Thermal Resistance, Junction to Case | H Package | | 12 | 15 | | 12 | 15 | °C/W |
| | K Package | | 2.3 | 3 | | 2.3 | 3 | °C/W |
| | T Package | | | | | 4 | | °C/W |
| | P Package | | | | | 12 | | °C/W |

**Note 1:** Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM137, $-25°C \le T_j \le +150°C$ for the LM237 and $0°C \le T_j \le +125°C$ for the LM337; $V_{IN} - V_{OUT} = 5V$; and $I_{OUT} = 0.1A$ for the TO-5 package and TO-202 package and $I_{OUT} = 0.5A$ for the TO-3 package and TO-220 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-5 and TO-202 and 20W for the TO-3 and TO-220. $I_{MAX}$ is 1.5A for the TO-3 and TO-220 package and 0.5A for the TO-5 package and TO-202 package.

**Note 2:** Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation. Load regulation is measured on the output pin at a point 1/8" below the base of the TO-3 and TO-5 packages.

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

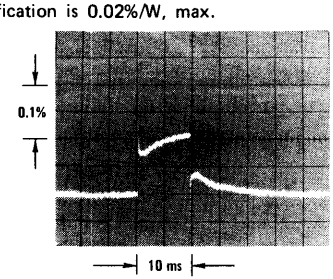
## Schematic Diagram




## Thermal Regulation

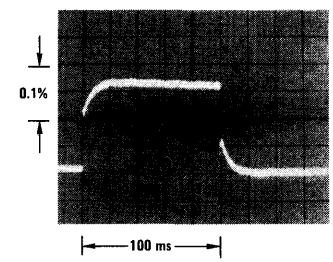
When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of $V_{OUT}$, per Watt, within the first 10 ms after a step of power is applied. The LM137's specification is 0.02%/W, max.

In *Figure 1*, a typical LM137's output drifts only 3 mV (or 0.03% of $V_{OUT}$ = −10V) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.02%/W x 10W = 0.2% max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step as the LM137 chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In *Figure 2*, when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).




LM137, $V_{OUT}$ = −10V
$V_{IN}-V_{OUT}$ = −40V
$I_L$ = 0A → 0.25A → 0A
Vertical sensitivity, 5 mV/div

**FIGURE 1**

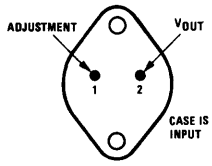



LM137, $V_{OUT}$ = −10V
$V_{IN}-V_{OUT}$ = −40V
$I_L$ = 0A → 0.25A → 0A
Horizontal sensitivity, 20 ms/div

**FIGURE 2**

## Connection Diagrams

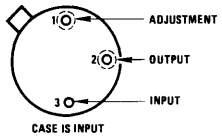
**TO-3**
**Metal Can Package**




BOTTOM VIEW

**Order Number:**
**LM137K STEEL**
**LM237K STEEL**
**LM337K STEEL**
**See Package K02A**

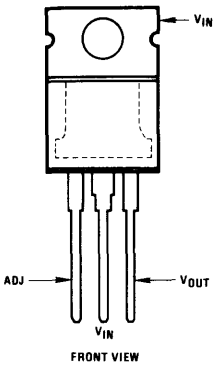
**TO-5**
**Metal Can Package**




BOTTOM VIEW

**Order Number:**
**LM137H**
**LM237H**
**LM337H**
**See Package H03B**

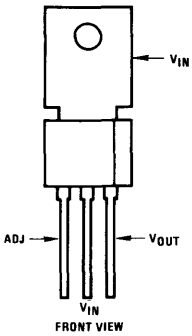
**TO-220**
**Plastic Package**




FRONT VIEW

**Order Number:**
**LM337T**
**See Package T03B**

**TO-202**
**Plastic Package**



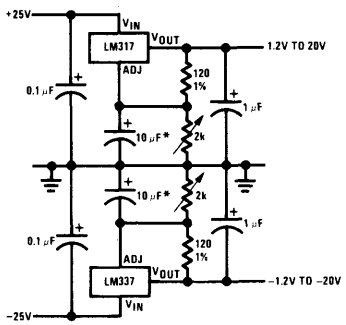

FRONT VIEW

**Order Number:**
**LM337MP**
**See Package P03A**

**For Tab Bend TO-202**
**Order Number:**
**LM337MPTB**
**See Package P03E**

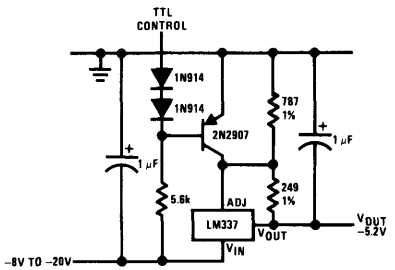
## Typical Applications (Continued)

**Adjustable Lab Voltage Regulator**



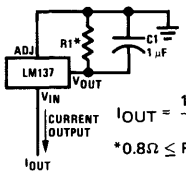

*The 10 μF capacitors are optional to improve ripple rejection

**-5.2V Regulator with Electronic Shutdown***




*Minimum output ≅ -1.3V when control input is low

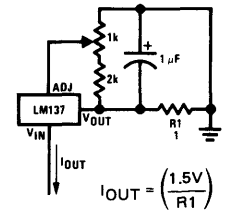
**Current Regulator**




$I_{OUT} = \frac{1.250V}{R1}$

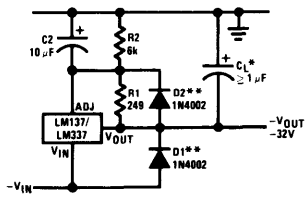
*0.8Ω ≤ R1 ≤ 120Ω

**Adjustable Current Regulator**




$I_{OUT} = \left(\frac{1.5V}{R1}\right)$ ±15% adjustable

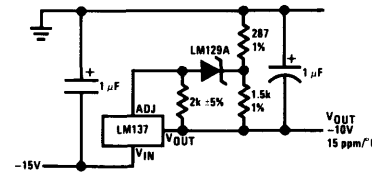
**Negative Regulator with Protection Diodes**




*When $C_L$ is larger than 20 μF, D1 protects the LM137 in case the input supply is shorted

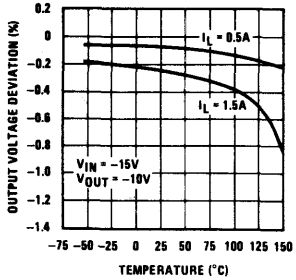
**When C2 is larger than 10 μF and $-V_{OUT}$ is larger than -25V, D2 protects the LM137 in case the output is shorted

**High Stability -10V Regulator**

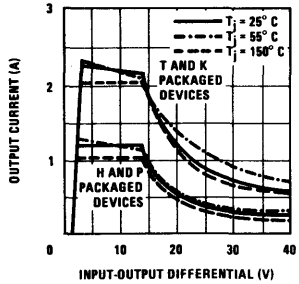


## Typical Performance Characteristics (K Steel, KC and T Packages)

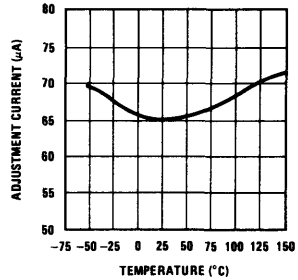
**Load Regulation**



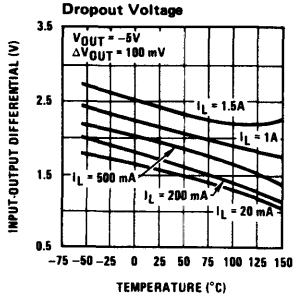

**Current Limit**



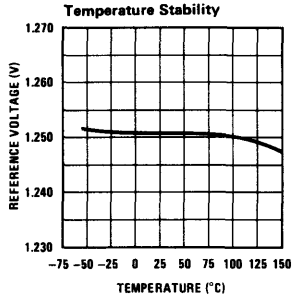

**Adjustment Current**



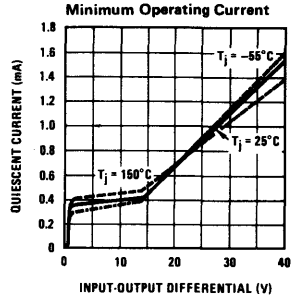

**Dropout Voltage**



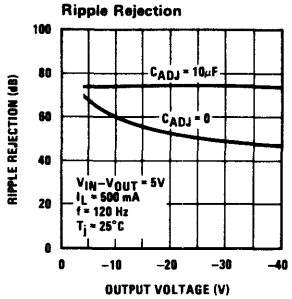

**Temperature Stability**



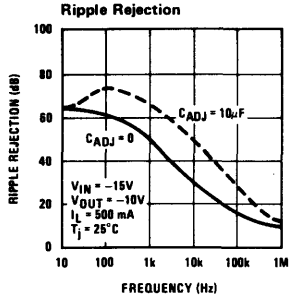

**Minimum Operating Current**



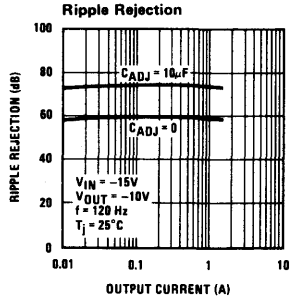

**Ripple Rejection**



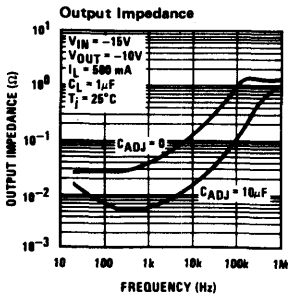

**Ripple Rejection**



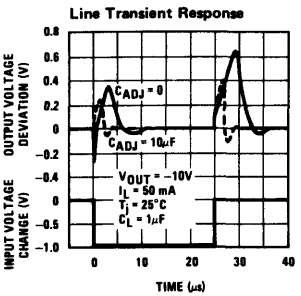

**Ripple Rejection**



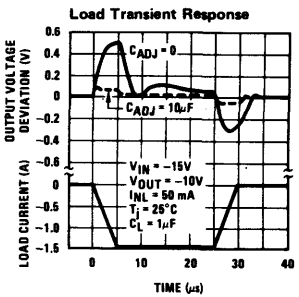

**Output Impedance**




**Line Transient Response**




**Load Transient Response**



National Semiconductor

# LM137HV/LM237HV/LM337HV
# 3-Terminal Adjustable Negative Regulators (High Voltage)

## General Description

The LM137HV/LM237HV/LM337HV are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −1.5A over an output voltage range of −1.2V to −47V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137HV series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

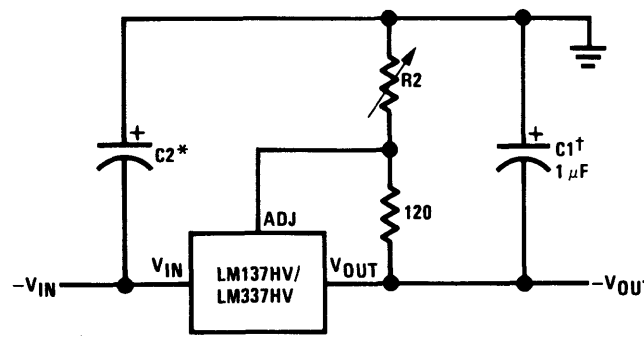
The LM137HV/LM237HV/LM337HV serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137HV/LM237HV/LM337HV are ideal complements to the LM117HV/LM217HV/LM317HV adjustable positive regulators.

## Features

- Output voltage adjustable from −1.2V to −47V
- 1.5A output current guaranteed, −55°C to +150°C
- Line regulation typically 0.01%/V
- Load regulation typically 0.3%
- Excellent thermal regulation, 0.002%/W
- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/°C temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- 100% electrical burn-in
- Standard 3-lead transistor package

## Typical Applications

**Adjustable Negative Voltage Regulator**




$$-V_{OUT} = -1.25V\left(1 + \frac{R2}{120\Omega}\right)$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability
*C2 = 1 μF solid tantalum is required only if regulator is more than 4" from power-supply filter capacitor

## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 50V |
| Operating Junction Temperature Range | |
| LM137HV | −55°C to +150°C |
| LM237HV | −25°C to +150°C |
| LM337HV | 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** **100% All Devices**

## Electrical Characteristics (Note 1)

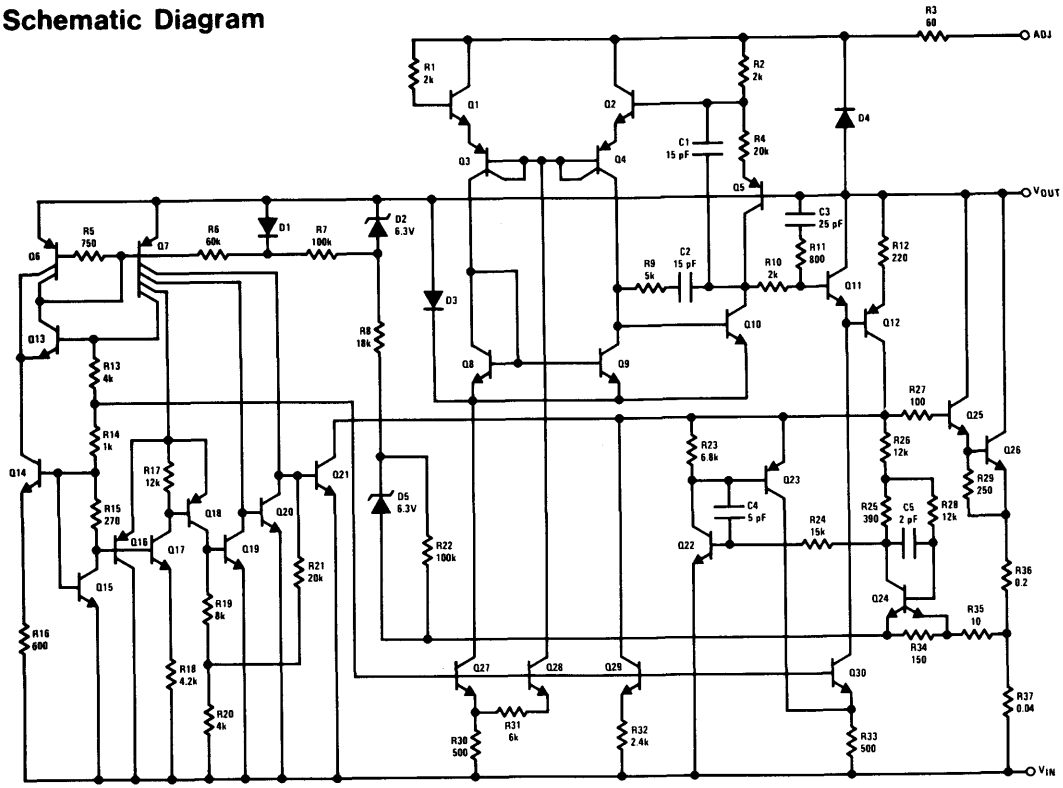
| PARAMETER | CONDITIONS | LM137HV/LM237HV | | | LM337HV | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Line Regulation | $T_A = 25°C$, $3V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 2) | | 0.01 | 0.02 | | 0.01 | 0.04 | %/V |
| Load Regulation | $T_A = 25°C$, $10\ mA \le I_{OUT} \le I_{MAX}$ | | | | | | | |
| | $\lvert V_{OUT}\rvert \le 5V$, (Note 2) | | 15 | 25 | | 15 | 50 | mV |
| | $\lvert V_{OUT}\rvert \ge 5V$, (Note 2) | | 0.3 | 0.5 | | 0.3 | 1.0 | % |
| Thermal Regulation | $T_A = 25°C$, 10 ms Pulse | | 0.002 | 0.02 | | 0.003 | 0.04 | %/W |
| Adjustment Pin Current | | | 65 | 100 | | 65 | 100 | μA |
| Adjustment Pin Current Change | $10\ mA \le I_L \le I_{MAX}$ | | 2 | 5 | | 2 | 5 | μA |
| | $2.5V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, $T_A = 25°C$ | | 3 | 6 | | 3 | 6 | μA |
| Reference Voltage | $T_A = 25°C$, (Note 3) | −1.225 | −1.250 | −1.275 | −1.213 | −1.250 | −1.287 | V |
| | $3 \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 3) | −1.200 | −1.250 | −1.300 | −1.200 | −1.250 | −1.300 | V |
| | $10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$ | | | | | | | |
| Line Regulation | $3V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 2) | | 0.02 | 0.05 | | 0.02 | 0.07 | %/V |
| Load Regulation | $10\ mA \le I_{OUT} \le I_{MAX}$, (Note 2) | | | | | | | |
| | $\lvert V_{OUT}\rvert \le 5V$ | | 20 | 50 | | 20 | 70 | mV |
| | $\lvert V_{OUT}\rvert \ge 5V$ | | 0.3 | 1 | | 0.3 | 1.5 | % |
| Temperature Stability | $T_{MIN} \le T_j \le T_{MAX}$ | | 0.6 | | | 0.6 | | % |
| Minimum Load Current | $\lvert V_{IN}-V_{OUT}\rvert \le 50V$ | | 2.5 | 5 | | 2.5 | 10 | mA |
| | $\lvert V_{IN}-V_{OUT}\rvert \le 10V$ | | 1.2 | 3 | | 1.5 | 6 | mA |
| Current Limit | $\lvert V_{IN}-V_{OUT}\rvert \le 13V$ | | | | | | | |
| | K Package | 1.5 | 2.2 | 3.2 | 1.5 | 2.2 | 3.5 | A |
| | H Package | 0.5 | 0.8 | 1.6 | 0.5 | 0.8 | 1.8 | A |
| | $\lvert V_{IN}-V_{OUT}\rvert = 50V$ | | | | | | | |
| | K Package | 0.2 | 0.4 | 0.8 | 0.2 | 0.4 | 0.8 | A |
| | H Package | 0.1 | 0.17 | 0.5 | 0.1 | 0.17 | 0.5 | 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 |
| | $C_{ADJ} = 10\ \mu F$ | 66 | 77 | | 66 | 77 | | dB |
| Long-Term Stability | $T_A = 125°C$, 1000 Hours | | 0.3 | 1 | | 0.3 | 1 | % |
| Thermal Resistance, Junction to Case | H Package | | 12 | 15 | | 12 | 15 | °C/W |
| | K Package | | 2.3 | 3 | | 2.3 | 3 | °C/W |

**Note 1:** Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM137HV, $-25°C \le T_j \le +150°C$ for the LM237HV and $0°C \le T_j \le +125°C$ for the LM337HV; $V_{IN} - V_{OUT} = 5V$; and $I_{OUT} = 0.1A$ for the TO-5 package and $I_{OUT} = 0.5A$ for the TO-3 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-5 and 20W for the TO-3. $I_{MAX}$ is 1.5A for the TO-3 package and 0.5A for the TO-5 package.

**Note 2:** Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation. Load regulation is measured on the output pin at a point 1/8" below the base of the TO-3 and TO-5 packages.

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

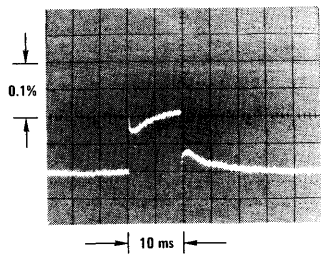
## Schematic Diagram




## Thermal Regulation

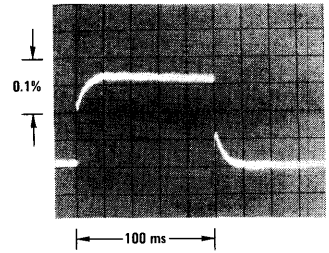
When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of $V_{OUT}$, per Watt, within the first 10 ms after a step of power is applied. The LM137HV's specification is 0.02%/W, max.

In *Figure 1*, a typical LM137HV's output drifts only 3 mV (or 0.03% of $V_{OUT} = -10V$) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.02%/W x 10W = 0.2% max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step as the LM137HV chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In *Figure 2*, when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).




LM137HV, $V_{OUT} = -10V$
$V_{IN} - V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Vertical sensitivity, 5 mV/div

**FIGURE 1**

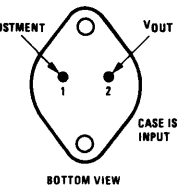



LM137HV, $V_{OUT} = -10V$
$V_{IN} - V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Horizontal sensitivity, 20 ms/div

**FIGURE 2**

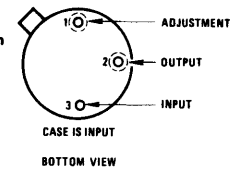
## Connection Diagrams

**TO-3**
**Metal Can Package**




**Ordering Information**
LM137HVK STEEL
LM237HVK STEEL
LM337HVK STEEL
See Package K02A

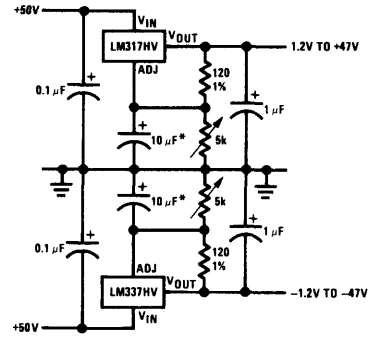
**TO-5**
**Metal Can Package**




**Ordering Information**
LM137HVH
Lm237HVH
LM337HVH
See Package H03B

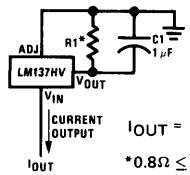
## Typical Applications (Continued)

**Adjustable High Voltage Regulator**




*The 10 μF capacitors are optional to improve ripple rejection

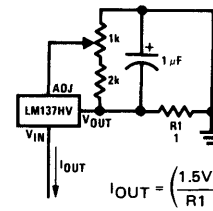
**Current Regulator**




$I_{OUT} = \frac{1.250V}{R1}$

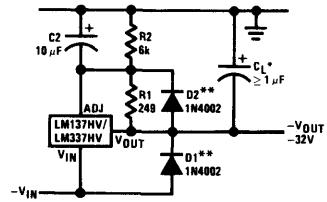
*0.8Ω ≤ R1 ≤ 120Ω

**Adjustable Current Regulator**




$I_{OUT} = \left(\frac{1.5V}{R1}\right)$ ±15% adjustable

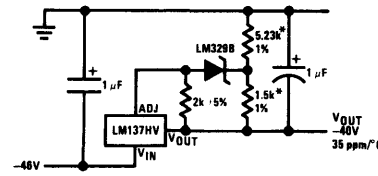
**Negative Regulator with Protection Diodes**




*When $C_L$ is larger than 20 μF, D1 protects the LM137HV is case the input supply is shorted

**When C2 is larger than 10 μF and $-V_{OUT}$ is larger than −25V, D2 protects the LM137HV in case the output is shorted

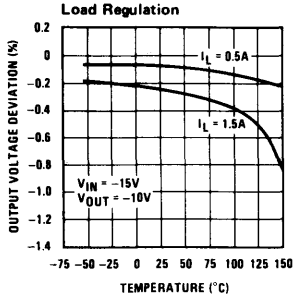
***High Stability −40V Regulator***



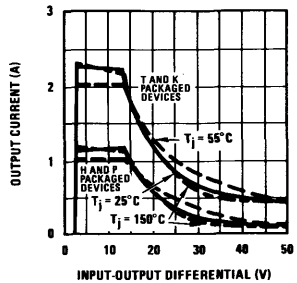

*Use resistors with good tracking TC < 25 ppm/°C

## Typical Performance Characteristics (H and K-STEEL Package)

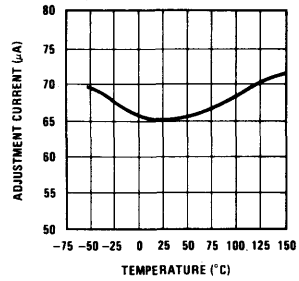
**Load Regulation**



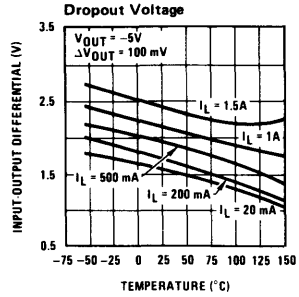

**Current Limit**



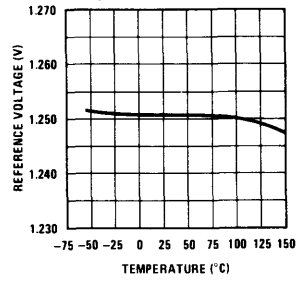

**Adjustment Current**



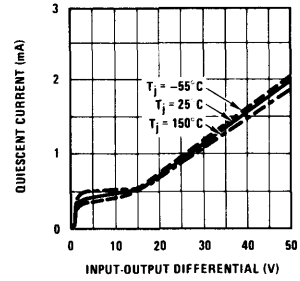

**Dropout Voltage**



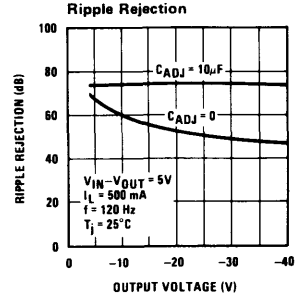

**Temperature Stability**



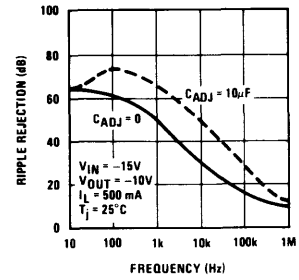

**Minimum Operating Current**



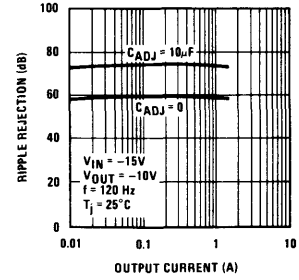

**Ripple Rejection**



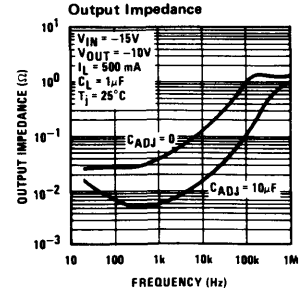

**Ripple Rejection**



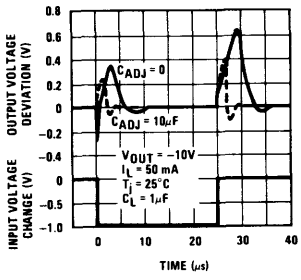

**Ripple Rejection**



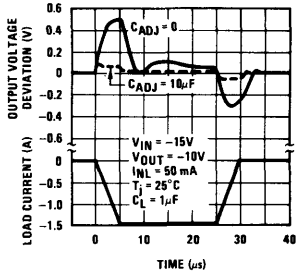

**Output Impedance**




**Line Transient Response**




**Load Transient Response**



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.

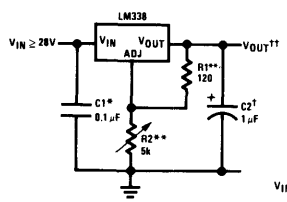
The LM138/LM238/LM338 are packaged in standard steel TO-3 transistor packages. The LM138 is rated for operation from −55°C to +150°C, the LM238 from −25°C to +150°C and the LM338 from 0°C to +125°C.

## 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

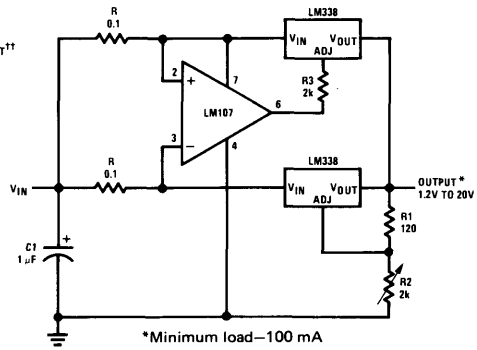
*Needed if device is far from filter capacitors

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

*R1 = 240Ω for LM138 and LM238

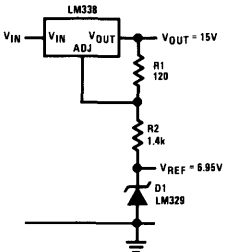
**R1, R2 as an assembly can be ordered from Bourns.
MIL part no. 7105A-AT2-502
COMM part no. 7105A-AT7-502

**10A Regulator**




*Minimum load—100 mA

**Regulator and Voltage Reference**



## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 35V |
| 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 | $10\ mA \le I_L \le 5A$, $3V \le (V_{IN} - V_{OUT}) \le 35V$ | | 0.2 | 5 | | 0.2 | 5 | μA |
| Reference Voltage | $3 \le (V_{IN} - V_{OUT}) \le 35V$, (Note 3), $10\ mA \le I_{OUT} \le 5A$, $P \le 50W$ | 1.19 | 1.24 | 1.29 | 1.19 | 1.24 | 1.29 | V |
| 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 ≤ f ≤ 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 |

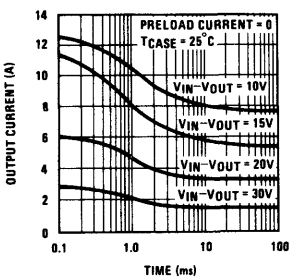
**Note 1:** Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM138, $-25°C \le T_j \le +150°C$ for the LM238 and $0°C \le T_j \le +125°C$ for the LM338, $V_{IN} - V_{OUT} = 5V$ and $I_{OUT} = 2.5A$. Although power dissipation is internally limited, these specifications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

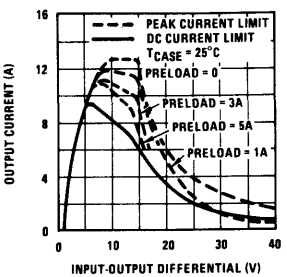
**Note 3:** Selected devices with tightened tolerance reference voltage available.

## Typical Performance Characteristics

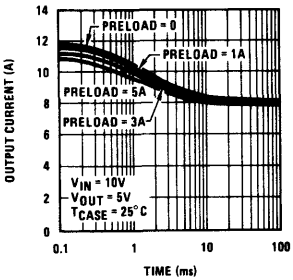
**Current Limit**




**Current Limit**

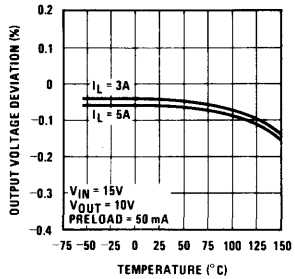



**Current Limit**

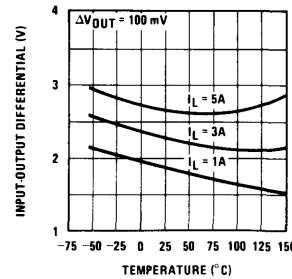


## Typical Performance Characteristics (Continued)

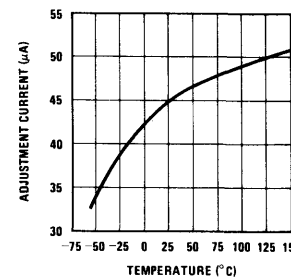
### Load Regulation



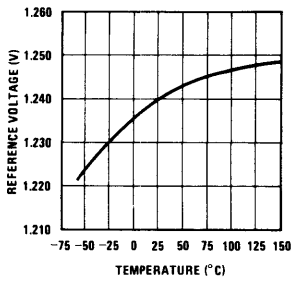

### Dropout Voltage



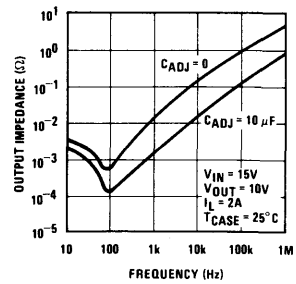

### Adjustment Current



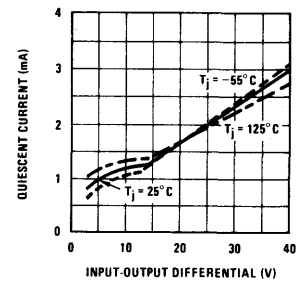

### Temperature Stability



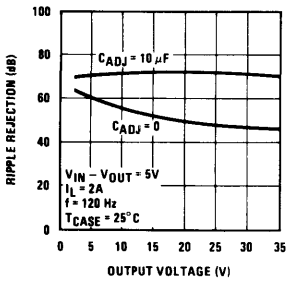

### Output Impedance



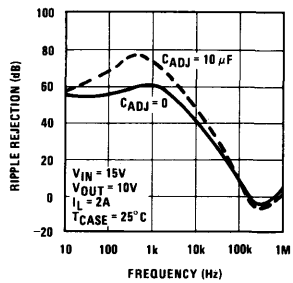

### Minimum Operating Current



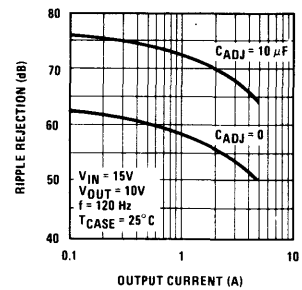

### Ripple Rejection



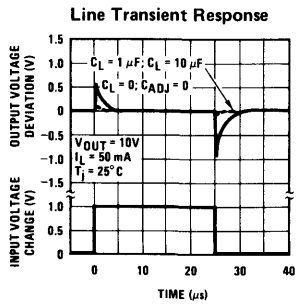

### Ripple Rejection



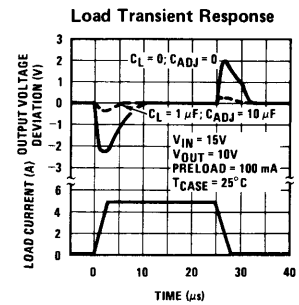

### Ripple Rejection




### 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

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

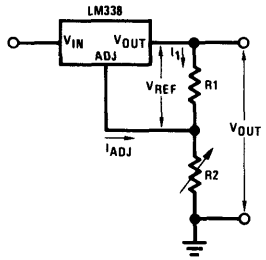



**FIGURE 1**

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.

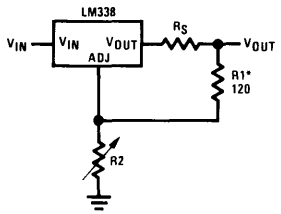



**FIGURE 2. Regulator with Line Resistance in Output Lead**

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

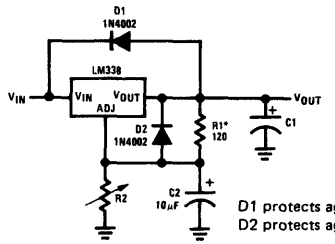
When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although 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 $\mu$F 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 $\mu$F capacitance. *Figure 3* shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

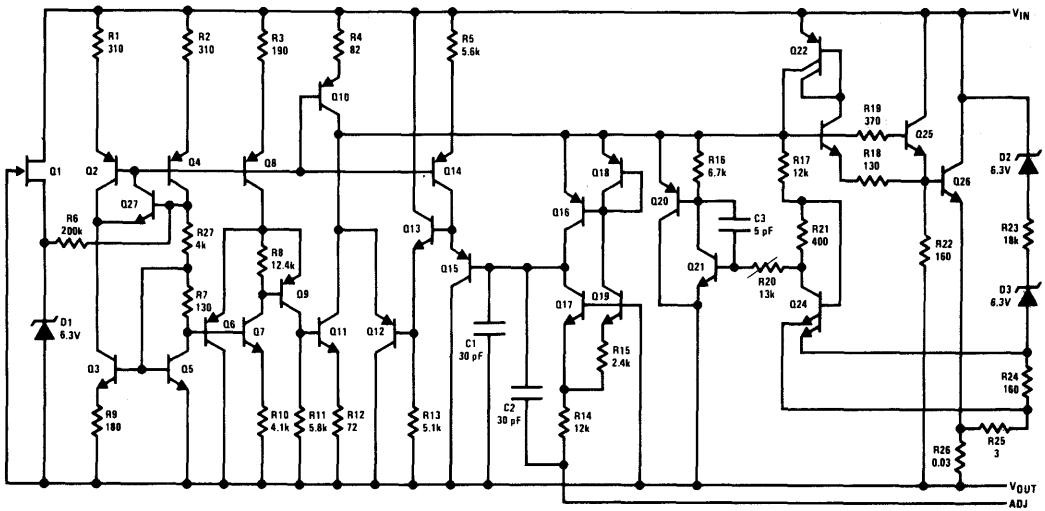



$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right) + R2I_{ADJ}$$

*R1 = 240Ω for LM138 and LM238

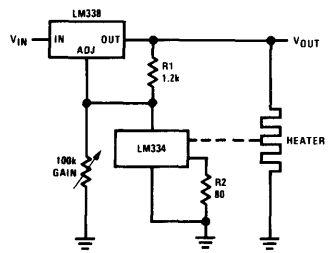
**FIGURE 3. Regulator with Protection Diodes**

## Schematic Diagram

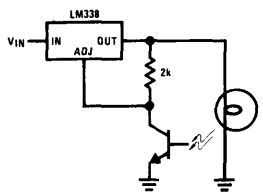



## Typical Applications (Continued)

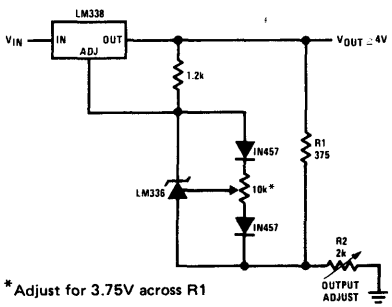
**Temperature Controller**




**Light Controller**



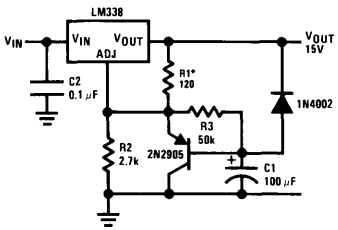

**Precision Power Regulator with Low Temperature Coefficient**




*Adjust for 3.75V across R1

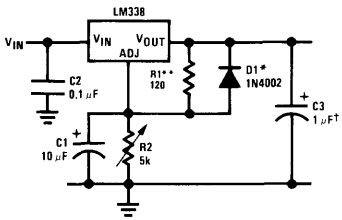
## Typical Applications (Continued)

### Slow Turn-ON 15V Regulator



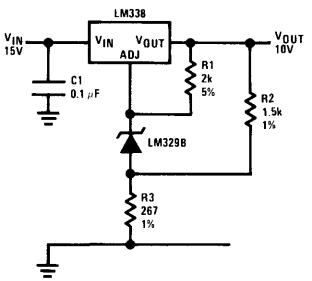

*R1 = 240Ω for LM138 and LM238

### Adjustable Regulator with Improved Ripple Rejection

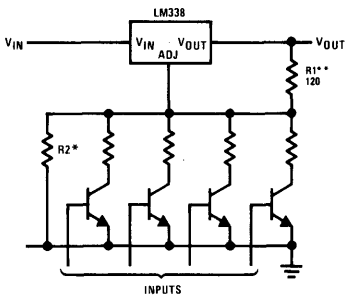



†Solid tantalum
*Discharges C1 if output is shorted to ground
**R1 = 240Ω for LM138 and LM238

### High Stability 10V Regulator

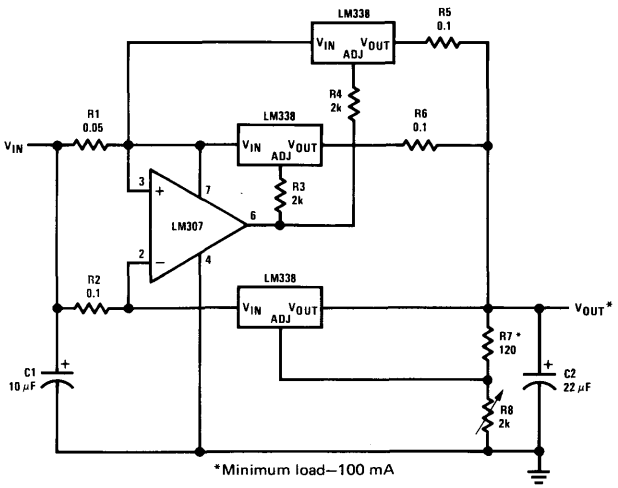



### Digitally Selected Outputs



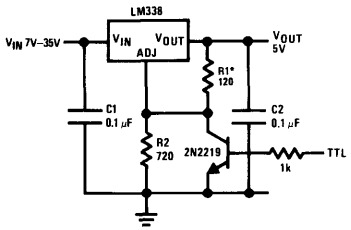

*Sets maximum $V_{OUT}$
**R1 = 240Ω for LM138 and LM238

### 15A Regulator



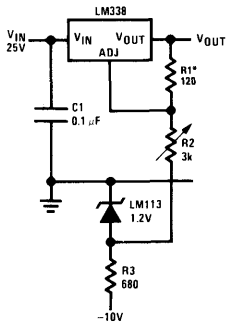

*Minimum load—100 mA

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




*R1 = 240Ω for LM138 or LM238
**Minimum output ≈ 1.2V

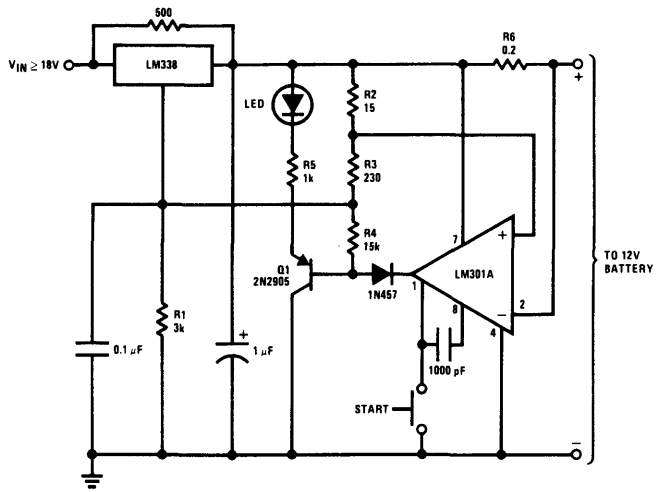
### 0 to 22V Regulator



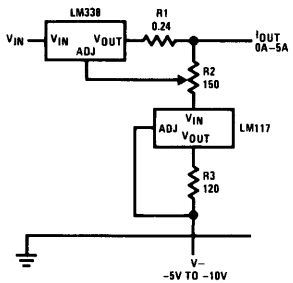

*R1=240Ω for LM138 and LM238

## Typical Applications (Continued)

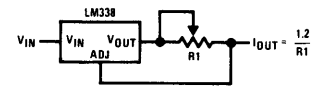
### 12V Battery Charger




### Adjustable Current Regulator

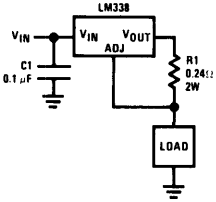



### Precision Current Limiter

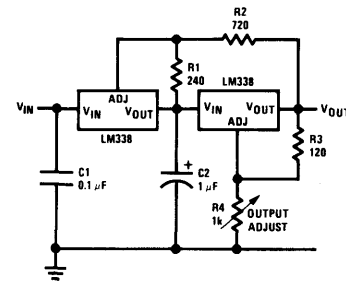



*$0.4 \leq R1 \leq 120\Omega$

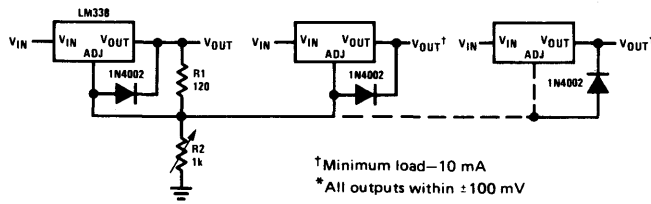
### 5A Current Regulator




### Tracking Preregulator




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

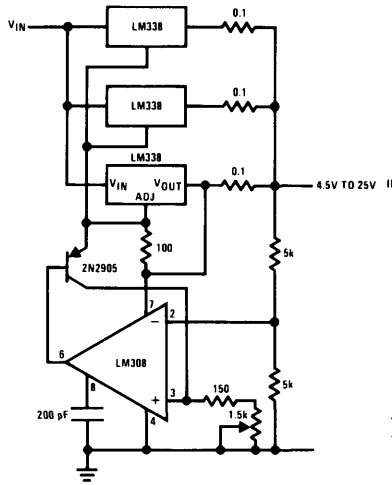



†Minimum load–10 mA

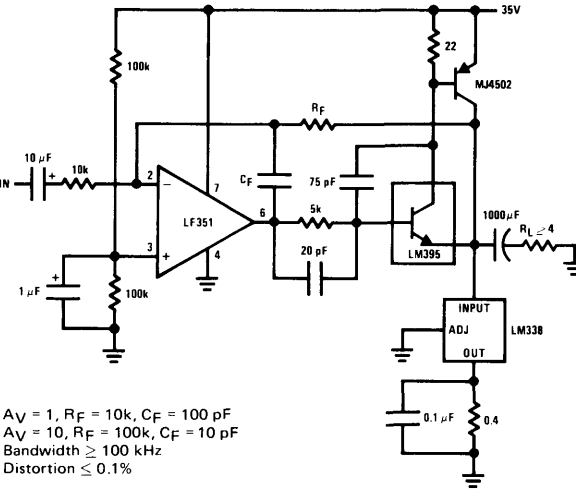
*All outputs within ±100 mV

## Typical Applications (Continued)

### Adjustable 15A Regulator

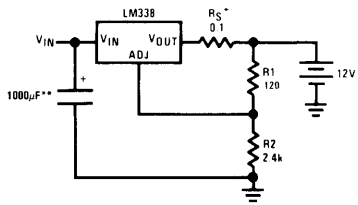



### Power Amplifier




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

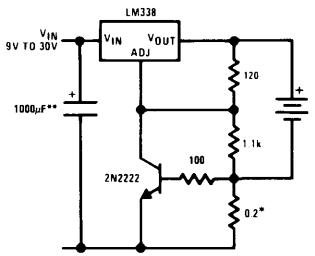
### Simple 12V Battery Charger




*$R_S$—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

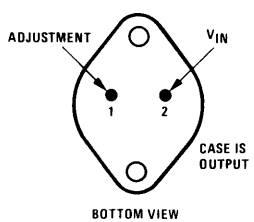



*Sets max charge current to 3A

**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**

National Semiconductor

# LM140A/LM140/LM340A/LM340 Series 3-Terminal Positive Regulators

## General Description

The LM140A/LM140/LM340A/LM340 series of positive 3-terminal voltage regulators are designed to provide superior performance as compared to the previously available 78XX series regulator. Computer programs were used to optimize the electrical and thermal performance of the packaged IC which results in outstanding ripple rejection, superior line and load regulation in high power applications (over 15W).

With these advances in design, the LM340 is now guaranteed to have line and load regulation that is a factor of 2 better than previously available devices. Also, all parameters are guaranteed at 1A vs 0.5A output current. The LM140A/LM340A provide tighter output voltage tolerance, ±2% along with 0.01%/V line regulation and 0.3%/A load regulation.

Current limiting is included to limit peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over limiting die temperature.

Considerable effort was expended to make the LM140-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The entire LM140A/LM140/LM340A/LM340 series of regulators is available in the metal TO-3 power package and the LM340A/LM340 series is also available in the TO-220 plastic power package.

For output voltages other than 5V, 12V, and 15V, the LM117 series provides an output voltage range from +1.2V to +57V.

## Features

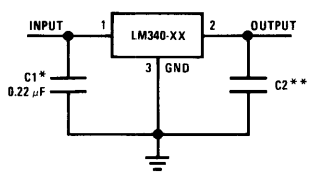
- Complete specifications at 1A load
- Output voltage tolerances of ±2% at $T_j$ = 25°C and ±4% over the temperature range (LM140A/LM340A)
- Fixed output voltages available 5, 12, and 15V
- Line regulation of 0.01% of $V_{OUT}/V$ $\Delta V_{IN}$ at 1A load (LM140A/LM340A)
- Load regulation of 0.3% of $V_{OUT}/A$ $\Delta I_{LOAD}$ (LM140A/LM340A)
- Internal thermal overload protection
- Internal short-circuit current limit
- Output transistor safe area protection
- 100% thermal limit burn-in
- Special circuitry allows start-up even if output is pulled to negative voltage (± supplies)

**LM140 Series Package and Power Capability**

| DEVICE | PACKAGE | RATED POWER DISSIPATION | DESIGN LOAD CURRENT |
|---|---|---|---|
| LM140<br>LM340 | TO-3 | 20W | 1.5A |
| LM340T | TO-220 | 15W | 1.5A |
| LM341 | TO-202 | 7.5W | 0.5A |
| LM342 | TO-202 | 7.5W | 0.25A |
| LM140L<br>LM340L | TO-39 | 2W | 0.1A |
| LM340L | TO-92+ | 1.2W | 0.1A |

## Typical Applications

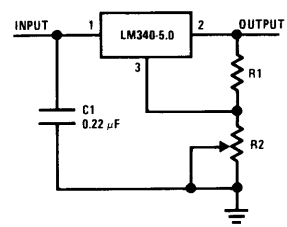
**Fixed Output Regulator**




*Required if the regulator is located far from the power supply filter

**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1 μF, ceramic disc)

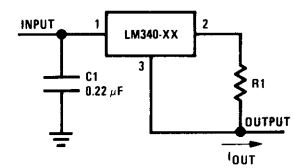
**Adjustable Output Regulator**




$V_{OUT} = 5V + (5V/R1 + I_Q)\,R2$

$5V/R1 > 3\,I_Q$, load regulation $(L_r) \approx [(R1 + R2)/R1]$ ($L_r$ of LM340-5)

**Current Regulator**




$$I_{OUT} = \frac{V2\text{-}3}{R1} + I_Q$$

$\Delta I_Q$ = 1.3 mA over line and load changes

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage ($V_O$ = 5V, 12V, 15V) | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range ($T_A$) | |
| LM140A/LM140 | −55°C to +125°C |
| LM340A/LM340 | 0°C to +70°C |
| Maximum Junction Temperature | |
| (TO-3 Package K, KC) | 150°C |
| (TO-220 Package T) | 125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 Seconds) | |
| TO-3 Package K, KC | 300°C |
| TO-220 Package T | 230°C |

## Electrical Characteristics LM140A/LM340A (Note 2)

$I_{OUT}$ = 1A, −55°C ≤ Tj ≤ +150°C (LM140A), or 0°C ≤ Tj ≤ +125°C (LM340A) unless otherwise specified.

| OUTPUT VOLTAGE | | | | 5V | | | 12V | | | 15V | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | | 10V | | | 19V | | | 23V | | | UNITS |
| PARAMETER | | CONDITIONS | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | Tj = 25°C | | 4.9 | 5 | 5.1 | 11.75 | 12 | 12.25 | 14.7 | 15 | 15.3 | V |
| | | $P_D$ ≤ 15W, 5 mA ≤ $I_O$ ≤ 1A | | 4.8 | | 5.2 | 11.5 | | 12.5 | 14.4 | | 15.6 | V |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.8 ≤ $V_{IN}$ ≤ 27) | | | (17.9 ≤ $V_{IN}$ ≤ 30) | | | V |
| $\Delta V_O$ | Line Regulation | $I_O$ = 500 mA | | | | 10 | | | 18 | | | 22 | mV |
| | | $\Delta V_{IN}$ | | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.8 ≤ $V_{IN}$ ≤ 27) | | | (17.9 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | Tj = 25°C | | | 3 | 10 | | 4 | 18 | | 4 | 22 | mV |
| | | $\Delta V_{IN}$ | | (7.3 ≤ $V_{IN}$ ≤ 20) | | | (14.5 ≤ $V_{IN}$ ≤ 27) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | Tj = 25°C | | | | 4 | | | 9 | | | 10 | mV |
| | | Over Temperature | | | | 12 | | | 30 | | | 30 | mV |
| | | Δ $V_{IN}$ | | (8 ≤ $V_{IN}$ ≤ 12) | | | (16 ≤ $V_{IN}$ ≤ 22) | | | (20 ≤ $V_{IN}$ ≤26) | | | V |
| Δ $V_O$ | Load Regulation | Tj = 25°C | 5 mA ≤ $I_O$ ≤ 1.5A | | 10 | 25 | | 12 | 32 | | 12 | 35 | mV |
| | | | 250 mA ≤ $I_O$ ≤ 750 mA | | | 15 | | | 19 | | | 21 | mV |
| | | Over Temperature, 5 mA ≤ $I_O$ ≤ 1A | | | | 25 | | | 60 | | | 75 | mV |
| $I_Q$ | Quiescent Current | Tj = 25°C | | | | 6 | | | 6 | | | 6 | mA |
| | | Over Temperature | | | | 6.5 | | | 6.5 | | | 6.5 | mA |
| Δ $I_Q$ | Quiescent Current Change | 5mA ≤ $I_O$ ≤ 1A | | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | Tj = 25°C, $I_O$ = 1A | | | | 0.8 | | | 0.8 | | | 0.8 | mA |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.8 ≤ $V_{IN}$ ≤ 27) | | | (17.9 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | $I_O$ = 500 mA | | | | 0.8 | | | 0.8 | | | 0.8 | mA |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (8 ≤ $V_{IN}$ ≤ 25) | | | (15 ≤ $V_{IN}$ ≤ 30) | | | (17.9 ≤ $V_{IN}$ ≤ 30) | | | V |
| $V_N$ | Output Noise Voltage | $T_A$ = 25°C, 10 Hz ≤ f ≤ 100 kHz | | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | Tj = 25°C, f = 120 Hz, $I_O$ = 1A or | | 68 | 80 | | 61 | 72 | | 60 | 70 | | dB |
| | | f = 120 Hz, $I_O$ = 500 mA, | | 68 | | | 61 | | | 60 | | | dB |
| | | Over Temperature, $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (8 ≤ $V_{IN}$ ≤ 18) | | | (15 ≤ $V_{IN}$ ≤ 25) | | | (18.5 ≤ $V_{IN}$ ≤ 28.5) | | | V |
| | Dropout Voltage | Tj = 25°C, $I_O$ = 1A | | | 2.0 | | | 2.0 | | | 2.0 | | V |
| | Output Resistance | f = 1 kHz | | | 8 | | | 18 | | | 19 | | mΩ |
| $R_O$ | Short-Circuit Current | Tj = 25°C | | | 2.1 | | | 1.5 | | | 1.2 | | A |
| | Peak Output Current | Tj = 25°C | | | 2.4 | | | 2.4 | | | 2.4 | | A |
| | Average TC of $V_O$ | Min, Tj = 0°C, $I_O$ = 5mA | | | −0.6 | | | −1.5 | | | −1.8 | | mV/°C |
| $V_{IN}$ | Input Voltage Required to Maintain Line Regulation | Tj = 25°C | | 7.3 | | | 14.5 | | | 17.5 | | | v |

**Note 1:** Thermal resistance of the TO-3 package (K, KC) is typically 4° C/W junction to case and 35° C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50° C/W case to ambient.

**Note 2:** All characteristics are measured with a capacitor across the input of 0.22 μF and a capacitor across the output of 0.1 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W$ ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

## Electrical Characteristics LM140 (Note 2) $-55°C \leq T_j \leq +150°C$ unless otherwise noted.

| OUTPUT VOLTAGE | | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | | 10V | | | 19V | | | 23V | | | |
| PARAMETER | | CONDITIONS | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j = 25°C$, 5 mA $\leq I_O \leq$ 1A | | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D \leq$ 15W, 5 mA $\leq I_O \leq$ 1A<br>$V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | 4.75 | | 5.25<br>(8 ≤ $V_{IN}$ ≤ 20) | 11.4 | | 12.6<br>(15.5 ≤ $V_{IN}$ ≤ 27) | 14.25 | | 15.75<br>(18.5 ≤ $V_{IN}$ ≤ 30) | V<br>V |
| $\Delta V_O$ | Line Regulation | $I_O$ = 500 mA | $T_j = 25°C$ | | 3 | 50 | | 4 | 120 | | 4 | 150 | mV |
| | | | $\Delta V_{IN}$ | | (7 ≤ $V_{IN}$ ≤ 25) | | (14.5 ≤ $V_{IN}$ ≤ 30) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | | $-55°C \leq T_j \leq +150°C$ | | | 50 | | | 120 | | | 150 | mV |
| | | | $\Delta V_{IN}$ | | (8 ≤ $V_{IN}$ ≤ 20) | | (15 ≤ $V_{IN}$ ≤ 27) | | | (18.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | $I_O \leq$ 1A | $T_j = 25°C$ | | | 50 | | | 120 | | | 150 | mV |
| | | | $\Delta V_{IN}$ | | (7.3 ≤ $V_{IN}$ ≤ 20) | | (14.6 ≤ $V_{IN}$ ≤ 27) | | | (17.7 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | | $-55°C \leq T_j \leq +150°C$ | | | 25 | | | 60 | | | 75 | mV |
| | | | $\Delta V_{IN}$ | | (8 ≤ $V_{IN}$ ≤ 12) | | (16 ≤ $V_{IN}$ ≤ 22) | | | (20 ≤ $V_{IN}$ ≤ 26) | | | V |
| $\Delta V_O$ | Load Regulation | $T_j = 25°C$ | 5 mA $\leq I_O \leq$ 1.5A | | 10 | 50 | | 12 | 120 | | 12 | 150 | mV |
| | | | 250 mA $\leq I_P \leq$ 750 mA | | | 25 | | | 60 | | | 75 | mV |
| | | $-55°C \leq T_j \leq +150°C$, 5 mA $\leq I_O \leq$ 1A | | | | 50 | | | 120 | | | 150 | mV |
| $I_Q$ | Quiescent Current | $I_O \leq$ 1A | $T_j = 25°C$ | | | 6 | | | 6 | | | 6 | mA |
| | | | $-55°C \leq T_j \leq +150°C$ | | | 7 | | | 7 | | | 7 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 5 mA $\leq I_O \leq$ 1A | | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | $T_j = 25°C$, $I_O \leq$ 1A<br>$V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | | | 0.8<br>(8 ≤ $V_{IN}$ ≤ 20) | | | 0.8<br>(15 ≤ $V_{IN}$ ≤ 27) | | | 0.8<br>(18.5 ≤ $V_{IN}$ ≤ 30 | mA<br>V |
| | | $I_O \leq$ 500 mA, $-55°C \leq T_j \leq +150°C$<br>$V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | | | 0.8<br>(8 ≤ $V_{IN}$ ≤ 25) | | | 0.8<br>(15 ≤ $V_{IN}$ ≤ 30) | | | 0.8<br>(18.5 ≤ $V_{IN}$ ≤ 30) | mA<br>V |
| $V_N$ | Output Noise Voltage | $T_A = 25°C$, 10 Hz $\leq f \leq$ 100 kHz | | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | $I_O \leq$ 1A, $T_j = 25°C$ or | 68 | 80 | | 61 | 72 | | 60 | 70 | | dB |
| | | | $I_O \leq$ 500 mA, | 68 | | | 61 | | | 60 | | | dB |
| | | | $-55° < T_j \leq +150°C$ | | | | | | | | | | |
| | | $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | | | (8 ≤ $V_{IN}$ ≤ 18) | | | (15 ≤ $V_{IN}$ ≤ 25) | | | (18.5 ≤ $V_{IN}$ ≤ 28.5) | V |
| $R_O$ | Dropout Voltage | $T_j = 25°C$, $I_{OUT}$ = 1A | | | 2.0 | | | 2.0 | | | 2.0 | | V |
| | Output Resistance | f = 1 kHz | | | 8 | | | 18 | | | 19 | | mΩ |
| | Short-Circuit Current | $T_j = 25°C$ | | | 2.1 | | | 1.5 | | | 1.2 | | A |
| | Peak Output Current | $T_j = 25°C$ | | | 2.4 | | | 2.4 | | | 2.4 | | A |
| | Average TC of $V_{OUT}$ | $0°C \leq T_j \leq +150°C$, $I_O$ = 5 mA | | | −0.6 | | | −1.5 | | | −1.8 | | mV/°C |
| $V_{IN}$ | Input Voltage Required to Maintain Line Regulation | $T_j = 25°C$, $I_O \leq$ 1A | | 7.3 | | | 14.6 | | | 17.7 | | | V |

**Note 2:** All characteristics are measured with a capacitor across the input of 0.22 μF and a capacitor across the output of 0.1 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq$ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

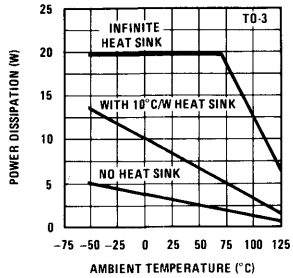
## Electrical Characteristics LM340 (Note 2) 0°C ≤ Tj ≤ +125°C unless otherwise noted.

| OUTPUT VOLTAGE | | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | | 10V | | | 19V | | | 23V | | | |
| PARAMETER | | CONDITIONS | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j = 25°C$, 5 mA ≤ $I_O$ ≤ 1A | | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D$ ≤ 15W, 5 mA ≤ $I_O$ ≤ 1A<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | 4.75<br>($7 \le V_{IN} \le 20$) | | 5.25 | 11.4<br>($14.5 \le V_{IN} \le 27$) | | 12.6 | 14.25<br>($17.5 \le V_{IN} \le 30$) | | 15.75 | V<br>V |
| $\Delta V_O$ | Line Regulation | $I_O$ = 500 mA | $T_j = 25°C$<br>$\Delta V_{IN}$ | | 3<br>($7 \le V_{IN} \le 25$) | 50 | | 4<br>($14.5 \le V_{IN} \le 30$) | 120 | | 4<br>($17.5 \le V_{IN} \le 30$) | 150 | mV<br>V |
| | | | 0°C ≤ $T_j$ ≤ +125°C<br>$\Delta V_{IN}$ | | | 50<br>($8 \le V_{IN} \le 20$) | | | 120<br>($15 \le V_{IN} \le 27$) | | | 150<br>($18.5 \le V_{IN} \le 30$) | mV<br>V |
| | | $I_O \le$ 1A | $T_j = 25°C$<br>$\Delta V_{IN}$ | | | 50<br>($7.3 \le V_{IN} \le 20$) | | | 120<br>($14.6 \le V_{IN} \le 27$) | | | 150<br>($17.7 \le V_{IN} \le 30$) | mV<br>V |
| | | | 0°C ≤ $T_j$ ≤ +125°C<br>$\Delta V_{IN}$ | | | 25<br>($8 \le V_{IN} \le 12$) | | | 60<br>($16 \le V_{IN} \le 22$) | | | 75<br>($20 \le V_{IN} \le 26$) | mV<br>V |
| $\Delta V_O$ | Load Regulation | $T_j = 25°C$ | 5 mA ≤ $I_O$ ≤ 1.5 A | | 10 | 50 | | 12 | 120 | | 12 | 150 | mV |
| | | | 250 mA ≤ $I_O$ ≤ 750 mA | | | 25 | | | 60 | | | 75 | mV |
| | | 5 mA ≤ $I_O$ ≤ 1A, 0°C ≤ $T_j$ ≤ +125°C | | | | 50 | | | 120 | | | 150 | mV |
| $I_Q$ | Quiescent Current | $I_O \le$ 1A | $T_j = 25°C$ | | | 8 | | | 8 | | | 8 | mA |
| | | | 0°C ≤ $T_j$ ≤ +125°C | | | 8.5 | | | 8.5 | | | 8.5 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 5 mA ≤ $I_O$ ≤ 1A | | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | $T_j = 25°C$, $I_O \le$ 1A<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | | | 1.0<br>($7.5 \le V_{IN} \le 20$) | | | 1.0<br>($14.8 \le V_{IN} \le 27$) | | | 1.0<br>($17.9 \le V_{IN} \le 30$) | mA<br>V |
| | | $I_O \le$ 500 mA, 0°C ≤ $T_j$ ≤ +125°C<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | | | 1.0<br>($7 \le V_{IN} \le 25$) | | | 1.0<br>($14.5 \le V_{IN} \le 30$) | | | 1.0<br>($17.5 \le V_{IN} \le 30$) | mA<br>V |
| $V_N$ | Output Noise Voltage | $T_A = 25°C$, 10 Hz ≤ f ≤ 100 kHz | | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | $I_O \le$ 1A, $T_j = 25°C$ or | 62 | 80 | | 55 | 72 | | 54 | 70 | | dB |
| | | | $I_O \le$ 500 mA, | 62 | | | 55 | | | 54 | | | dB |
| | | | 0°C ≤ $T_j$ ≤ +125°C | | | | | | | | | | |
| | | $V_{MIN} \le V_{IN} \le V_{MAX}$ | | | | ($8 \le V_{IN} \le 18$) | | | ($15 \le V_{IN} \le 25$) | | | ($18.5 \le V_{IN} \le 28.5$) | V |
| $R_O$ | Dropout Voltage | $T_j = 25°C$, $I_{OUT}$ = 1A | | | 2.0 | | | 2.0 | | | 2.0 | | V |
| | Output Resistance | f = 1 kHz | | | 8 | | | 18 | | | 19 | | mΩ |
| | Short-Circuit Current | $T_j = 25°C$ | | | 2.1 | | | 1.5 | | | 1.2 | | A |
| | Peak Output Current | $T_j = 25°C$ | | | 2.4 | | | 2.4 | | | 2.4 | | A |
| | Average TC of $V_{OUT}$ | 0°C ≤ $T_j$ ≤ +125°C, $I_O$ = 5 mA | | | −0.6 | | | −1.5 | | | −1.8 | | mV/°C |
| $V_{IN}$ | Input Voltage Required to Maintain Line Regulation | $T_j = 25°C$, $I_O \le$ 1A | | 7.3 | | | 14.6 | | | 17.7 | | | V |

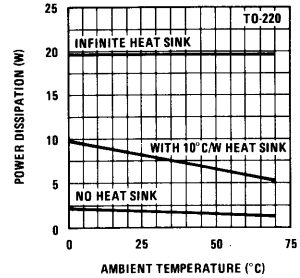
**Note 2:** All characteristics are measured with a capacitor across the input of 0.22 μF and a capacitor across the output of 0.1 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \le$ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

## Typical Performance Characteristics

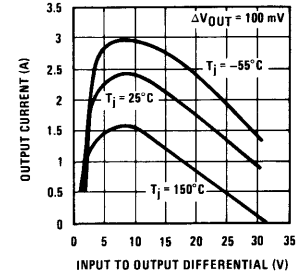
**Maximum Average Power Dissipation**



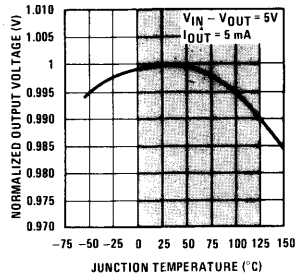

**Maximum Average Power Dissipation**



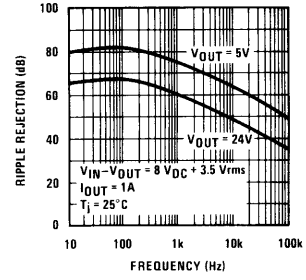

**Peak Output Current**



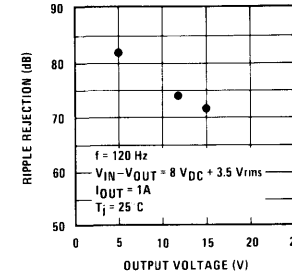

**Output Voltage (Normalized to 1V at $T_j = 25°C$)**




**Ripple Rejection**

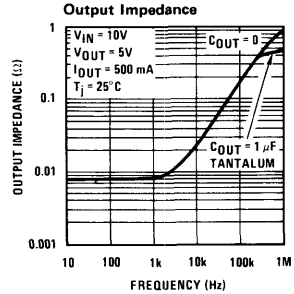



**Ripple Rejection**

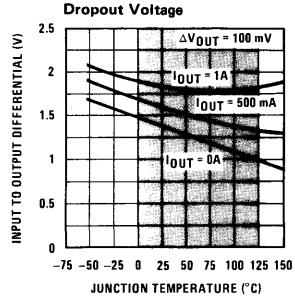



Note. Shaded area refers to LM340A/LM340

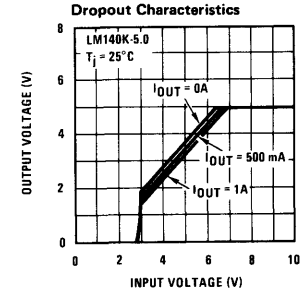
**Output Impedance**




**Dropout Voltage**

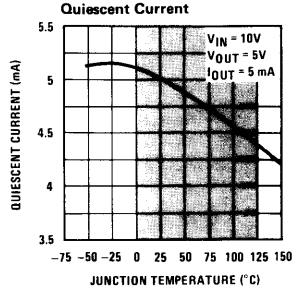



**Dropout Characteristics**

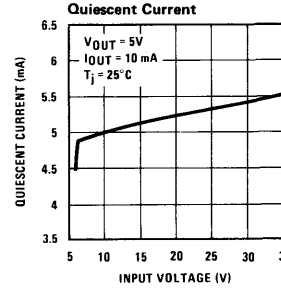



Note. Shaded area refers to LM340A/LM340

**Quiescent Current**



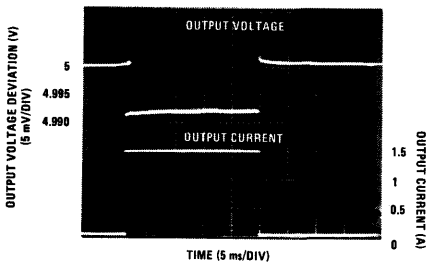

**Quiescent Current**



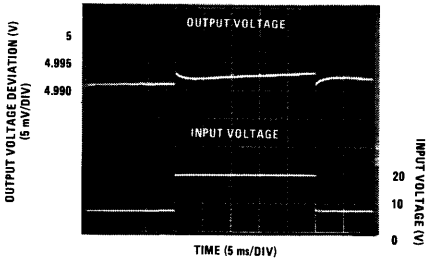

Note. Shaded area refers to LM340A/LM340

## Typical Performance Characteristics (Continued)

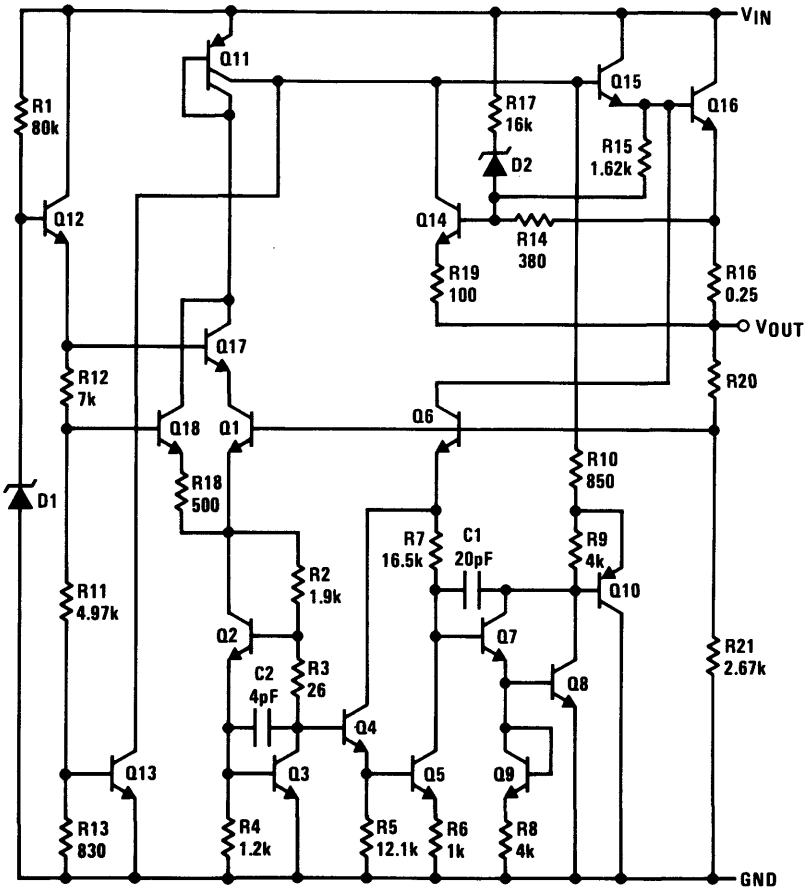
**Load Regulation**
**140AK-5.0, $V_{IN}$ = 10V, $T_A$ = 25°C**




**Line Regulation**
**140AK-5.0, $I_{OUT}$ = 1A, $T_A$ = 25°C**




## Equivalent Schematic



## Application Hints

The LM340 is designed with thermal protection, output short-circuit protection and output transistor safe area protection. However, as with *any* IC regulator, it becomes necessary to take precautions to assure that the regulator is not inadvertently damaged. The following describes possible misapplications and methods to prevent damage to the regulator.

**Shorting the Regulator Input:** When using large capacitors at the output of these regulators that have $V_{OUT}$ greater than 6V, a protection diode connected input to output *(Figure 1)* may be required if the input is shorted to ground. Without the protection diode, an input short will cause the input to rapidly approach ground potential, while the output remains near the initial $V_{OUT}$ because of the stored charge in the large output capacitor. The capacitor will then discharge through reverse biased emitter-base junction of the pass device, Q16, which breaks down at 6.5V and forward biases the base-collector junction. If the energy released by the capacitor into the emitter-base junction is large enough, the junction and the regulator will be destroyed. The fast diode in *Figure 1* will shunt the capacitor's discharge current around the regulator.

**Raising the Output Voltage above the Input Voltage:** Since the output of the LM340 does not sink current, forcing the output high can cause damage to internal low current paths in a manner similar to that just described in the "Shorting the Regulator Input" section.

**Regulator Floating Ground** *(Figure 2)*: When the ground pin alone becomes disconnected, the output approaches the unregulated input, causing possible damage to other circuits connected to $V_{OUT}$. If ground is reconnected with power "ON", damage may also occur to the regulator. This fault is most likely to occur when plugging in regulators or modules with on card regulators into powered up sockets. Power should be turned off first, thermal limit ceases operating, or ground should be connected first if power must be left on.

**Transient Voltages:** If transients exceed the maximum rated input voltage of the 340, or reach more than 0.8V below ground and have sufficient energy, they will damage the regulator. The solution is to use a large input capacitor, a series input breakdown diode, a choke, a transient suppressor or a combination of these.

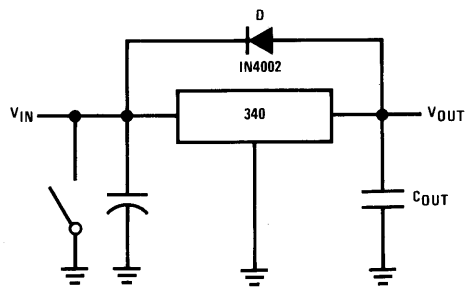



FIGURE 1. Input Short

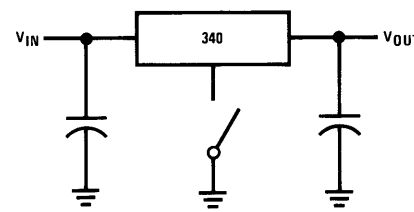



FIGURE 2. Regulator Floating Ground

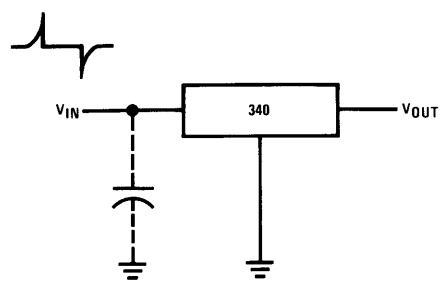
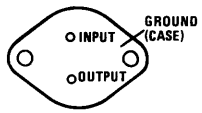



FIGURE 3. Transients

## Connection Diagrams

TO-3 Metal Can Package (K and KC)




BOTTOM VIEW

Steel Package Order Numbers:

| | | | |
|---|---|---|---|
| LM140AK-5.0 | LM140K-5.0 | LM340AK-5.0 | LM340K-5.0 |
| LM140AK-12 | LM140K-12 | LM340AK-12 | LM340K-12 |
| LM140AK-15 | LM140K-15 | LM340AK-15 | LM340K-15 |

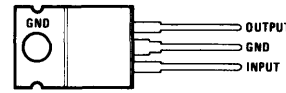
See Package K02A

Aluminum Package Order Numbers:

LM340KC-5.0
LM340KC-12
LM340KC-15

See Package KC02A

TO-220 Power Package (T)




TOP VIEW

Plastic Package Order Numbers:

| | |
|---|---|
| LM340AT-5.0 | LM340T-5.0 |
| LM340AT-12 | LM340T-12 |
| LM340AT-15 | LM340T-15 |

See Package TO3B

National Semiconductor

# LM140L/LM340L Series 3-Terminal Positive Regulators

## General Description

The LM140L series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. The LM140LA is an improved version of the LM78LXX series with a tighter output voltage tolerance (specified over the full military temperature range), higher ripple rejection, better regulation and lower quiescent current. The LM140LA regulators have ±2% $V_{OUT}$ specification, 0.04%/V line regulation, and 0.01%/mA load regulation. When used as a zener diode/resistor combination replacement, the LM140LA usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM140LA to be used in logic systems, instrumentation, Hi-Fi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The LM140LA/LM340LA are available in the low profile metal three lead TO-39 (H) and the LM340LA are also available in the plastic T)-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over, preventing the IC from overheating.

For applications requiring other voltages, see LM117 Data Sheet.

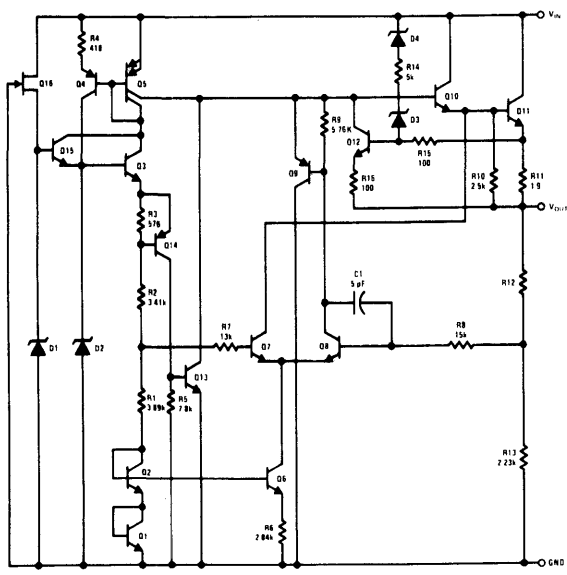
## Features

- Line regulation of 0.04%/V
- Load regulation of 0.01%/mA
- Output voltage tolerances of ±2% at $T_J$ = 25°C and ±4% over the temperature range (LM140LA)
  ±3% over the temperature range (LM340LA)
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in metal TO-39 low profile package (LM140LA/LM340LA) and plastic TO-92 (LM340LA)

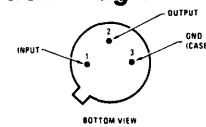
## Output Voltage Options

| | | | |
|---|---|---|---|
| LM140LA-5.0 | 5V | LM340LA-5.0 | 5V |
| LM140LA-12 | 12V | LM340LA-12 | 12V |
| LM140LA-15 | 15V | LM340LA-15 | 15V |

## Equivalent Circuit



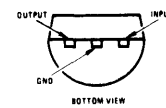

## Connection Diagrams




**Order Number:**

| | |
|---|---|
| LM140LAH-5.0 | LM340LAH-5.0 |
| LM140LAH-12 | LM340LAH-12 |
| LM140LAH-15 | LM340LAH-15 |

**See Package H03A**




**Order Number:**
**LM340LAZ-5.0**
**LM340LAZ-12**
**LM340LAZ-15**
**See Package Z03A**

## Absolute Maximum Ratings

Input Voltage
- 5.0V, 12V, 15V Output Voltage Options 35V

Internal Power Dissipation (Note 1) Internally Limited
Operating Temperature Range
- LM140LA −55°C to +125°C
- LM340LA 0°C to 70°C

Maximum Junction Temperature +150°C
Storage Temperature Range
- Metal Can (H package) −65°C to +150°C
- Molded TO-92 −55° to +150°C

Lead Temperature (Soldering, 10 seconds) +300°C

## Electrical Characteristics (Note 2)

Test conditions unless otherwise specified
$T_A = -55°C$ to $+125°C$ (LM140LA)
$T_A = 0°C$ to $+70°C$ (LM340LA)
$I_O = 40$ mA
$C_{IN} = 0.33\mu F$, $C_O = 0.01\mu F$

| OUTPUT VOLTAGE OPTION | | | | 5.0V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | | 10V | | | 19V | | | 23V | | | |
| PARAMETER | | CONDITIONS | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j = 25°C$ | | 4.9 | 5 | 5.1 | 11.75 | 12 | 12.25 | 14.7 | 15 | 15.3 | V |
| | Output Voltage Over Temp. (Note 4) | LM140LA<br>LM240LA | $I_O$ = 1-100 mA | 4.8 | | 5.2 | 11.5 | | 12.5 | 14.4 | | 15.6 | V |
| | | | $I_O$ = 1-40 mA and $V_{IN}$ = ( )V | (7.2-20) | | | (14.5-27) | | | (17.6-30) | | | |
| | | LM340LA | $I_O$ = 1-100 mA or | 4.85 | | 5.15 | 11.65 | | 12.35 | 14.55 | | 15.45 | |
| | | | $I_O$ = 1-40 mA and $V_{IN}$ = ( )V | (7-20) | | | (14.3-27) | | | (17.5-30) | | | |
| $\Delta V_O$ | Line Regulation | $T_j = 25°C$ | $I_O$ = 40 mA | | 18 | 30 | | 30 | 65 | | 37 | 70 | mV |
| | | | $V_{IN}$ = ( ) V | (7-25) | | | (14.2-30) | | | (17.3-30) | | | |
| | | | $I_O$ = 100 mA | | 18 | 30 | | 30 | 65 | | 37 | 70 | |
| | | | $V_{IN}$ = ( )V | (7.5-25) | | | (14.5-30) | | | (17.5-30) | | | |
| | Load Regulation | $T_j = 25°C$ | $I_O$ = 1-40 mA | | 5 | 20 | | 10 | 40 | | 12 | 50 | |
| | | | $I_O$ = 1-100 mA | | 20 | 40 | | 30 | 80 | | 35 | 100 | |
| | Long Term Stability | | | | 12 | | | 24 | | | 30 | | mV 1000 hrs |
| $I_O$ | Quiescent Current | $T_j = 25°C$ | | | 3 | 4.5 | | 3 | 4.5 | | 3.1 | 4.5 | mA |
| | | $T_j = 125°C$ | | | | 4.2 | | | 4.2 | | | 4.2 | |
| $\Delta I_Q$ | Quiescent Current Change | $T_j = 25°C$ | $\Delta$Load $I_O$ = 1-40mA | | | 0.1 | | | 0.1 | | | 0.1 | mA |
| | | | $\Delta$Line | | | 0.5 | | | 0.5 | | | 0.5 | |
| | | | $V_{IN}$ = ( ) V | (7.5-25) | | | (14.3-30) | | | (17.5-30) | | | |
| $V_N$ | Output Noise Voltage | $T_j = 25°C$ (Note 3)<br>f = 10 Hz-10 kHz | | | 40 | | | 80 | | | 90 | | $\mu V$ |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz, $V_{IN}$ = ( ) V | | 55 | 62 | | 47 | 54 | | 45 | 52 | | dB |
| | | | | (7.5-18) | | | (14.5-25) | | | (17.5-28.5) | | | |
| | Input Voltage Required to Maintain Line Regulation | $T_j = 25°C$, $I_O$ = 40 mA | | 7 | | | 14.2 | | | 17.3 | | | V |

**Note 1:** Thermal resistance of the Metal Can Package (H) without a heat sink is 40°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4 inch leads from PC board and 160°C/W junction to ambient with 0.125 inch lead length to a PC board.

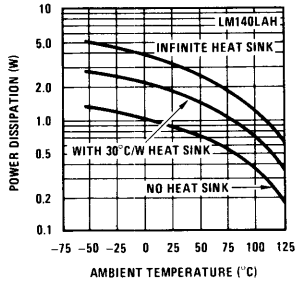
**Note 2:** The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of tests.

**Note 3:** It is recommended that a minimum load capacitor of 0.01μF be used to limit the high frequency noise bandwidth.

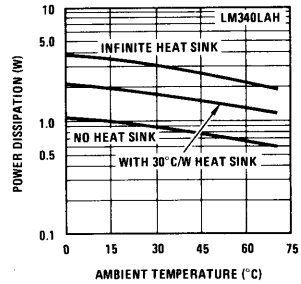
**Note 4:** The temperature coefficient of $V_{OUT}$ is typically within $0.01\% V_O/°C$.

# Typical Performance Characteristics

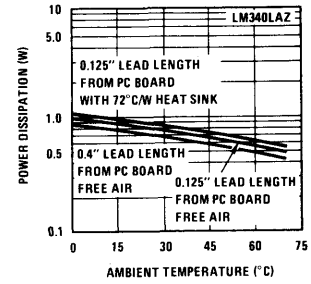
**Maximum Average Power Dissipation**



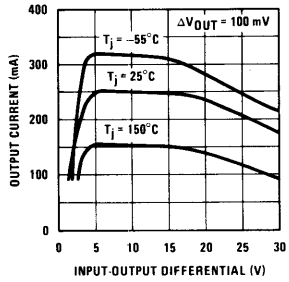

**Maximum Average Power Dissipation (Metal Can Package)**



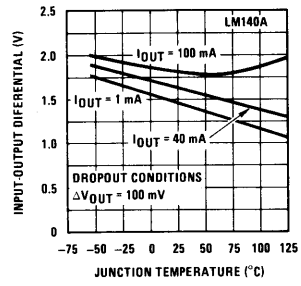

**Maximum Average Power Dissipation (Plastic Package)**



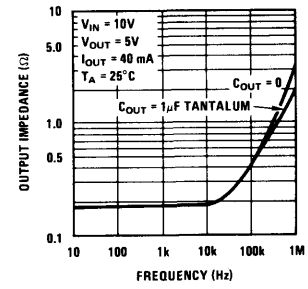

**Peak Output Current**



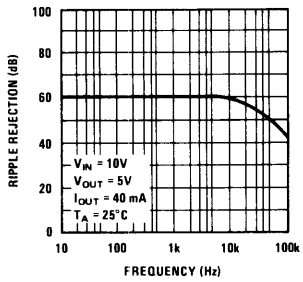

**Dropout Voltage**



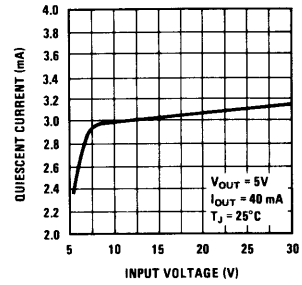

**Output Impedance**



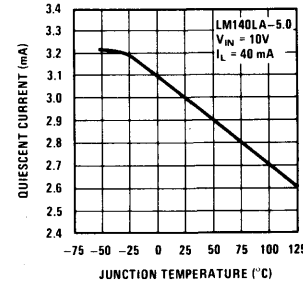

**Ripple Rejection**



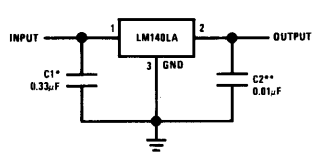

**Quiescent Current**




**Quiescent Current**

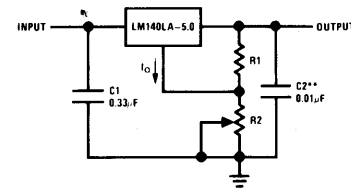



# Typical Applications




*Required if the regulator is located far from the power supply filter.
**See note 3 in the electrical characteristics table.

**Fixed Output Regulator**




$V_{OUT} = 5V + (5V/R1 + I_Q) R2$

$5V/R1 \cdot 3I_Q$ load regulation $(L_r) = [(R1 + R2)/R1]$ $(L_r$ of LM140LA−5.0)

**Adjustable Output Regulator**

National Semiconductor

Voltage Regulators

# LM145/LM245/LM345 Negative Three Amp Regulator

## General Description

The LM145 is a three-terminal negative regulator with a fixed output voltage of −5V or −5.2V, and up to 3A load current capability. This device needs only one external component—a compensation capacitor at the output, making it easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM145 immune to overload conditions. The regulator has current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

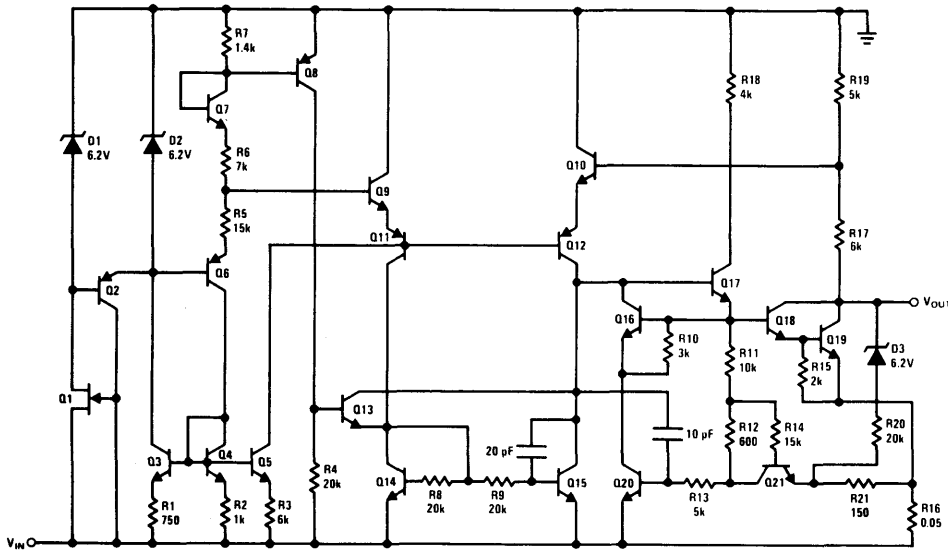
Although primarily intended for fixed output voltage applications, the LM145 may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain current of the device allows this technique to be used with good regulation.

The LM145 comes in a hermetic TO-3 package rated at 25W. Two reduced temperature range parts, LM245 and LM345, are also available.

## Features

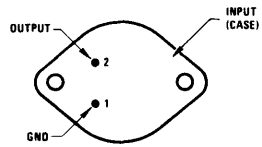
- Output voltage accurate to better than ±2%
- Current limit constant with temperature
- Internal thermal shutdown protection
- Operates with input-output voltage differential of 2.8V at full rated load over full temperature range
- Regulation guaranteed with 25W power dissipation
- 3A output current guaranteed
- Only one external component needed
- 100% electrical burn-in

## Schematic Diagram




## Connection Diagram

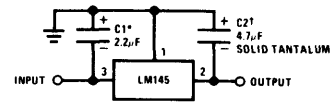
**Metal Can Package**




**BOTTOM VIEW**

**Order Number LM145K-5.0, LM245K-5.0 LM345K-5.0, LM145K-5.2, LM245K-5.2, or LM345K-5.2**
**See NS Package K02A**

## Typical Applications




†Required for stability. For value given, capacitor must be solid tantalum. 50μF aluminum electrolytic may be substituted. Values given may be increased without limit.

*Required if regulator is separated from filter capacitor. For value given, capacitor must be solid tantalum. 50μF aluminum electrolytic may be substituted.

**Fixed Regulator**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | 20V |
| Input-Output Differential | 20V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | |
| LM145 | −55°C to +150°C |
| LM245 | −25°C to +150°C |
| LM345 | 0°C to +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (−5V & −5.2V) (Note 1)

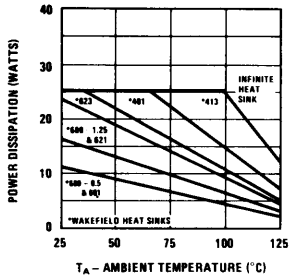
| PARAMETER | CONDITIONS | LIMITS | | | | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | LM145/LM245 | | | LM345 | | | |
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Output Voltage | $T_j = 25°C$, $I_{OUT} = 5$ mA, | | | | | | | |
| 5.0V | $V_{IN} = -7.5$ | −5.1 | −5.0 | −4.9 | −5.2 | −5.0 | −4.8 | V |
| 5.2V | | −5.3 | −5.2 | −5.1 | −5.4 | −5.2 | −5.0 | V |
| Line Regulation (Note 2) | $T_j = 25°C$<br>$-20V \leq V_{IN} \leq -7.5V$ | | 5 | 15 | | 5 | 25 | mV |
| Load Regulation (Note 2) | $T_j = 25°C$, $V_{IN} = -7.5V$<br>$5\text{ mA} \leq I_{OUT} \leq 3A$ | | 30 | 75 | | 30 | 100 | mV |
| Output Voltage | $-20V \leq V_{IN} \leq -7.8V$ | | | | | | | |
| 5.0V | $5\text{ mA} \leq I_{OUT} \leq 3A$ | −5.20 | | −4.80 | −5.25 | | −4.75 | V |
| 5.2V | $P \leq 25W$ | −5.40 | | −5.00 | −5.45 | | −4.95 | V |
| | $T_{MIN} \leq T_j \leq T_{MAX}$ | | | | | | | |
| Quiescent Current | $-20V \leq V_{IN} \leq -7.5V$<br>$5\text{ mA} \leq I_{OUT} \leq 3A$ | | 1.0 | 3.0 | | 1.0 | 3.0 | mA |
| Short Circuit Current | $V_{IN} = -7.5V$, $T_j = +25°C$ | | 4 | 5.0 | | 4 | 5.0 | A |
| | $V_{IN} = -20V$, $T_j = +25°C$ | | 2 | 3.5 | | 2 | 3.5 | A |
| Output Noise Voltage | $T_A = 25°C$, $C_L = 4.7\mu F$<br>$10\text{ Hz} \leq f \leq 100\text{ kHz}$ | | 150 | | | 150 | | $\mu V$ |
| Long Term Stability | | | 5 | 50 | | 5 | 50 | mV |
| Thermal Resistance Junction to Case | | | 2 | | | 2 | | °C/W |

**Note 1:** Unless otherwise specified, these specifications apply: $-55°C \leq T_j \leq +150°C$ for the LM145; $-25°C \leq T_j \leq +150°C$ for the LM245 and $0°C \leq T_j \leq +125°C$ for the LM345. $V_{IN} = -7.5V$ and $I_{OUT} = 5$ mA. Although power dissipation is internally limited, electrical specifications apply only for power levels up to 25W. For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 35°C/W for the TO-3 with no heat sink. With a heat sink, use 2°C/W for junction to case thermal resistance.

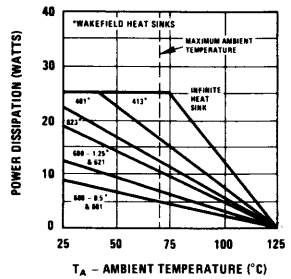
**Note 2:** Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

# Typical Performance Characteristics

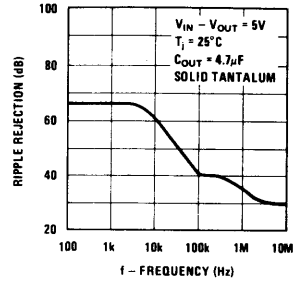
**Maximum Average Power Dissipation for LM145, LM245**



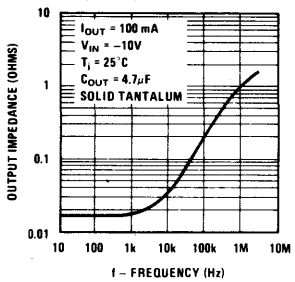

**Maximum Average Power Dissipation for LM345**



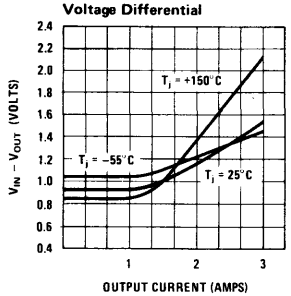

**Ripple Rejection**



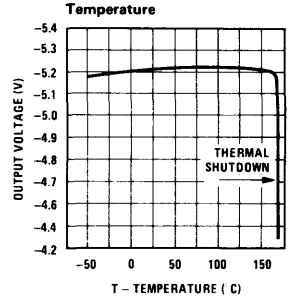

**Output Impedance**



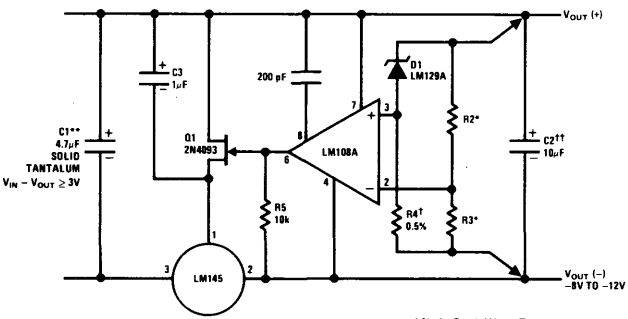

**Minimum Input-Output Voltage Differential**




**Output Voltage vs Temperature**




# Typical Applications (Continued)




*Select resistors to set output voltage. 1 ppm/°C tracking suggested.

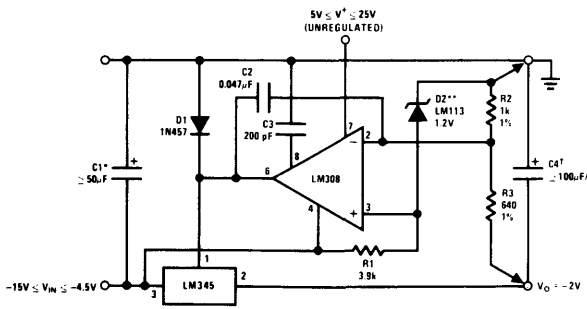
**C1 is not needed if power supply filter capacitor is within 3" of regulator.

†Determines zener current. May be adjusted to minimize temperature drift.

††Solid tantalum.

Load and line regulation < 0.01%
Temperature drift < 0.001%/°C

**High Stability Regulator**



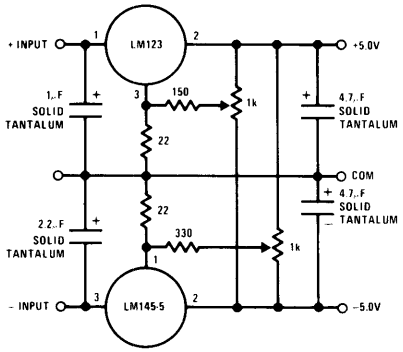

**C1 is not needed if power supply filter capacitor is within 3" of regulator.

†Keep C4 within 2" of LM345. There is no upper limit on C4 and unlimited capacitance can be added at extended distances from the regulator.

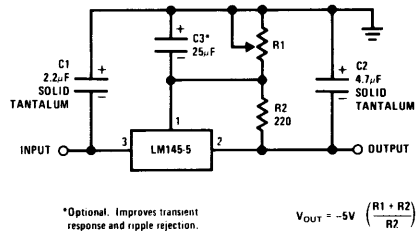
**D2 sets initial output voltage accuracy. The LM113 is available in ·5, ·2, and ·1% tolerance.

**–2V ECL Termination Regulator**

## Typical Applications (Continued)




Dual 3 Amp Trimmed Supply




Variable Output (-5.0V to -15V)

National Semiconductor

# LM150/LM250/LM350
# 3 Amp Adjustable Power Regulators

## General Description

The LM150/LM250/LM350 are adjustable 3-terminal positive voltage regulators 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 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 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.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment 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.

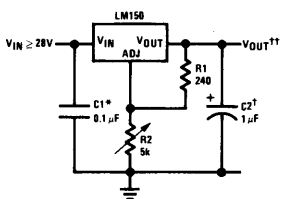
The LM150/LM250/LM350 are packaged in standard steel TO-3 transistor packages. The LM150 is rated for operation from −55°C to +150°C, the LM250 from −25°C to +150°C and the LM350 from 0°C to +125°C.

## Features

- Adjustable output down to 1.2V
- Guaranteed 3A output current
- 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**
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 86 dB ripple rejection

## Typical Applications

**1.2V–25V Adjustable Regulator**



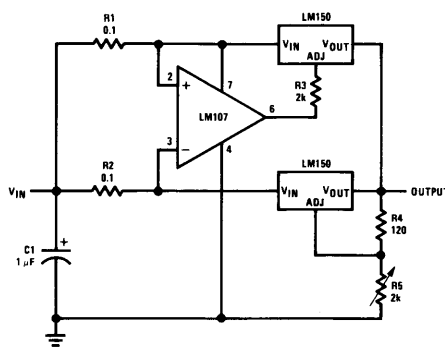

†Optional—improves transient response.

*Needed if device is far from filter capacitors

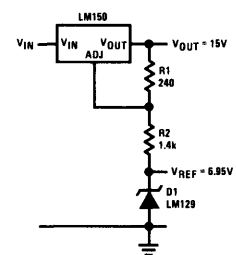
$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right)$$

**Note:** Usually R1 = 240Ω for LM150 and LM250 and R1=120Ω for LM350

**6A Regulator**




**Regulator and Voltage Reference**



## Absolute Maximum Ratings

| | |
|---|---|
| Power Dissipation | Internally limited |
| Input–Output Voltage Differential | 35V |
| LM150 | −55°C to +150°C |
| LM250 | −25°C to +150°C |
| LM350 | 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 | LM150/LM250 | | | LM350 | | | 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 | $T_A = 25°C$, $10\ mA \le I_{OUT} \le 3A$ | | | | | | | |
| | $V_{OUT} \le 5V$, (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 | 0.03 | %/W |
| Adjustment Pin Current | | | 50 | 100 | | 50 | 100 | μA |
| Adjustment Pin Current Change | $10\ mA \le I_L \le 3A$<br>$3V \le (V_{IN} - V_{OUT}) \le 35V$ | | 0.2 | 5 | | 0.2 | 5 | μA |
| Reference Voltage | $3 \le (V_{IN} - V_{OUT}) \le 35V$, (Note 3)<br>$10\ mA \le I_{OUT} \le 3A$, $P \le 30W$ | 1.20 | 1.25 | 1.30 | 1.20 | 1.25 | 1.30 | V |
| Line Regulation | $3V \le V_{IN} - V_{OUT} \le 35V$, (Note 2) | | 0.02 | 0.05 | | 0.02 | 0.07 | %/V |
| Load Regulation | $10\ mA \le I_{OUT} \le 3A$, (Note 2) | | | | | | | |
| | $V_{OUT} \le 5V$ | | 20 | 50 | | 20 | 70 | mV |
| | $V_{OUT} \ge 5V$ | | 0.3 | 1 | | 0.3 | 1.5 | % |
| 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 | $V_{IN} - V_{OUT} \le 10V$ | 3.0 | 4.5 | | 3.0 | 4.5 | | 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 | | 65 | | | 65 | | dB |
| | $C_{ADJ} = 10\ \mu F$ | 66 | 86 | | 66 | 86 | | dB |
| Long Term Stability | $T_A = 125°C$ | | 0.3 | 1 | | 0.3 | 1 | % |
| Thermal Resistance, Junction to Case | K Package | | | 1.5 | | | 1.5 | °C/W |

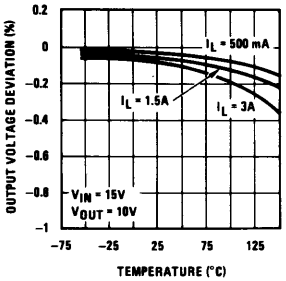
**Note 1:** Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM150, $-25°C \le T_j \le +150°C$ for the LM250 and $0°C \le T_j \le +125°C$ for the LM350, $V_{IN} - V_{OUT} = 5V$ and $I_{OUT} = 1.5A$. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 30W.

**Note 2:** Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

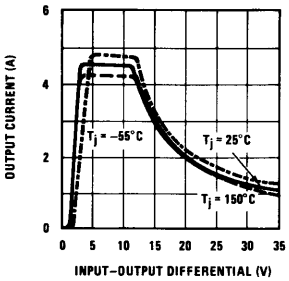
**Note 3:** Selected devices with tightened tolerance reference voltage available.

# Typical Performance Characteristics

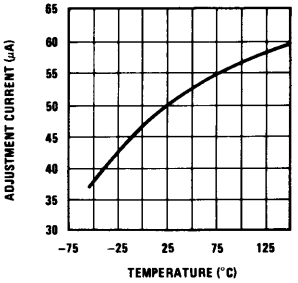
### Load Regulation



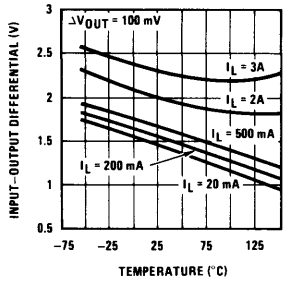

### Current Limit



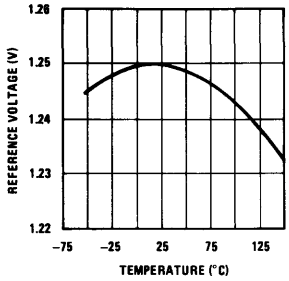

### Adjustment Current



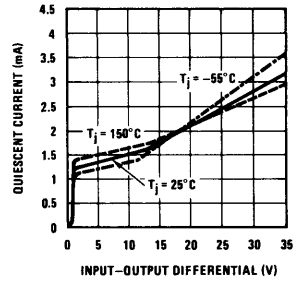

### Dropout Voltage



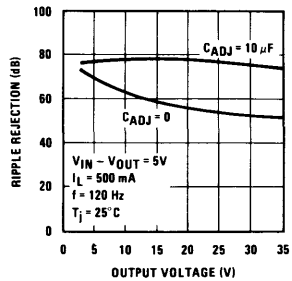

### Temperature Stability



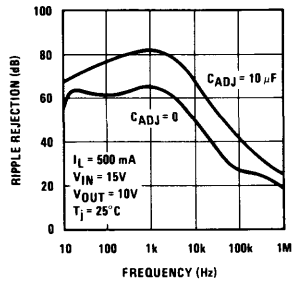

### Minimum Operating Current



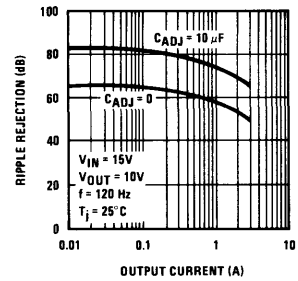

### Ripple Rejection



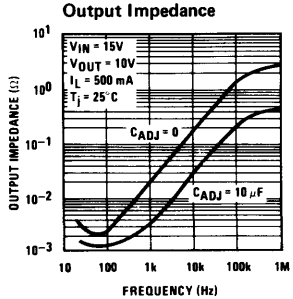

### Ripple Rejection



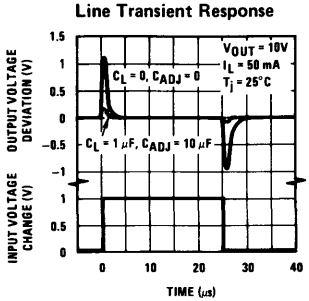

### Ripple Rejection



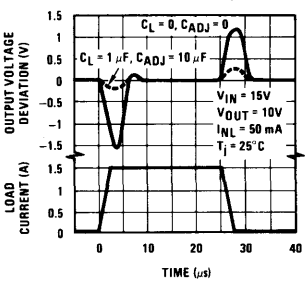

### Output Impedance




### 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

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

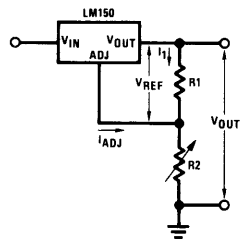



FIGURE 1

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 are 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 between 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 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.

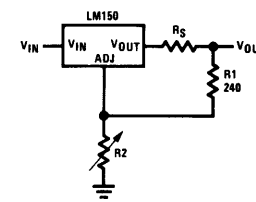



**FIGURE 2. Regulator with Line Resistance in Output Lead**

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 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

## Application Hints (Continued)

regulators. For output capacitors of 25 μF 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 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 LM150 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

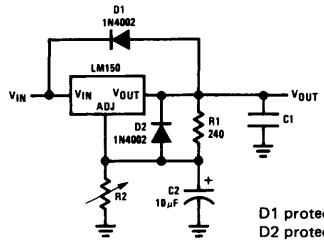
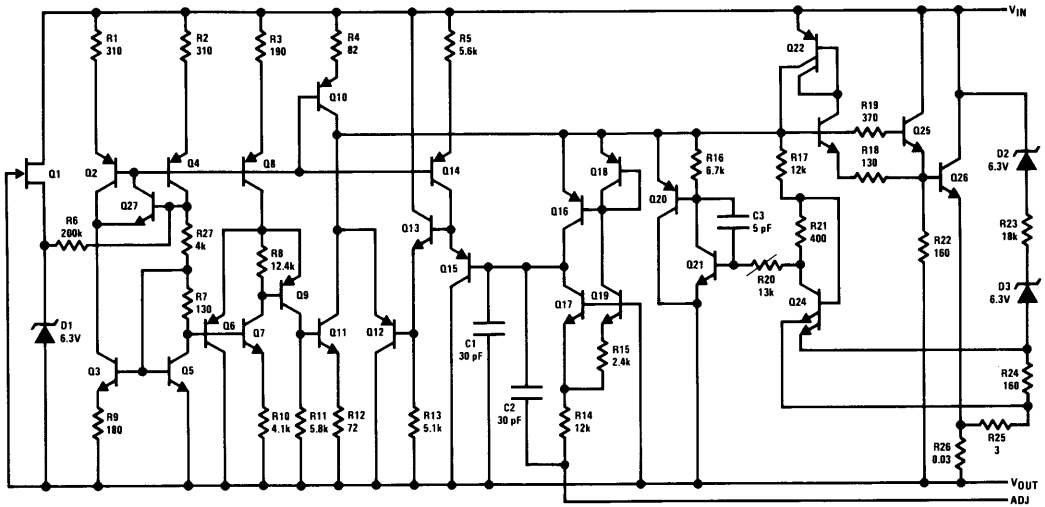


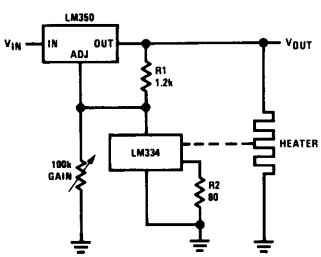

**FIGURE 3. Regulator with Protection Diodes**

## Schematic Diagram

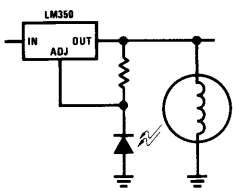



## Typical Applications (Continued)

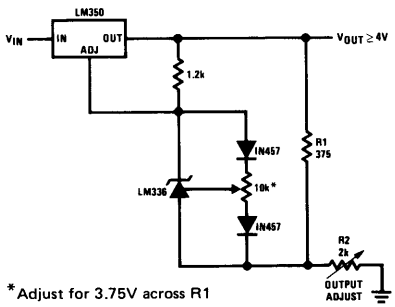
**Temperature Controller**




**Light Controller**



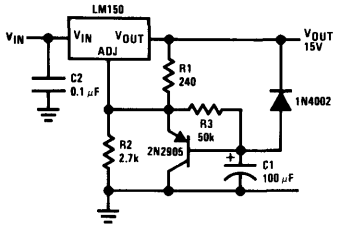

**Precision Power Regulator with Low Temperature Coefficient**



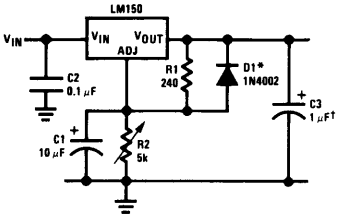

*Adjust for 3.75V across R1

## Typical Applications (Continued)

### Slow Turn-ON 15V Regulator

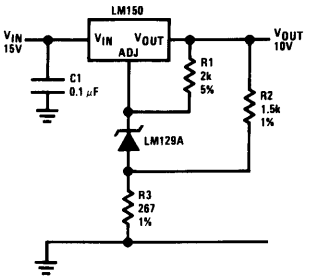



### Adjustable Regulator with Improved Ripple Rejection

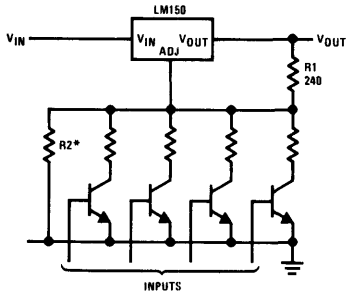



†Solid tantalum
*Discharges C1 if output is shorted to ground

### High Stability 10V Regulator

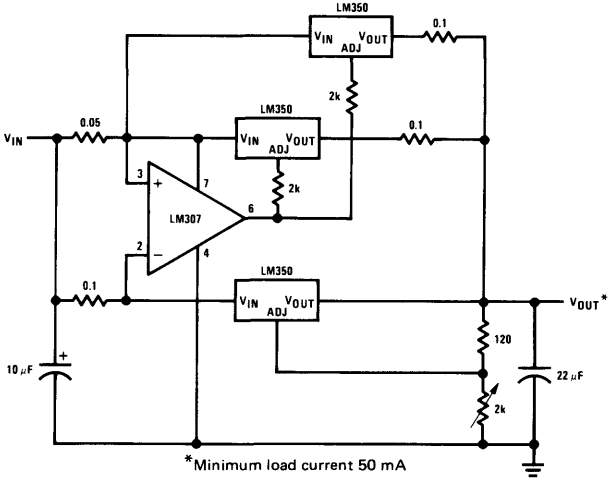



### Digitally Selected Outputs



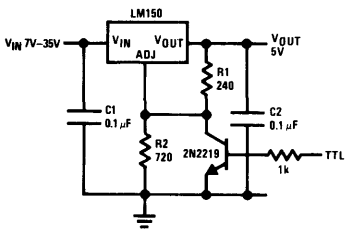

*Sets maximum $V_{OUT}$

### 10A Regulator



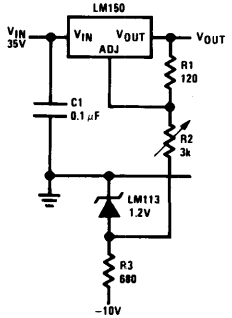

*Minimum load current 50 mA

### 5V Logic Regulator with Electronic Shutdown*

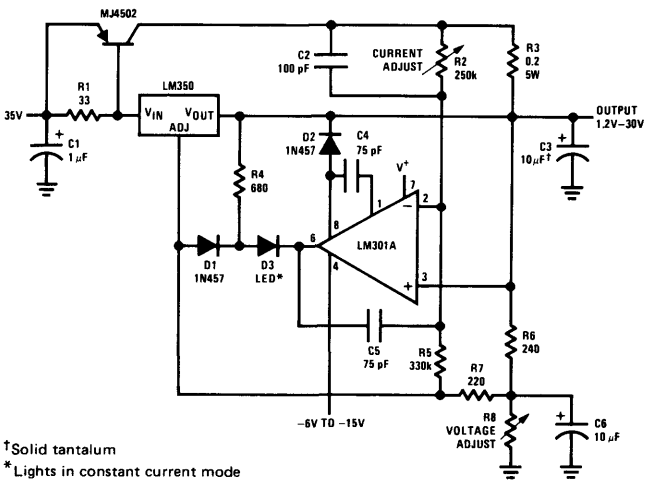



*Min output ≈ 1.2V

### 0 to 30V Regulator



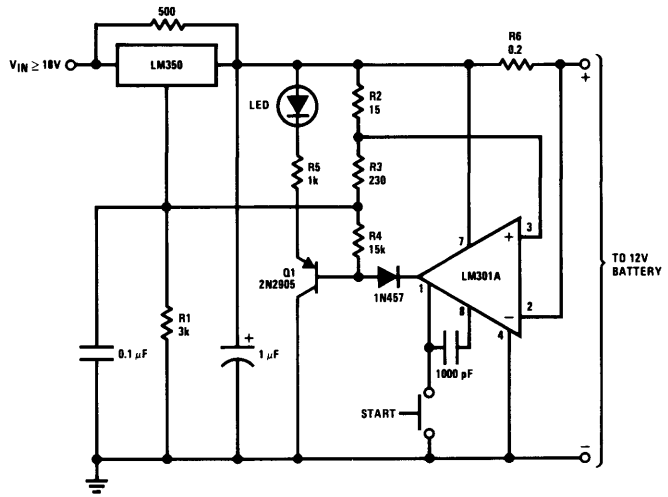

### 5A Constant Voltage/Constant Current Regulator



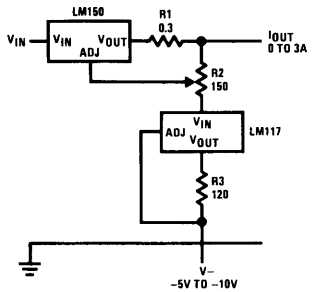

†Solid tantalum
*Lights in constant current mode

## Typical Applications (Continued)

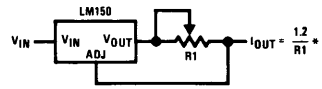
### 12V Battery Charger




### Adjustable Current Regulator

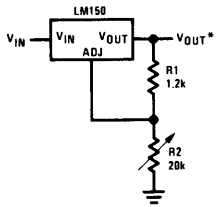



### Precision Current Limiter



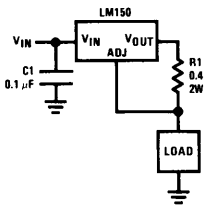

*$0.4 \leq R1 \leq 120\Omega$

### 1.2V – 20V Regulator with Minimum Program Current

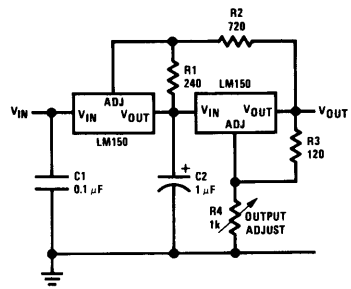



*Minimum load current ≈ 4 mA

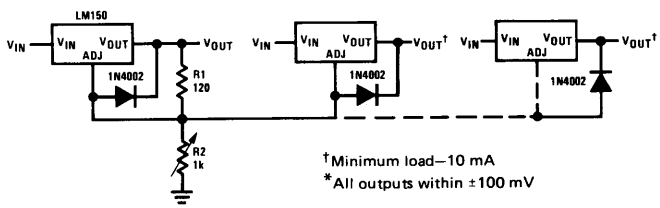
### 3A Current Regulator




### Tracking Preregulator



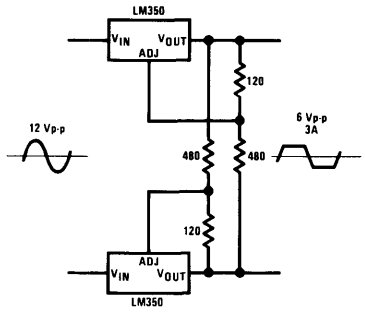

### Adjusting Multiple On-Card Regulators with Single Control*



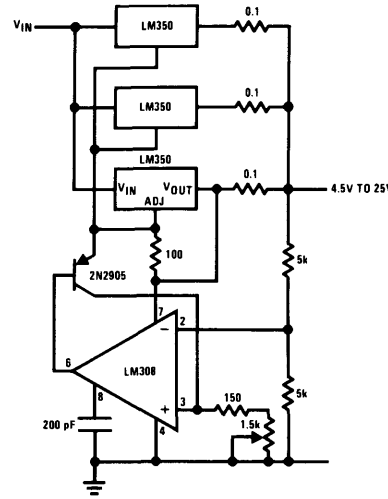

†Minimum load–10 mA
*All outputs within ±100 mV

## Typical Applications (Continued)

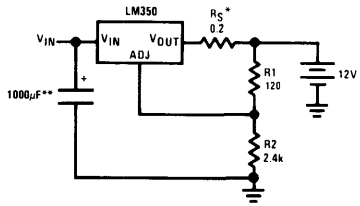
### AC Voltage Regulator




### Adjustable 10A Regulator



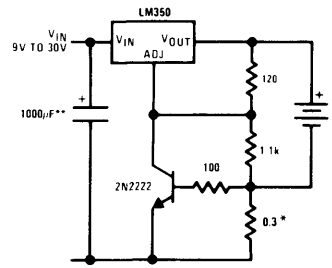

### Simple 12V Battery Charger




*$R_S$—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 1000μF is recommended to filter out input transients.

### Current Limited 6V Charger

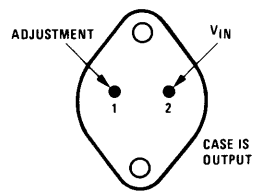



*Sets peak current (2A for 0.3Ω)

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

## Connection Diagram

**Metal Can Package**




BOTTOM VIEW

**Order Number:**
**LM150K STEEL**
**LM250K STEEL**
**LM350K STEEL**
**See NS Package K02A**

National Semiconductor

# LM199/LM299/LM399 Precision Reference

## General Description

The LM199/LM299/LM399 are precision, temperature-stabilized monolithic zeners offering temperature coefficients a factor of ten better than high quality reference zeners. Constructed on a single monolithic chip is a temperature stabilizer circuit and an active reference zener. The active circuitry reduces the dynamic impedance of the zener to about 0.5Ω and allows the zener to operate over 0.5 mA to 10 mA current range with essentially no change in voltage or temperature coefficient. Further, a new subsurface zener structure gives low noise and excellent long term stability compared to ordinary monolithic zeners. The package is supplied with a thermal shield to minimize heater power and improve temperature regulation.

The LM199 series references are exceptionally easy to use and free of the problems that are often experienced with ordinary zeners. There is virtually no hysteresis in reference voltage with temperature cycling. Also, the LM199 is free of voltage shifts due to stress on the leads. Finally, since the unit is temperature stabilized, warm up time is fast.

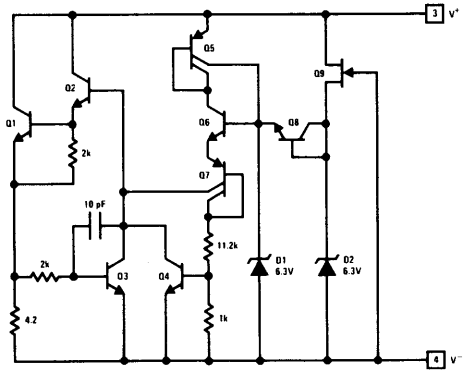
The LM199 can be used in almost any application in place of ordinary zeners with improved performance. Some ideal applications are analog to digital converters, calibration standards, precision voltage or current sources or precision power supplies. Further in many cases the LM199 can replace references in existing equipment with a minimum of wiring changes.

The LM199 series devices are packaged in a standard hermetic TO-46 package inside a thermal shield. The LM199 is rated for operation from −55°C to +125°C while the LM299 is rated for operation from −25°C to +85°C and the LM399 is rated from 0°C to +70°C.

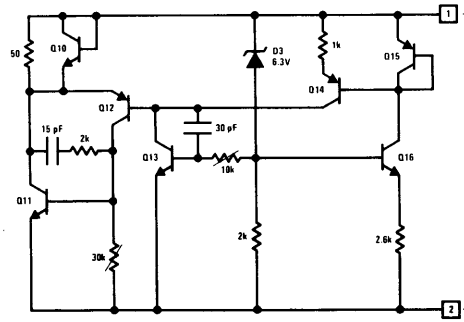
## Features

- Guaranteed 0.0001%/°C temperature coefficient
- Low dynamic impedance – 0.5Ω
- Initial tolerance on breakdown voltage – 2%
- Sharp breakdown at 400μA
- Wide operating current – 500μA to 10 mA
- Wide supply range for temperature stabilizer
- Guaranteed low noise
- Low power for stabilization – 300 mW at 25°C
- Long term stability – 20 ppm

## Schematic Diagrams



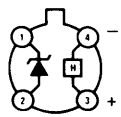

Temperature Stabilizer




Reference

## Connection Diagram

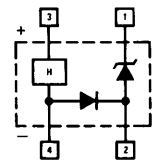
Metal Can Package




TOP VIEW

Order Number LM199H, LM299H or LM399H
See Package H04A

## Functional Block Diagram



## Absolute Maximum Ratings

| | |
|---|---|
| Temperature Stabilizer Voltage | 40V |
| Reverse Breakdown Current | 20 mA |
| Forward Current | 1 mA |
| Reference to Substrate Voltage $V_{(RS)}$ (Note 1) | 40V<br>−0.1V |
| Operating Temperature Range | |
| LM199 | −55°C to +125°C |
| LM299 | −25°C to +85°C |
| LM399 | 0°C to +70°C |
| Storage Temperature Range | −55°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (Note 2)

| PARAMETER | CONDITIONS | LM199/LM299 | | | LM399 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| Reverse Breakdown Voltage | $0.5\ mA \le I_R \le 10\ mA$ | 6.8 | 6.95 | 7.1 | 6.6 | 6.95 | 7.3 | V |
| Reverse Breakdown Voltage Change With Current | $0.5\ mA \le I \le 10\ mA$ | | 6 | 9 | | 6 | 12 | mV |
| Reverse Dynamic Impedance | $I_R = 1\ mA$ | | 0.5 | 1 | | 0.5 | 1.5 | Ω |
| Reverse Breakdown Temperature Coefficient | $-55°C \le T_A \le 85°C$ LM199 | | 0.00003 | 0.0001 | | | | %/°C |
| | $85°C \le T_A \le 125°C$ LM199 | | 0.0005 | 0.0015 | | | | %/°C |
| | $-25°C \le T_A \le 85°C$ LM299 | | 0.00003 | 0.0001 | | | | %/°C |
| | $0°C \le T_A \le 70°C$ LM399 | | | | | 0.00003 | 0.0002 | %/°C |
| RMS Noise | $10\ Hz \le f \le 10\ kHz$ | | 7 | 20 | | 7 | 50 | μV |
| Long Term Stability | Stabilized, $22°C \le T_A \le 28°C$, 1000 Hours, $I_R = 1\ mA \pm 0.1\%$ | | 20 | | | 20 | | ppm |
| Temperature Stabilizer Supply Current | $T_A = 25°C$, Still Air, $V_S = 30V$ | | 8.5 | 14 | | 8.5 | 15 | mA |
| | $T_A = -55°C$ | | 22 | 28 | | | | |
| Temperature Stabilizer Supply Voltage | (Note 3) | 9 | | 40 | 9 | | 40 | V |
| Warm-Up Time to 0.05% | $V_S = 30V$, $T_A = 25°C$ | | 3 | | | 3 | | Seconds |
| Initial Turn-on Current | $9 \le V_S \le 40$, $T_A = 25°C$, (Note 3) | | 140 | 200 | | 140 | 200 | mA |

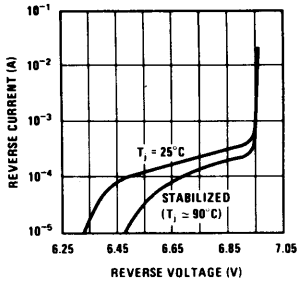
**Note 1:** The substrate is electrically connected to the negative terminal of the temperature stabilizer. The voltage that can be applied to either terminal of the reference is 40V more positive or 0.1V more negative than the substrate.

**Note 2:** These specifications apply for 30V applied to the temperature stabilizer and $-55°C \le T_A \le +125°C$ for the LM199; $-25°C \le T_A \le +85°C$ for the LM299 and $0°C \le T_A \le +70°C$ for the LM399.

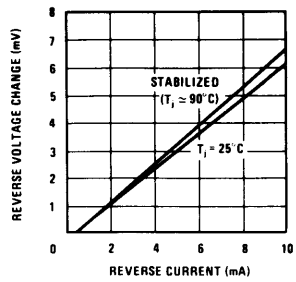
**Note 3:** This initial current can be reduced by adding an appropriate resistor and capacitor to the heater circuit. See the performance characteristic graphs to determine values.

# Typical Performance Characteristics

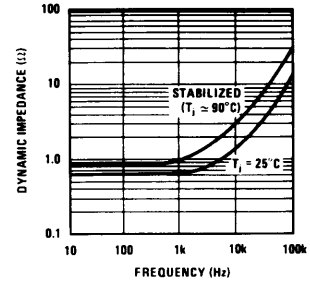
**Reverse Characteristics**



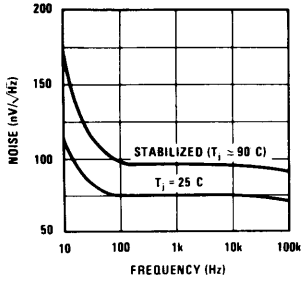

**Reverse Voltage Change**



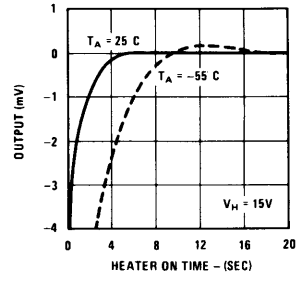

**Dynamic Impedance**



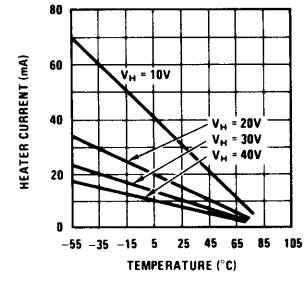

**Zener Noise Voltage**



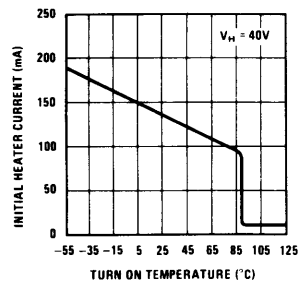

**Stabilization Time**



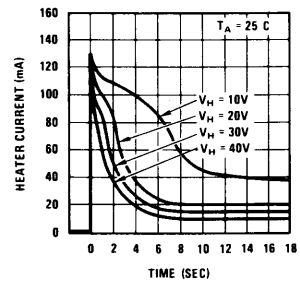

**Heater Current**



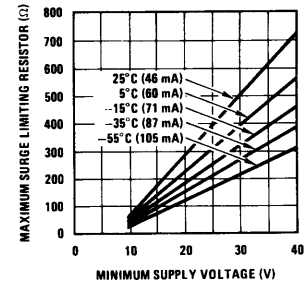

**Initial Heater Current**




**Heater Current (To Limit This Surge, See Next Graph)**

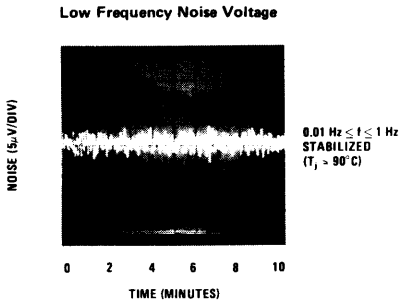



**Heater Surge Limit Resistor vs Minimum Supply Voltage at Various Minimum Temperatures**

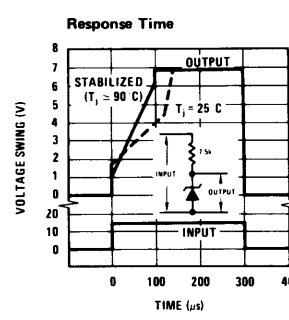



*Heater must be bypassed with a 2 μF or larger tantalum capacitor if maximum value resistors are used. Otherwise, 30% to 50% smaller values must be used. If heater oscillates, resistor value may be too small.

**Low Frequency Noise Voltage**

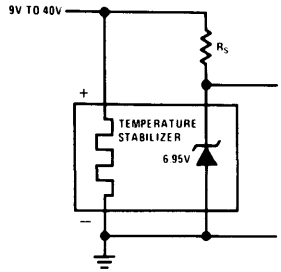



**Response Time**

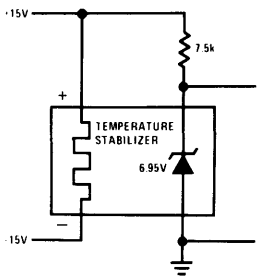


# Typical Applications

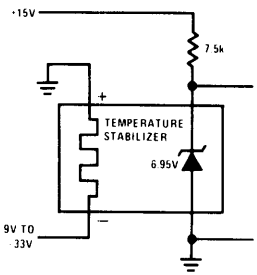
Single Supply Operation



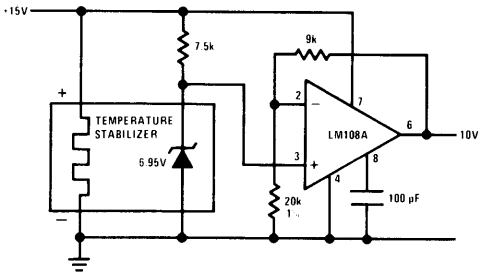

Split Supply Operation



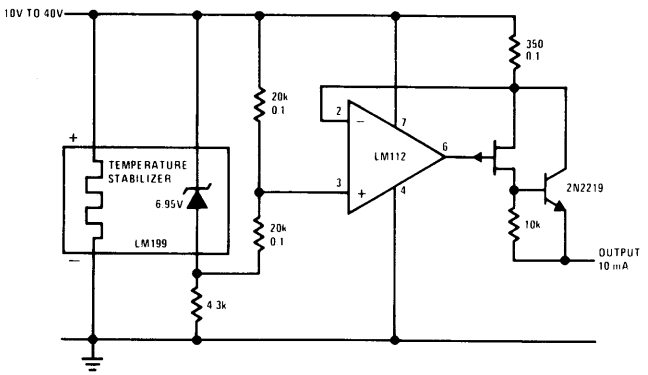

Negative Heater Supply with Positive Reference



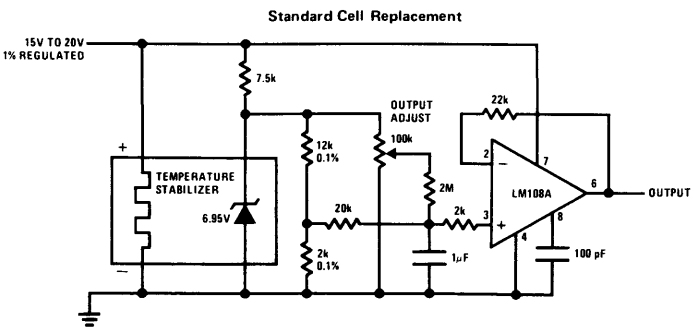

Buffered Reference With Single Supply




Positive Current Source

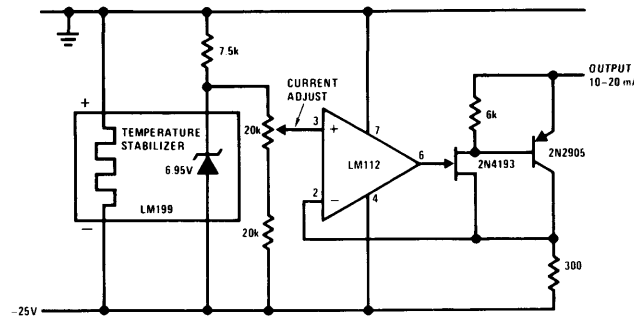



Standard Cell Replacement

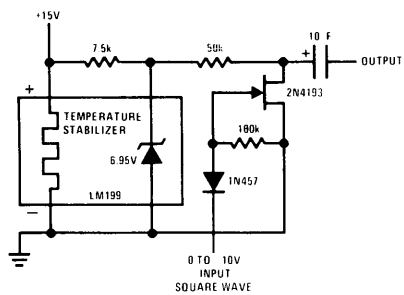


## Typical Applications (cont'd.)

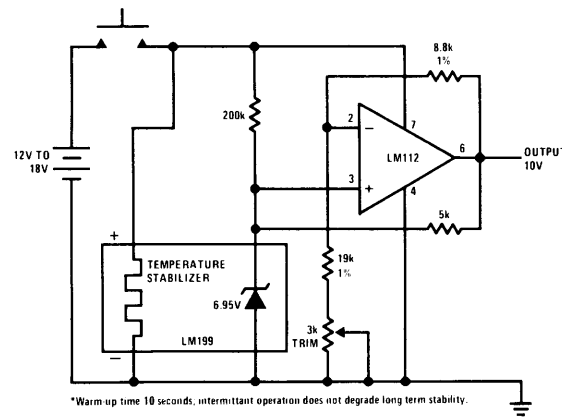
### Negative Current Source




### Square Wave Voltage Reference

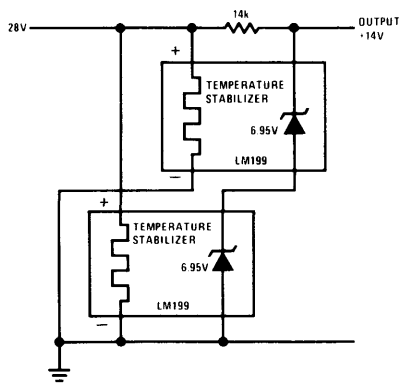



### Portable Calibrator*

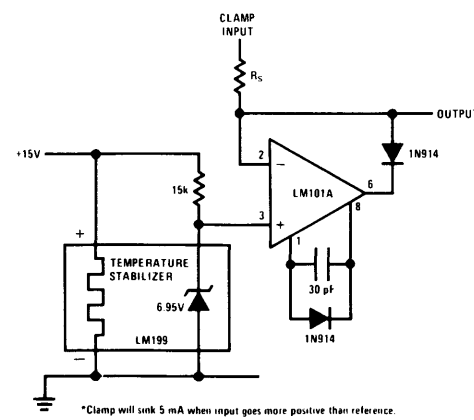



*Warm-up time 10 seconds, intermittant operation does not degrade long term stability.

### 14V Reference



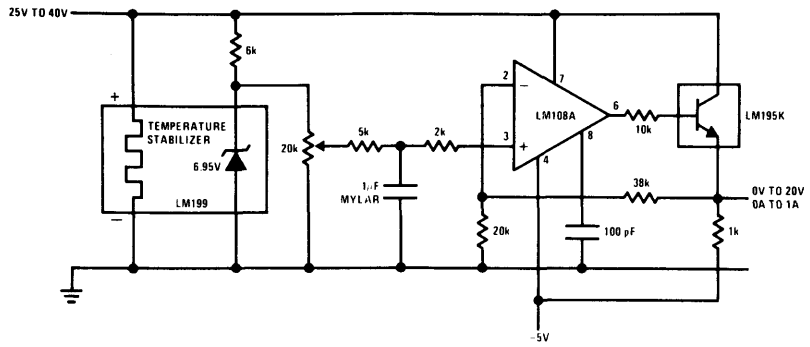

### Precision Clamp*



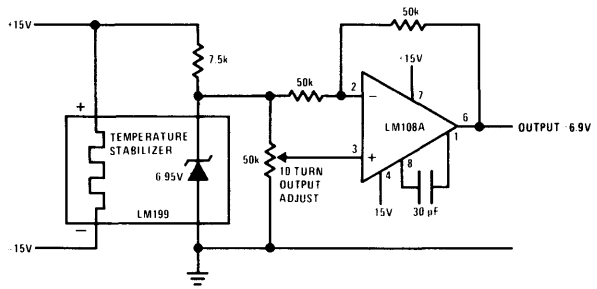

*Clamp will sink 5 mA when input goes more positive than reference.

## Typical Applications (cont'd.)

0V to 20V Power Reference




Bipolar Output Reference



National Semiconductor

# LM320L/LM320ML Series 3-Terminal Negative Regulators

## General Description

The LM320L/LM320ML series of 3-terminal negative voltage regulators features fixed output voltages of -5V, -12V, and -15V, with output current capabilities in excess of 100 mA, for the LM320L series, and 250 mA for the LM320ML series. These devices were designed using the latest computer techniques for optimizing the packaged IC thermal/electrical performance. The LM320L/LM320ML series, even when combined with a minimum output compensation capacitor of 0.1 $\mu$F, exhibits an excellent transient response, a maximum line regulation of 0.07% $V_O$/V, and a maximum load regulation of 0.01% $V_O$/mA.

The LM320L/LM320ML series also includes, as self-protection circuitry: safe operating area circuitry for output transistor power dissipation limiting, a temperature independent short circuit current limit for peak output current limiting, and a thermal shutdown circuit to prevent excessive junction temperature. Although designed primarily as fixed voltage regulators, these devices may be combined with simple external circuitry for boosted and/or adjustable voltages and currents. The LM320L series is available in the 3-lead TO-92 package,

and the LM320ML series is available in the 3-lead TO-202 package.

For output voltages other than -5V, -12V and -15V, the LM137 series provides an output voltage range from -1.2V to -47V.

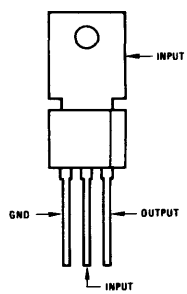
## Features

- Preset output voltage error is less than ±5% over load, line and temperature
- LM320L is specified at an output current of 100 mA
- LM320ML is specified at an output current of 250 mA
- Internal short-circuit, thermal and safe operating area protection
- Easily adjustable to higher output voltages
- Maximum line regulation less than 0.07% $V_{OUT}$/V
- Maximum load regulation less than 0.01% $V_{OUT}$/mA
- Easily compensated with a small 0.1 $\mu$F output capacitor

| DEVICE | PACKAGE | RATED POWER DISSIPATION | DESIGN OUTPUT CURRENT |
|---|---|---|---|
| LM320ML | TO-202 | 7.5W | 0.25A |
| LM320L | TO-92 | 0.6W | 0.1A |

## Connection Diagrams

**TO-202 Power Package (P)**




FRONT VIEW

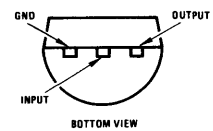
**Order Numbers:**

**LM320MLP-5.0**
**LM320MLP-12**
**LM320MLP-15**

**See Package PO3A**

**For Tab Bend TO-202**
**Order Numbers:**
**LM320MLP-5.0 TB**
**LM320MLP-12 TB**
**LM320MLP-15 TB**
**See Package PO3E**

**TO-92 Plastic Package (Z)**




BOTTOM VIEW

**Order Numbers:**

**LM320LZ-5.0**
**LM320LZ-12**
**LM320LZ-15**

**See Package ZO3A**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| $V_{OUT}$ = −5V 12V and 15V | −35V |
| Internal Power Dissipation | |
| (Notes 1 and 3) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | +125°C |
| Storage Temperature Range | |
| Molded TO-92 | −55°C to +150°C |
| Molded TO-202 | −65°C to +150°C |
| Lead | Temperature |
| (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics LM320ML

(Note 2) $T_A$ = 0°C to +70°C unless otherwise noted.

| OUTPUT VOLTAGE | | | −5V | | | −12V | | | −15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | −10V | | | −17V | | | −20V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j$ = 25°C, $I_O$ = 250 mA | −5.2 | −5 | −4.8 | −12.5 | −12 | −11.5 | −15.6 | −15 | −14.4 | |
| | | 1 mA ≤ $I_O$ ≤ 250 mA ($V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$) | −5.25 (−20 ≤ $V_{IN}$ ≤ −7.5) | | −4.75 | −12.6 (−27 ≤ $V_{IN}$ ≤ −14.8) | | −11.4 | −15.75 (−30 ≤ $V_{IN}$ ≤ −18) | | −14.25 | V |
| $\Delta V_O$ | Line Regulation | $T_j$ = 25°C, $I_O$ = 250 mA | | | 50 | | | 40 | | | 40 | mV |
| | | ($V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$) | (−25 ≤ $V_{IN}$ ≤ −7.3) | | | (−30 ≤ $V_{IN}$ ≤ −14.6) | | | (−30 ≤ $V_{IN}$ ≤ 17.7) | | | V |
| $\Delta V_O$ | Load Regulation | $T_j$ = 25°C, 1 mA ≤ $I_O$ ≤ 250 mA | | | 50 | | | 120 | | | 150 | mV |
| $\Delta V_O$ | Long Term Stability | $I_O$ = 250 mA | | 20 | | | 48 | | | 60 | | mV/khr |
| $I_Q$ | Quiescent Current | $I_O$ = 250 mA | | 2 | 6 | | 2 | 6 | | 2 | 6 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 1 mA ≤ $I_O$ ≤ 250 mA | | | 0.3 | | 0.3 | | 0.3 | | | mA |
| | | $I_O$ = 250 mA ($V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$) | | | 0.25 (−20 ≤ $V_{IN}$ ≤ −7.5) | | | 0.25 (−27 ≤ $V_{IN}$ ≤ −14.8) | | | 0.25 (−30 ≤ $V_{IN}$ ≤ −18) | V |
| $V_n$ | Output Noise Voltage | $T_j$ = 25°C, $I_O$ = 250 mA f = 10 Hz-10 kHz | | 40 | | | 100 | | | 120 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_O}$ | Ripple Rejection | $T_j$ = 25°C, $I_O$ = 250 mA f = 120 Hz | 54 | | | 56 | | | 54 | | | dB |
| | Input Voltage Required to Maintain Line Regulation | $T_j$ = 25°C, $I_O$ = 250 mA | | | −7.3 | | | −14.6 | | | −17.7 | V |

**Note 1:** Thermal resistance of the TO-202 Package (P) without a heat sink is 12°C/W junction to case and 70°C/W case to ambient.

**Note 2:** To ensure constant junction temperature, low duty cycle pulse testing is used.

**Note 3:** Thermal resistance, junction to ambient, of the TO-92 (Z) Package is 180°C/W when mounted with 0.40 inch leads on a PC board, and 160°C/W when mounted with 0.25 inch leads on a PC board.

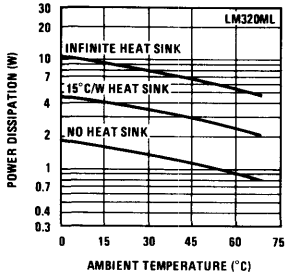
## Electrical Characteristics LM320L (Note 4) $T_A = 0°C$ to $+70°C$ unless otherwise noted.

| OUTPUT VOLTAGE | | | −5V | | | −12V | | | −15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | −10V | | | −17V | | | −20V | | | |
| PARAMETER | | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j = 25°C$, $I_O = 100$ mA | −5.2 | −5 | −4.8 | −12.5 | −12 | −11.5 | −15.6 | −15 | −14.4 | |
| | | 1mA ≤ $I_O$ ≤ 100 mA<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | −5.25<br>(−20 ≤ $V_{IN}$ ≤ −7.5) | | −4.75 | −12.6<br>(−27 ≤ $V_{IN}$ ≤ −14.8) | | −11.4 | −15.75<br>(−30 ≤ $V_{IN}$ ≤ −18) | | −14.25 | V |
| | | 1 mA ≤ $I_O$ ≤ 40 mA<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | −5.25<br>(−20 ≤ $V_{IN}$ ≤ −7) | | −4.75 | −12.6<br>(−27 ≤ −14.5) | | −11.4 | −15.75<br>(−30 ≤ $V_{IN}$ ≤ −17.5) | | −14.25 | |
| $\Delta V_O$ | Line Regulation | $T_j = 25°C$, $I_O = 100$ mA<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | | 60<br>(−20 ≤ $V_{IN}$ ≤ −7.3) | | | 45<br>(−27 ≤ $V_{IN}$ ≤ −14.6) | | | 45<br>(−30 ≤ $V_{IN}$ ≤ −17.7) | mV<br>V |
| | | $T_j = 25°C$, $I_O = 40$ mA<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | | 60<br>(−20 ≤ $V_{IN}$ ≤ −7) | | | 45<br>(−27 ≤ $V_{IN}$ ≤ −14.5) | | | 45<br>(−30 ≤ $V_{IN}$ ≤ −17.5) | mV<br>V |
| $\Delta V_O$ | Load Regulation | $T_j = 25°C$<br>1 mA ≤ $I_O$ ≤ 100 mA | | | 50 | | | 100 | | | 125 | mV |
| $\Delta V_O$ | Long Term Stability | $I_O = 100$ mA | | 20 | | | 48 | | | 60 | | mV/khr |
| $I_Q$ | Quiescent Current | $I_O = 100$ mA | | 2 | 6 | | 2 | 6 | | 2 | 6 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 1 mA ≤ $I_O$ ≤ 100 mA | | | 0.3 | | | 0.3 | | | 0.3 | mA |
| | | 1 mA ≤ $I_O$ ≤ 40 mA | | | 0.1 | | | 0.1 | | | 0.1 | |
| | | $I_O = 100$ mA<br>$V_{MIN} \le V_{IN} \le V_{MAX}$ | | | 0.25<br>(−20 ≤ $V_{IN}$ ≤ −7.5) | | | 0.25<br>(−27 ≤ $V_{IN}$ ≤ −14.8) | | | 0.25<br>(−30 ≤ $V_{IN}$ ≤ −18) | mA<br>V |
| $V_n$ | Output Noise Voltage | $T_j = 25°$, $I_O = 100$ mA<br>f = 10 Hz-10 kHz | | 40 | | | 96 | | | 120 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_O}$ | Ripple Rejection | $T_j = 25°C$, $I_O = 100$ mA<br>f = 120 Hz | 50 | | | 52 | | | 50 | | | dB |
| | Input Voltage Required to Maintain Line Regulation | $T_j = 25°$<br>$I_O = 100$ mA<br>$I_O = 40$ mA | | | −7.3<br>−7.0 | | | −14.6<br>−14.5 | | | −17.7<br>−17.5 | V |

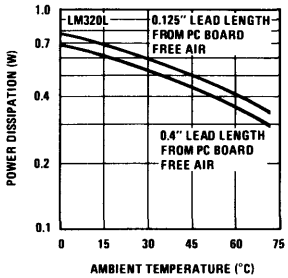
**Note 4:** To ensure constant junction temperature, low duty cycle pulse testing is used.

## Typical Performance Characteristics

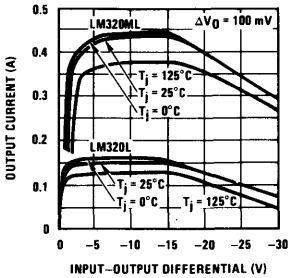
### Maximum Average Power Dissipation (TO-202)



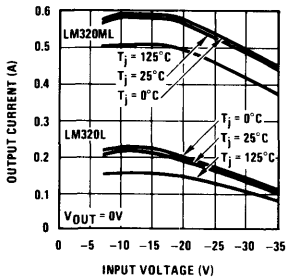

### Maximum Average Power Dissipation (TO-92)



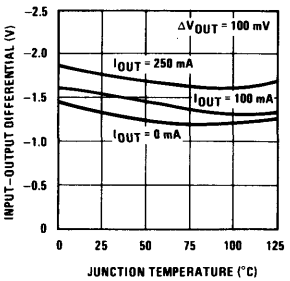

### Peak Output Current



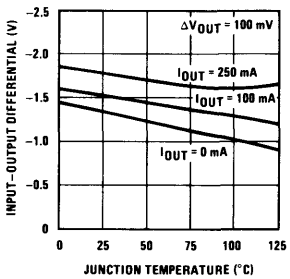

### Short-Circuit Output Current



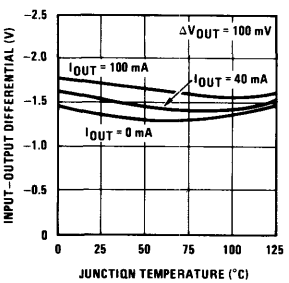

### Dropout Voltage, LM320ML, –5V



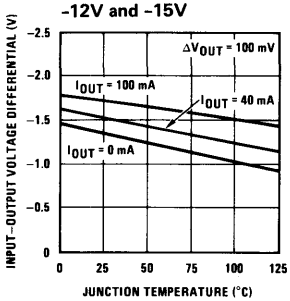

### Dropout Voltage, LM320ML, –12V and –15V



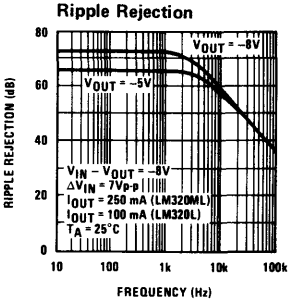

### Dropout Voltage, LM320L –5V



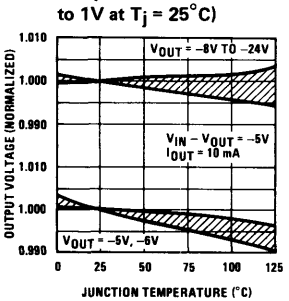

### Dropout Voltage, LM320L -12V and -15V



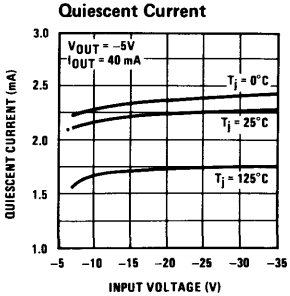

### Ripple Rejection



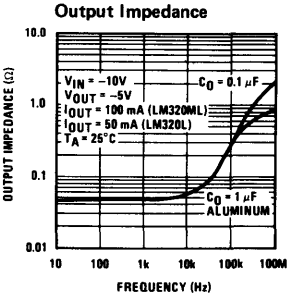

### Output Voltage vs. Temperature (Normalized to 1V at $T_j = 25°C$)




### Quiescent Current

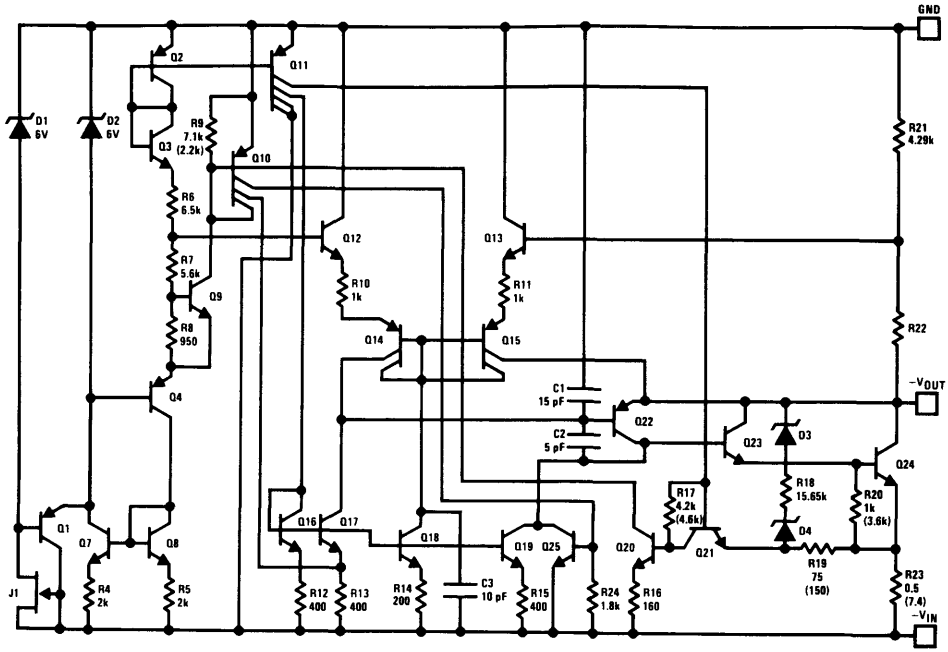



### Output Impedance

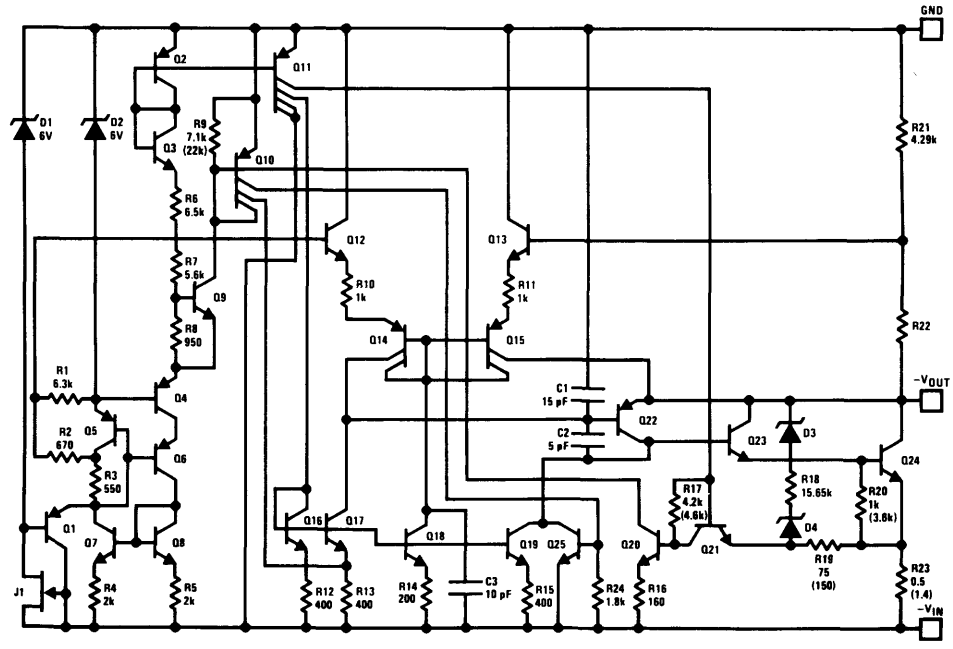


## Schematic Diagrams

-5V

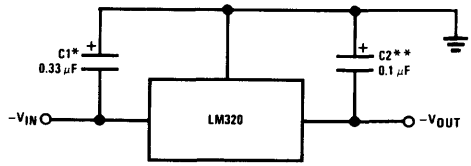



-12V and -15V



# Typical Applications

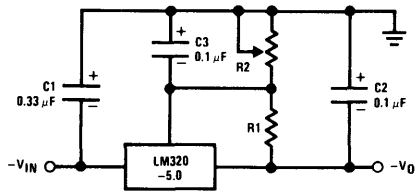
### Fixed Output Regulator




*Required if the regulator is located far from the power supply filter. A 1 μF aluminum electrolytic may be substituted.

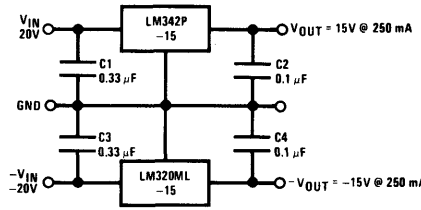
**Required for stability. A 1 μF aluminum electrolytic may be substituted.

### Adjustable Output Regulator




$-V_O = -5V - (5V/R1 + I_Q) \cdot R2$,
$5V/R1 > 3\ I_Q$

### ±15V, 250 mA Dual Power Supply



National Semiconductor

# LM341 Series 3-Terminal Positive Regulators

## General Description

The LM341-XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM341-XX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.5A if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

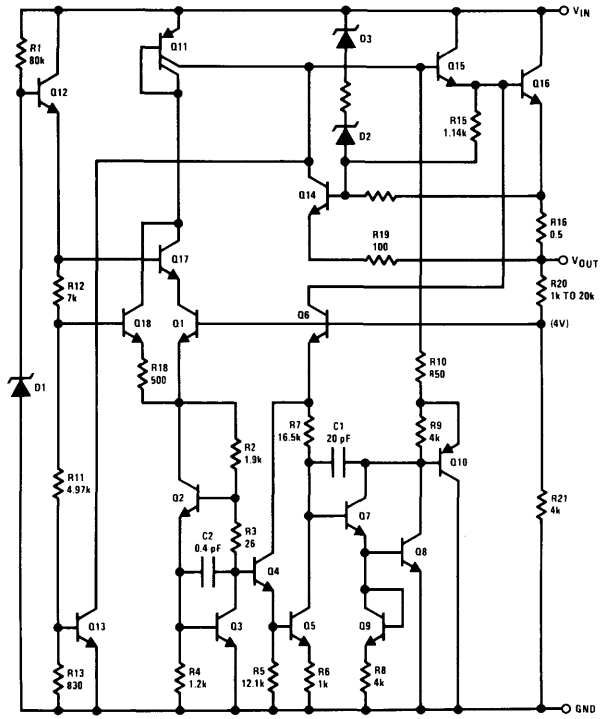
Considerable effort was expended to make the LM341-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

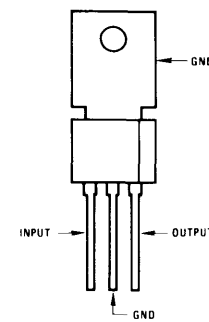
For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

- Output current in excess of 0.5A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package
- Special circuitry allows start-up even if output is pulled to negative voltage (± supplies)

## Schematic and Connection Diagrams




Plastic Package

FRONT VIEW

**Order Numbers**
**LM341P-5.0**
**LM341P-12**
**LM341P-15**
**See Package P03A**

**For Tab Bend TO-202**
**LM341P-5.0 TB**
**LM341P-12 TB**
**LM341P-15 TB**
**See Package PO3E**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage ($V_O$ = 5V, 12V, 15V) | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | +230°C |

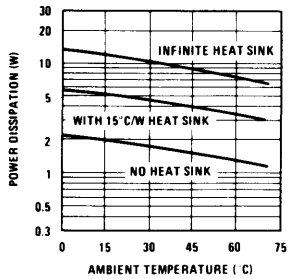
## Electrical Characteristics $T_A$ = 0°C to 70°C, $I_O$ = 500 mA, unless otherwise noted.

| OUTPUT VOLTAGE | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| PARAMETER | | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j$ = 25°C | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D \leq$ 7.5W, 5mA $\leq I_O \leq$ 500 mA and $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | 4.75 (7.5 $\leq V_{IN} \leq$ 20) | | 5.25 | 11.4 (14.8 $\leq V_{IN} \leq$ 27) | | 12.6 | 14.25 (18 $\leq V_{IN} \leq$ 30) | | 15.75 | V<br>V |
| $\Delta V_O$ | Line Regulation | $T_j$ = 25°C, $I_O$ = 100 mA<br>$T_j$ = 25°C, $I_O$ = 500 mA | (7.2 $\leq V_{IN} \leq$ 25) | | 50<br>100 | (14.5 $\leq V_{IN} \leq$ 30) | | 120<br>240 | (17.6 $\leq V_{IN} \leq$ 30) | | 150<br>300 | mV<br>mV<br>V |
| $\Delta V_O$ | Load Regulation | $T_j$ = 25°C, 5 mA $\leq I_O \leq$ 500 mA | | | 100 | | | 240 | | | 300 | mV |
| $\Delta V_O$ | Long Term Stability | | | | 20 | | | 48 | | | 60 | mV/khrs |
| $I_Q$ | Quiescent Current | $T_j$ = 25°C | | 4 | 10 | | 4 | 10 | | 4 | 10 | mA |
| $\Delta I_Q$ | Quiescent Current Change | $T_j$ = 25°C<br>5 mA $\leq I_O \leq$ 500 mA | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | $T_j$ = 25°C<br>$V_{MIN} \leq V_{IN} \leq V_{MAX}$ | (7.5 $\leq V_{IN} \leq$ 25) | | 1 | (14.8 $\leq V_{IN} \leq$ 30) | | 1 | (18 $\leq V_{IN} \leq$ 30) | | 1 | mA<br>V |
| $V_n$ | Output Noise Voltage | $T_j$ = 25°C, f = 10 Hz – 100kHz | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | | 78 | | | 71 | | | 69 | | dB |
| | Input Voltage Required to Maintain Line Regulation | $T_j$ = 25°C, $I_O$ = 500 mA | 7.2 | | | 14.5 | | | 17.6 | | | V |

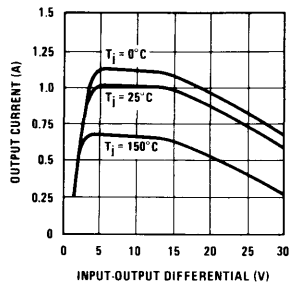
**Note 1:** Thermal resistance without a heat sink for junction to case temperature is 12°C/W for the TO-202 package. Thermal resistance for case to ambient temperature is 70°C/W for the TO-202 package.

# Typical Performance Characteristics

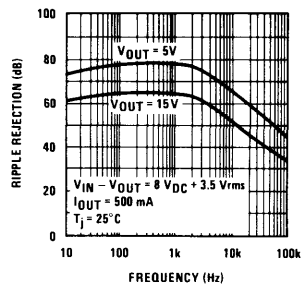
Maximum Average Power Dissipation



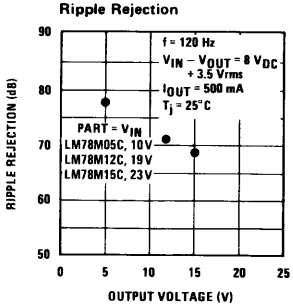

Peak Output Current



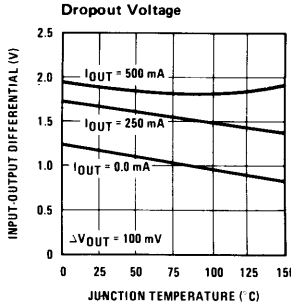

Ripple Rejection



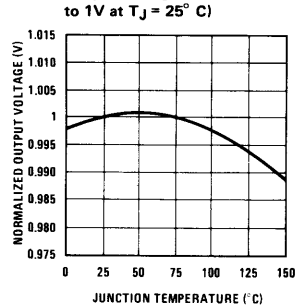

Ripple Rejection



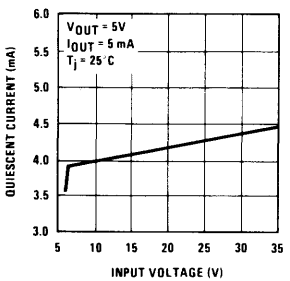

Dropout Voltage



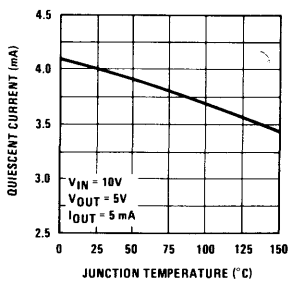

Output Voltage (Normalized to 1V at $T_J$ = 25° C)



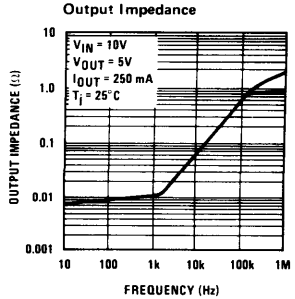

Quiescent Current




Quiescent Current




Output Impedance



National Semiconductor

# Voltage Regulators

## LM342 Series 3-Terminal Positive Regulators

### General Description

The LM342-XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM342-XX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.25A if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM342-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

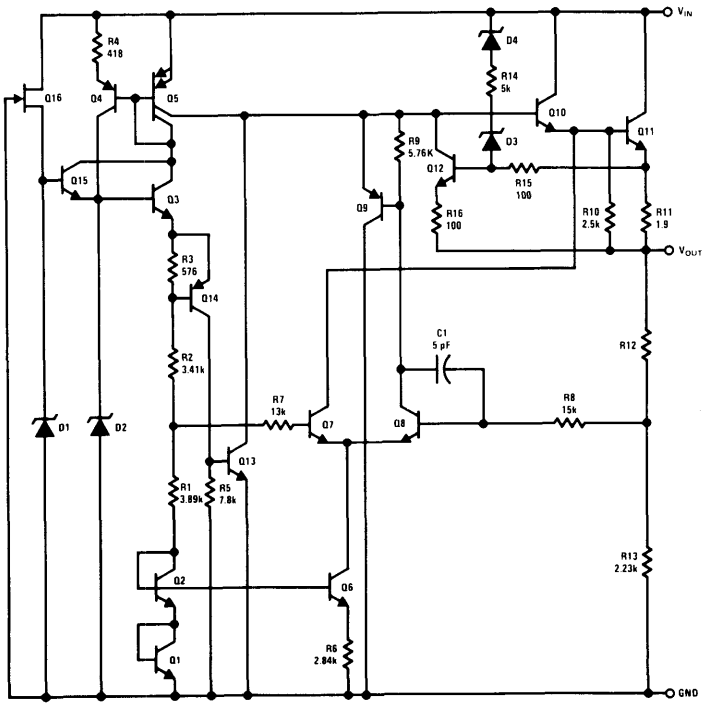
### Features

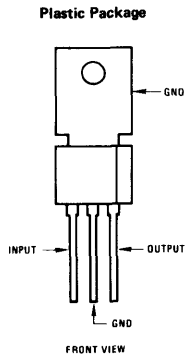
- Output current in excess of 0.25A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package
- Special circuitry allows start-up even if output is pulled to negative voltage (± supplies)

### Voltage Range

| | |
|---|---|
| LM342-5.0 | 5V |
| LM342-12 | 12V |
| LM342-15 | 15V |

### Schematic and Connection Diagrams




Plastic Package

FRONT VIEW

**Order Numbers:**

**LM342P-5.0**
**LM342P-12**
**LM342P-15**

**See Package PO3A**

**For Tab Bend TO-202**
**Order Numbers:**
**LM342P-5.0 TB**
**LM342P-12 TB**
**LM342P-15 TB**
**See Package PO3E**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| $V_O$ = 5V | 30V |
| $V_O$ = 12V and 15V | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | 125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 Seconds) | 300°C |

## Electrical Characteristics $T_A$ = 0°C to +70°C, $I_O$ = 250 mA (Note 2) unless noted.

| OUTPUT VOLTAGE | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage (Note 3) | Tj = 25°C | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | 1 mA ≤ $I_O$ ≤ 250 mA and $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | 4.75 (7.5 ≤ $V_{IN}$ ≤ 20) | | 5.25 | 11.4 (14.8 ≤ $V_{IN}$ ≤ 27) | | 12.6 | 14.25 (18 ≤ $V_{IN}$ ≤ 30) | | 15.75 | V<br>V |
| $\Delta V_O$ | Line Regulation | Tj = 25°C, $I_O$ = 250 mA | | | 55 (7.3 ≤ $V_{IN}$ ≤ 25) | | | 100 (14.6 ≤ $V_{IN}$ ≤ 30) | | | 100 (17.7 ≤ $V_{IN}$ ≤ 30) | mV<br>V |
| $\Delta V_O$ | Load Regulation | Tj = 25°C, 1 mA ≤ $I_O$ ≤ 250 mA | | | 50 | | | 120 | | | 150 | mV |
| $\Delta V_O$ | Long Term Stability | | | 20 | | | 48 | | | 60 | | mV/khrs |
| $I_Q$ | Quiescent Current | Tj = 25°C | | | 6 | | | 6 | | | 6 | mA |
| $\Delta I_Q$ | Quiescent Current Change | Tj = 25°C, 1 mA ≤ $I_O$ ≤ 250 mA | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | Tj = 25°C, $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | | | 1.5 (7.3 ≤ $V_{IN}$ ≤ 25) | | | 1.5 (14.6 ≤ $V_{IN}$ ≤ 30) | | | 1.5 (17.7 ≤ $V_{IN}$ ≤ 30) | mA<br>V |
| $V_n$ | Output Noise Voltage | Tj = 25°C, f = 10 Hz - 10 kHz | | 40 | | | 96 | | | 120 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | 50 | 64 | | 44 | 58 | | 42 | 56 | | dB |
| | Input Voltage Required to Maintain Line Regulation | Tj = 25°C, $I_O$ = 250 mA | 7.3 | | | 14.6 | | | 17.7 | | | V |

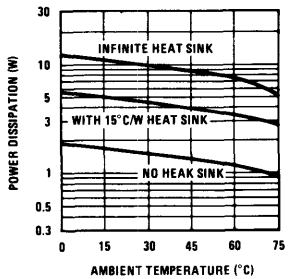
**Note 1:** Thermal resistance of the TO-202 package (P) without a heat sink is 12° C/W junction to case and 80°C/W juntion to ambient.

**Note 2:** The electrical characteristics data represent pulse test conditions with junction temperatures as shown at the initiation of tests.

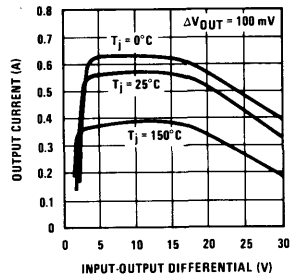
**Note 3:** The temperature coefficient of $V_{OUT}$ is typically within 0.01% $V_O$/°C.

# Typical Performance Characteristics

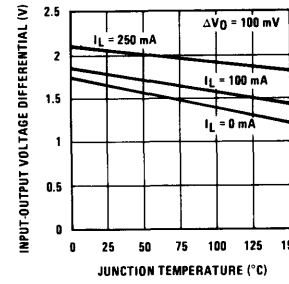
**Maximum Average Power Dissipation (TO-202 Package)**



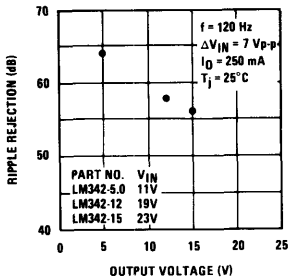

**Peak Output Current**



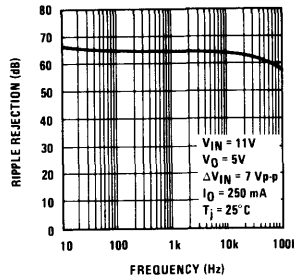

**Dropout Voltage**



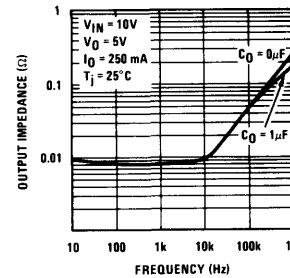

**Ripple Rejection**



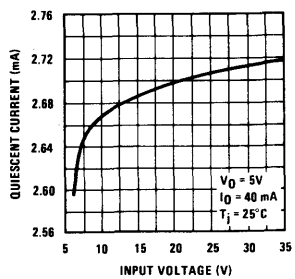

**Ripple Rejection**



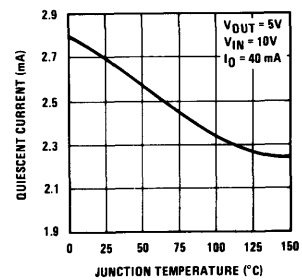

**Output Impedance**




**Quiescent Current**

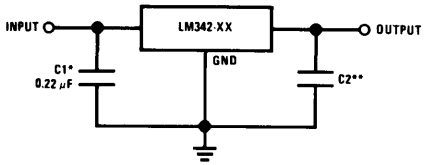



**Quiescent Current**



# Typical Applications

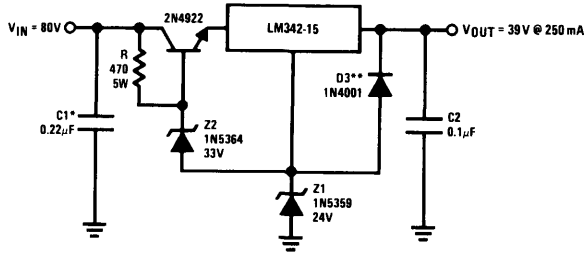
### Fixed Output Regulator




*Required if the regulator is located far from power supply filter

**Although not required, C2 does improve transient response. (If needed, use 0.1μF ceramic disc.)

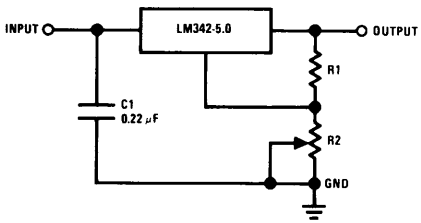
### High Output Voltage Regulator




*Necessary if regulator is located far from the power supply filter

**D3 aids in full load start-up and protects the regulator during short circuits from high input to output voltage differentials

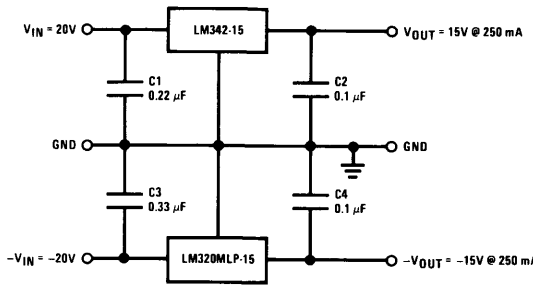
### Adjustable Output Regulator



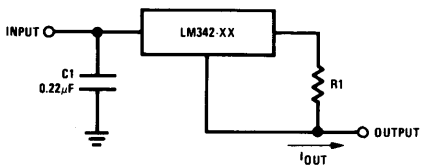

$V_o = 5V + (5V/R1 + I_Q)\ R2$

$5V/R1 > 3I_Q$, Load Regulation ($L_R$) = $[(R1 + R2)/R1] \cdot (L_r$ of LM342-05)

### ±15V, 250 mA Dual Power Supply



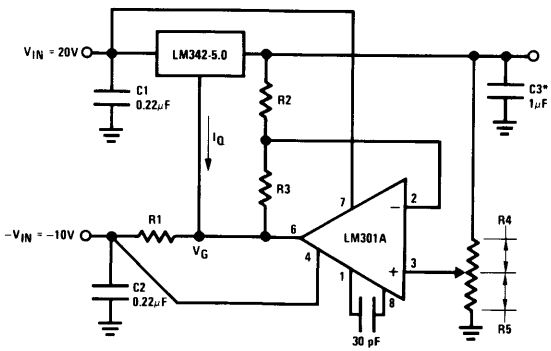

### Current Regulator




$I_{OUT} = V^{2-3}/R1 + I_Q$

$\Delta I_Q \leq 1.5$ mA over line and load changes

### Variable Output Regulator 0.5V – 18V




$V_{OUT} = V_G + 5V$, R1 = $(-V_{IN}/I_Q$ LM342)

$V_{OUT} = 5V(R2/R4)$ for (R2 + R3) = (R4 + R5)

A 0.5V output will correspond to (R2/R4) = 0.1, (R3/R4) = 0.9

*Solid tantalum

National Semiconductor

# LM78XX Series Voltage Regulators

## General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

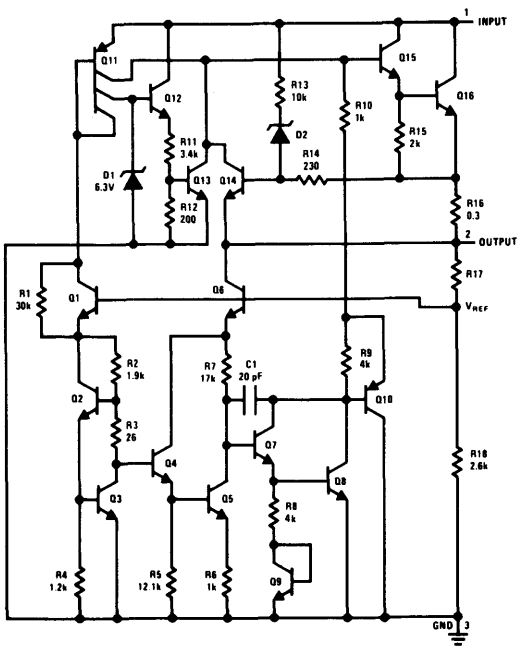
## Features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

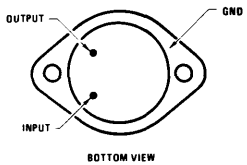
## Voltage Range

| | |
|---|---|
| LM7805C | 5V |
| LM7812C | 12V |
| LM7815C | 15V |

## Schematic and Connection Diagrams

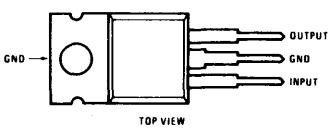



**Metal Can Package**
**TO-3 (K)**
**Aluminum**




**Order Numbers**
**LM7805CK**
**LM7812CK**
**LM7815CK**
**See Package KC02A**

**Plastic Package**
**TO-220 (T)**




**Order Numbers:**
**LM7805CT**
**LM7812CT**
**LM7815CT**
**See Package T03B**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage ($V_O$ = 5V, 12V and 15V) | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range ($T_A$) | 0°C to +70°C |
| Maximum Junction Temperature | |
| (K Package) | 150°C |
| (T Package) | 125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | |
| TO-3 Package K | 300°C |
| TO-220 Package T | 230°C |

## Electrical Characteristics LM78XXC (Note 2) 0°C ≤ Tj ≤ 125°C unless otherwise noted.

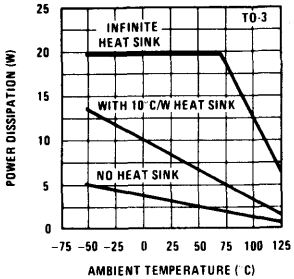
| OUTPUT VOLTAGE | | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | | 10V | | | 19V | | | 23V | | | |
| PARAMETER | | CONDITIONS | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | Tj = 25°C, 5 mA ≤ $I_O$ ≤ 1A | | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D$ ≤ 15W, 5 mA ≤ $I_O$ ≤ 1A<br>$V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | 4.75<br>(7 ≤ $V_{IN}$ ≤ 20) | | 5.25 | 11.4<br>(14.5 ≤ $V_{IN}$ ≤ 27) | | 12.6 | 14.25<br>(17.5 ≤ $V_{IN}$ ≤ 30) | | 15.75 | V<br>V |
| $\Delta V_O$ | Line Regulation | $I_O$ = 500 mA | Tj = 25°C<br>$\Delta V_{IN}$ | | 3 | 50 | | 4 | 120 | | 4 | 150 | mV<br>V |
| | | | (7 ≤ $V_{IN}$ ≤ 25)<br>0°C ≤ Tj ≤ +125°C<br>$\Delta V_{IN}$ | | | 50 | | | 120 | | | 150 | mV<br>V |
| | | | (8 ≤ $V_{IN}$ ≤ 20) | | | | (15 ≤ $V_{IN}$ ≤ 27) | | | (18.5 ≤ $V_{IN}$ ≤ 30) | | | |
| | | $I_O$ ≤ 1A | Tj = 25°C<br>$\Delta V_{IN}$ | | | 50 | | | 120 | | | 150 | mV<br>V |
| | | | (7.3 ≤ $V_{IN}$ ≤ 20)<br>0° ≤ Tj ≤ +125°C<br>$\Delta V_{IN}$ | | | 25 | | | 60 | | | 75 | mV<br>V |
| | | | (8 ≤ IN ≤ 12) | | | | (16 ≤ $V_{IN}$ ≤ 22) | | | (20 ≤ $V_{IN}$ ≤ 26) | | | |
| $\Delta V_O$ | Load Regulation | Tj = 25°C | 5 mA ≤ $I_O$ ≤ 1.5A<br>250 mA ≤ $I_O$ ≤ 750 mA | | 10 | 50<br>25 | | 12 | 120<br>60 | | 12 | 150<br>75 | mV<br>mV |
| | | 5 mA ≤ $I_O$ ≤ 1A, 0°C ≤ Tj ≤ +125°C | | | | 50 | | | 120 | | | 150 | mV |
| $I_Q$ | Quiescent Current | $I_O$ ≤ 1A | Tj = 25°C<br>0°C ≤ Tj ≤ +125°C | | | 8<br>8.5 | | | 8<br>8.5 | | | 8<br>8.5 | mA<br>mA |
| $\Delta I_Q$ | Quiescent Current Change | 5 mA ≤ $I_O$ ≤ 1A | | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | Tj = 25°C, $I_O$ ≤ 1A<br>$V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | | | 1.0<br>(7.5 ≤ $V_{IN}$ ≤ 20) | | | 1.0<br>(14.8 ≤ $V_{IN}$ ≤ 27) | | | 1.0<br>(17.9 ≤ $V_{IN}$ ≤ 30) | mA<br>V |
| | | $I_O$ ≤ 500 mA, 0°C ≤ Tj ≤ +125°C<br>$V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | | | 1.0<br>(7 ≤ $V_{IN}$ ≤ 25) | | | 1.0<br>(14.5 ≤ $V_{IN}$ ≤ 30) | | | 1.0<br>(17.5 ≤ $V_{IN}$ ≤ 30) | mA<br>V |
| $V_N$ | Output Noise Voltage | $T_A$ = 25°C, 10 Hz ≤ f ≤ 100 kHz | | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | $I_O$ ≤ 1A, Tj = 25°C or<br>$I_O$ ≤ 500 mA<br>0°C ≤ Tj ≤ +125°C | 62<br>62 | 80 | | 55<br>55 | 72 | | 54<br>54 | 70 | | dB<br>dB |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (8 ≤ $V_{IN}$ ≤ 18) | | | (15 ≤ $V_{IN}$ ≤ 25) | | | (18.5 ≤ $V_{IN}$ ≤ 28.5) | | | V |
| $R_O$ | Dropout Voltage<br>Output Resistance<br>Short-Circuit Current<br>Peak Output Current<br>Average TC of $V_{OUT}$ | Tj = 25°C, $I_{OUT}$ = 1A<br>f = 1 kHz<br>Tj = 25°C<br>Tj = 25°C<br>0°C ≤ Tj ≤ +125°C, $I_O$ = 5 mA | | | 2.0<br>8<br>2.1<br>2.4<br>0.6 | | | 2.0<br>18<br>1.5<br>2.4<br>1.5 | | | 2.0<br>19<br>1.2<br>2.4<br>1.8 | | V<br>mΩ<br>A<br>A<br>mV/°C |
| $V_{IN}$ | Input Voltage Required to Maintain Line Regulation | Tj = 25°C, $I_O$ ≤ 1A | | 7.3 | | | 14.6 | | | 17.7 | | | V |

**NOTE 1:** Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

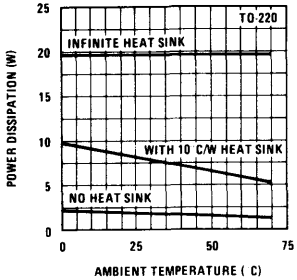
**NOTE 2:** All characteristics are measured with capacitor across the inut of 0.22 μF, and a capacitor across the output of 0.1 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W$ ≤ 10ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

# Typical Performance Characteristics

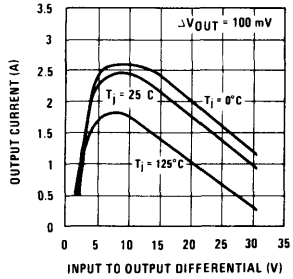
**Maximum Average Power Dissipation**



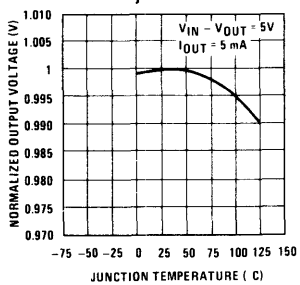

**Maximum Average Power Dissipation**



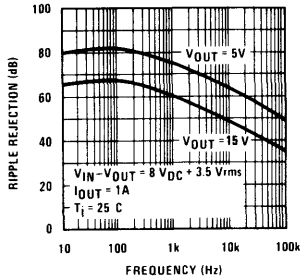

**Peak Output Current**



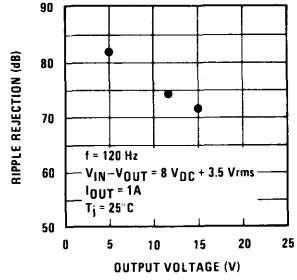

**Output Voltage (Normalized to 1V at $T_j = 25°C$)**



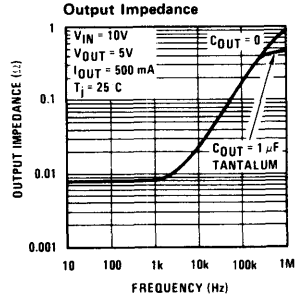

**Ripple Rejection**



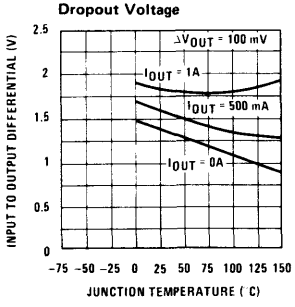

**Ripple Rejection**



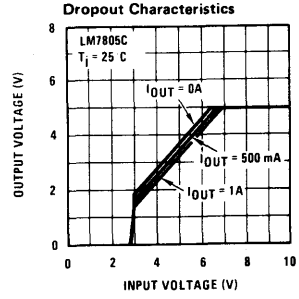

**Output Impedance**



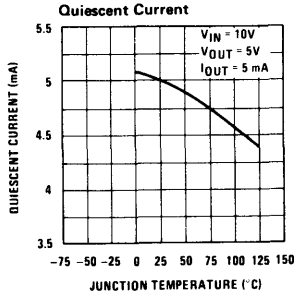

**Dropout Voltage**



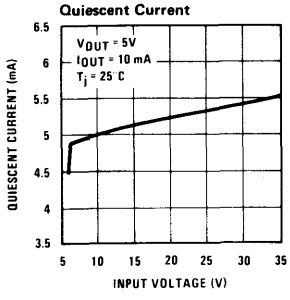

**Dropout Characteristics**




**Quiescent Current**




**Quiescent Current**



National Semiconductor

# Voltage Regulators

# LM78LXX Series 3-Terminal Positive Regulators

## General Description

The LM78LXX series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78LXX is available in the metal three lead TO-5 (H) and the plastic TO-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

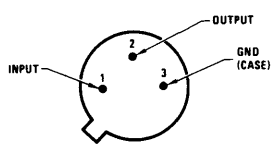
- Output voltage tolerances of ±5% (LM78LXXAC) and ±10% (LM78LXXC) over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-92 and metal TO-39 low profile packages

## Voltage Range

| | |
|---|---|
| LM78L05 | 5V |
| LM78L12 | 12V |
| LM78L15 | 15V |

## Connection Diagrams

**Metal Can Package**



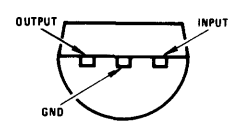

BOTTOM VIEW

**Order Numbers:**

| | |
|---|---|
| LM78L05ACH | LM78L05CH |
| LM78L12ACH | LM78L12CH |
| LM78L15ACH | LM78L15CH |

**See Package H03A**

**Plastic Package**




BOTTOM VIEW

**Order Numbers:**

| | |
|---|---|
| LM78L05ACZ | LM78L05CZ |
| LM78L12ACZ | LM78L12CZ |
| LM78L15ACZ | LM78L15CZ |

**See Package Z03A**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| $V_O$ = 5V | 30V |
| $V_O$ = 12V to 15V | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | 125°C |
| Storage Temperature Range | |
| Metal Can (H Package) | −65°C to +150°C |
| Molded TO-92 (Z Package) | −55°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (Note 2) $T_j$ = 0°C to 125°C, $I_O$ = 40mA, $C_{IN}$ = 0.33μF, $C_O$ = 0.1μF (unless noted)

| LM78LXXAC OUTPUT VOLTAGE | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j$ = 25°C | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | (Note 4) | 1 mA ≤ $I_O$ ≤ 70 mA | 4.75 | | 5.25 | 11.4 | | 12.6 | 14.25 | | 15.75 | V |
| | | 1 mA ≤ $I_O$ ≤ 40 mA and $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | 4.75 (7 ≤ $V_{IN}$ ≤ 20) | | 5.25 | 11.4 (14.5 ≤ $V_{IN}$ ≤ 27) | | 12.6 | 14.25 (17.5 ≤ $V_{IN}$ ≤ 30) | | 15.75 | V |
| $\Delta V_O$ | Line Regulation | $T_j$ = 25°C | | 10 | 54 | | 20 | 110 | | 25 | 140 | mV |
| | | | (8 ≤ $V_{IN}$ ≤ 20) | | | (16 ≤ $V_{IN}$ ≤ 27) | | | (20 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | | | 18 | 75 | | 30 | 180 | | 37 | 250 | mV |
| | | | (7 ≤ $V_{IN}$ ≤ 20) | | | (14.5 ≤ $V_{IN}$ ≤ 27) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| $\Delta V_O$ | Load Regulation | $T_j$ = 25°C, 1 mA ≤ $I_O$ ≤ 40 mA | | 5 | 30 | | 10 | 50 | | 12 | 75 | mV |
| | | $T_j$ = 25°C, 1 mA ≤ $I_O$ ≤ 100 mA | | 20 | 60 | | 30 | 100 | | 35 | 150 | mV |
| $\Delta V_O$ | Long Term Stability | | | 12 | | | 24 | | | 30 | | mV/1000 hrs |
| $I_Q$ | Quiescent Current | $T_j$ = 25°C | | 3 | 5 | | 3 | 5 | | 3.1 | 5 | mA |
| | | $T_j$ = 125°C | | | 4.7 | | | 4.7 | | | 4.7 | |
| $\Delta I_Q$ | Quiescent Current | 1 mA ≤ $I_O$ ≤ 40 mA | | | 0.1 | | | 0.1 | | | 0.1 | mA |
| | Change | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | | 1.0 | | | 1.0 | | | 1.0 | mA |
| | | | (8 ≤ $V_{IN}$ ≤ 20) | | | (16 ≤ $V_{IN}$ ≤ 27) | | | (20 ≤ $V_{IN}$ ≤ 30) | | | V |
| $V_n$ | Output Noise Voltage | $T_j$ = 25°C, (Note 3) f = 10 Hz – 10 kHz | | 40 | | | 80 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | 47 | 62 | | 40 | 54 | | 37 | 51 | | dB |
| | | | (8 ≤ $V_{IN}$ ≤ 16) | | | (15 ≤ $V_{IN}$ ≤ 25) | | | (18.5 ≤ $V_{IN}$ ≤ 28.5) | | | V |
| | Input Voltage Required to Maintain Line Regulation | $T_j$ = 25°C | 7 | | | 14.5 | | | 17.5 | | | V |

**Note 1:** Thermal resistance of the Metal Can Package (H) without a heat sink is 15°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4" leads from a PC board and 160°C/W junction to ambient with 0.125" lead length to a PC board.

**Note 2:** The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of test.

**Note 3:** Recommended minimum load capacitance of 0.01μF to limit high frequency noise bandwidth.

**Note 4:** The temperature coefficient of $V_{OUT}$ is typically within ±0.01% $V_O$/°C.

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| $V_O = 5V$ | 30V |
| $V_O = 12V$ to 15V | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | 125°C |
| Storage Temperature Range | |
| Metal Can (H Package) | −65°C to +150°C |
| Molded TO-92 | −55° to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (Note 2) $T_j = 0°C$ to $+125°C$, $I_O = 40$ mA, $C_{IN} = 0.33\mu F$, $C_O = 0.1\mu F$ (unless noted)

| LM78LXXC OUTPUT VOLTAGE | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j = 25°C$ | 4.6 | 5 | 5.4 | 11.1 | 12 | 12.9 | 13.8 | 15 | 16.2 | V |
| | (Note 4) | 1 mA ≤ $I_O$ ≤ 70 mA or 1 mA ≤ $I_O$ ≤ 40 mA and $\Delta V_{IN}$ | 4.5 (7 ≤ $V_{IN}$ ≤ 20) | | 5.5 | 10.8 (14.5 ≤ $V_{IN}$ ≤ 27) | | 13.2 | 13.5 (18 ≤ $V_{IN}$ ≤ 30) | | 16.5 | V V |
| $\Delta V_O$ | Line Regulation | $T_j = 25°C$ | | 10 (8 ≤ $V_{IN}$ ≤ 20) | 150 | | 20 (16 ≤ $V_{IN}$ ≤ 27) | 200 | | 25 (20 ≤ $V_{IN}$ ≤ 30) | 250 | mV V |
| | | | | 18 (7 ≤ $V_{IN}$ ≤ 20) | 200 | | 30 (14.5 ≤ $V_{IN}$ ≤ 27) | 250 | | 30 (18 ≤ $V_{IN}$ ≤ 30) | 300 | mV V |
| $\Delta V_O$ | Load Regulation | $T_j = 25°C$, 1 mA ≤ $I_O$ ≤ 40 mA | | 5 | 30 | | 10 | 50 | | 12 | 75 | mV |
| | | $T_j = 25°C$, 1 mA ≤ $I_O$ ≤ 100 mA | | 20 | 60 | | 30 | 100 | | 35 | 150 | mV |
| $\Delta V_O$ | Long Term Stability | | | 12 | | | 24 | | | 30 | | mV/1000 hrs |
| $I_Q$ | Quiescent Current | $T_j = 25°C$ | | 3 | 6 | | 3 | 6.5 | | 3.1 | 6.5 | mA |
| | | $T_j = 125°C$ | | | 5.5 | | | 6 | | | 6 | |
| $\Delta I_Q$ | Quiescent Current | $T_j = 25°C$, 1 mA ≤ $I_O$ ≤ 40 mA | | | 0.2 | | | 0.2 | | | 0.2 | mA |
| | Change | | | | 1.5 | | | 1.5 | | | 1.5 | mA |
| | | $T_j = 25°C$ | | (8 ≤ $V_{IN}$ ≤ 20) | | | (16 ≤ $V_{IN}$ ≤ 27) | | | (20 ≤ $V_{IN}$ ≤ 30) | | V |
| $V_n$ | Output Noise Voltage | $T_j = 25°C$, (Note 3) f = 10 Hz – 10 kHz | | 40 | | | 80 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 125 Hz | 40 (8 ≤ $V_{IN}$ ≤ 18) | 60 | | 36 (15 ≤ $V_{IN}$ ≤ 25) | 52 | | 33 (18.5 ≤ $V_{IN}$ ≤ 28.5) | 49 | | dB V |
| | Input Voltage Required to Maintain Line Regulation | $T_j = 25°C$ | | 7 | | | 14.5 | | | 18 | | V |

**Note 1:** Thermal resistance of the Metal Can Package (H) without a heat sink is 15°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4" leads from a PC board and 160°C/W junction to ambient with 0.125" lead length to a PC board.

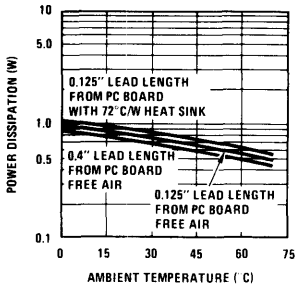
**Note 2:** The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of test.

**Note 3:** Recommended minimum load capacitance of 0.01μF to limit high frequency noise bandwidth.

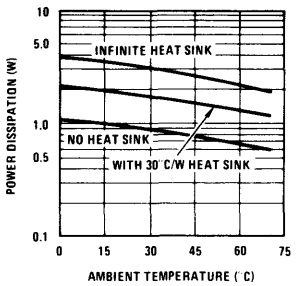
**Note 4:** The temperature coefficient of $V_{OUT}$ is typically within ±0.01% $V_O$/°C.

# Typical Performance Characteristics

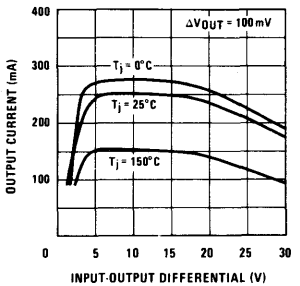
Maximum Average Power Dissipation (Plastic Package)



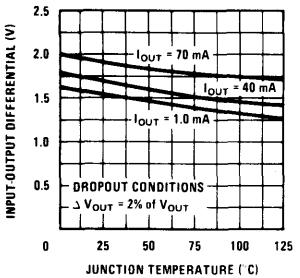

Maximum Average Power Dissipation (Metal Can Package)



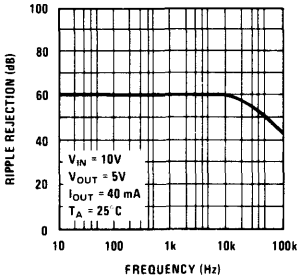

Peak Output Current



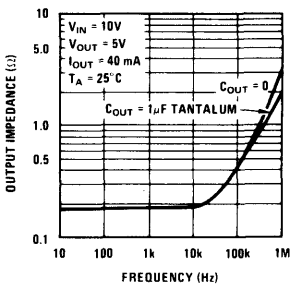

Dropout Voltage



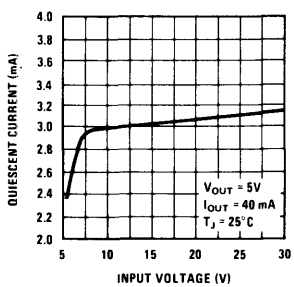

Ripple Rejection



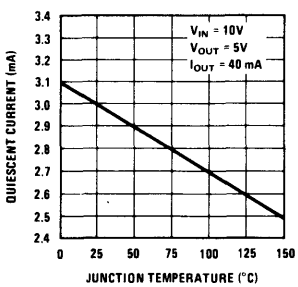

Output Impedance



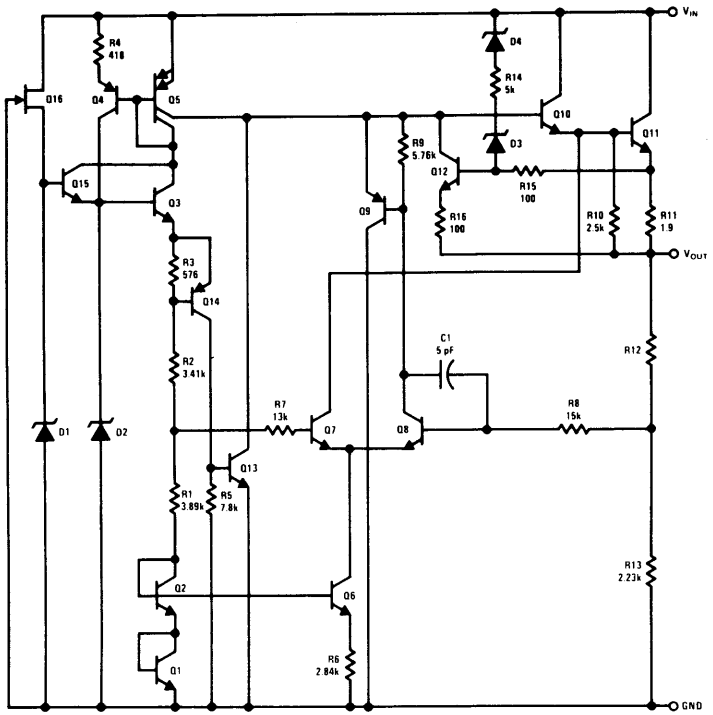

Quiescent Current




Quiescent Current

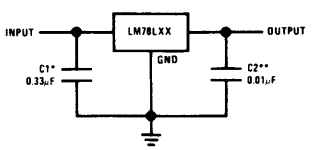


## Equivalent Circuit



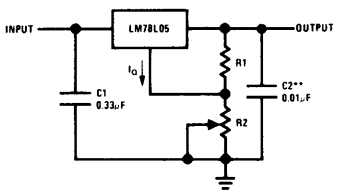

LM78LXX

## Typical Applications




*Required if the regulator is located far from the power supply filter.
**See Note 3 in the electrical characteristics table.

Fixed Output Regulator

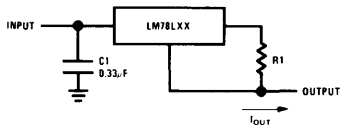



$V_{OUT} = 5V + (5V/R1 + I_Q) R2$

$5V/R1 \cdot 3\, I_Q$, load regulation $(L_r) \approx [(R1 + R2)/R1]$ (L, of LM78L05)

Adjustable Output Regulator

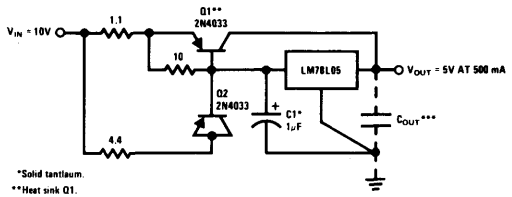
## Typical Applications (Continued)




$I_{OUT} = (V_{23}/R1) + I_Q$

$\Delta I_Q = 1.5$ mA over line and load changes

**Current Regulator**



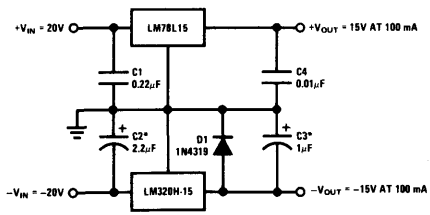

*Solid tantlaum.

**Heat sink Q1.

***Optional: Improves ripple rejection and transient response.

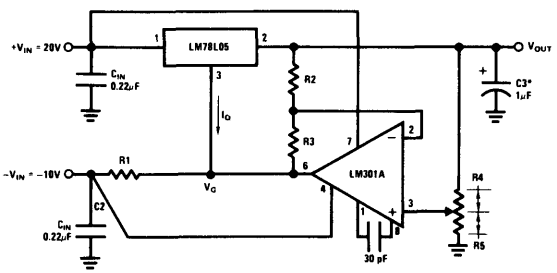
Load Regulation: 0.6% $0 \leq I_L \leq 250$ mA pulsed with $t_{ON} = 50$ ms.

**5V, 500 mA Regulator with Short Circuit Protection**




*Solid tantalum.

**±15V, 100 mA Dual Power Supply**




*Solid tantalum.

$V_{OUT} = V_O + 5V$, $R1 = (-V_{IN}/I_{Q\ LM78L05})$

$V_{OUT} = 5V\ (R2/R4)$ for $(R2 + R3) = (R4 + R5)$

A 0.5V output will correspond to $(R2/R4) = 0.1$, $(R3/R4) = 0.9$

**Variable Output Regulator 0.5V – 18V**

National Semiconductor

# Voltage Regulators

# LM78MXX Series 3-Terminal Positive Regulators

## General Description

The LM78MXX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78MXX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.5A if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

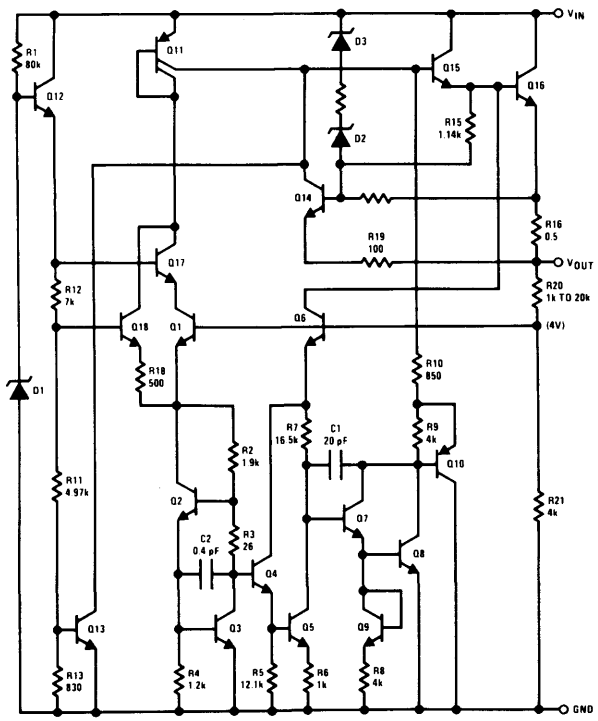
Considerable effort was expended to make the LM78MXX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

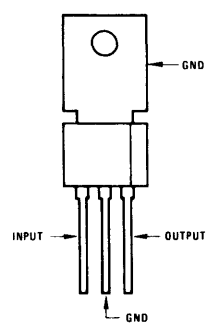
For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

- Output current in excess of 0.5A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package
- Special circuitry allows start-up even if output is pulled to negative voltage (± supplies)

## Schematic and Connection Diagrams




FRONT VIEW

**Order Numbers**
**LM78M05CP**
**LM78M12CP**
**LM78M15CP**
**See Package P03A**

**For Tab Bend TO-202**
**Order Numbers**
**LM78M05CP TB**
**LM78M12CP TB**
**LM78M15CP TB**
**See Package P03E**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage ($V_O$ = 5V, 12V, 15V) | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | +230°C |

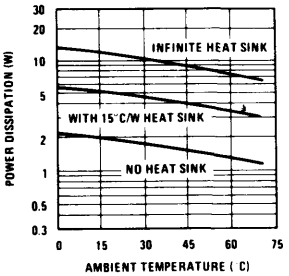
## Electrical Characteristics $T_A$ = 0°C to 70°C, $I_O$ = 500 mA, unless otherwise noted.

| OUTPUT VOLTAGE | | | 5V | | | 12V | | | 15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_j$ = 25°C | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D \leq$ 7.5W, 5 mA $\leq I_O \leq$ 500 mA and $V_{MIN} \leq V_{IN} \leq V_{MAX}$ | 4.75 (7.5 ≤ $V_{IN}$ ≤ 20) | | 5.25 | 11.4 (14.8 ≤ $V_{IN}$ ≤ 27) | | 12.6 | 14.25 (18 ≤ $V_{IN}$ ≤ 30) | | 15.75 | V<br>V |
| $\Delta V_O$ | Line Regulation | $T_j$ = 25°C, $I_O$ = 100 mA<br>$T_j$ = 25°C, $I_O$ = 500 mA | (7.2 ≤ $V_{IN}$ ≤ 25) | | 50<br>100 | (14.5 ≤ $V_{IN}$ ≤ 30) | | 120<br>240 | (17.6 ≤ $V_{IN}$ ≤ 30) | | 150<br>300 | mV<br>mV<br>V |
| $\Delta V_O$ | Load Regulation | $T_j$ = 25°C, 5 mA $\leq I_O \leq$ 500 mA | | | 100 | | | 240 | | | 300 | mV |
| $\Delta V_O$ | Long Term Stability | | | | 20 | | | 48 | | | 60 | mV/1000 hrs |
| $I_Q$ | Quiescent Current | $T_j$ = 25°C | | 4 | 10 | | 4 | 10 | | 4 | 10 | mA |
| $\Delta I_Q$ | Quiescent Current Change | $T_j$ = 25°C<br>5 mA $\leq I_O \leq$ 500 mA | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | $T_j$ = 25°C<br>$V_{MIN} \leq V_{IN} \leq V_{MAX}$ | (7.5 ≤ $V_{IN}$ ≤ 25) | | 1 | (14.8 ≤ $V_{IN}$ ≤ 30) | | 1 | (18 ≤ $V_{IN}$ ≤ 30) | | 1 | mA<br>V |
| $V_n$ | Output Noise Voltage | $T_j$ = 25°C, f = 10 Hz – 100 kHz | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | | 78 | | | 71 | | | 69 | | V |
| | Input Voltage Required to Maintain Line Regulation | $T_j$ = 25°C, $I_O$ = 500 mA | 7.2 | | | 14.5 | | | 17.6 | | | V |

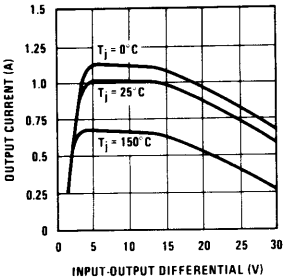
**Note 1:** Thermal resistance without a heat sink for junction to case temperature is 12°C/W for the TO-202 package. Thermal resistance for case to ambient temperature is 70°C/W for the TO-202 package.

# Typical Performance Characteristics

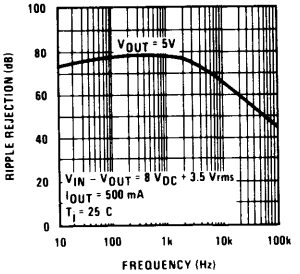
**Maximum Average Power Dissipation**



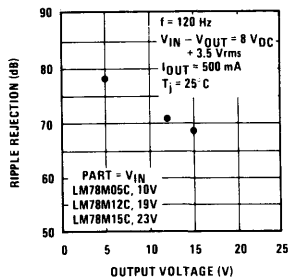

**Peak Output Current**



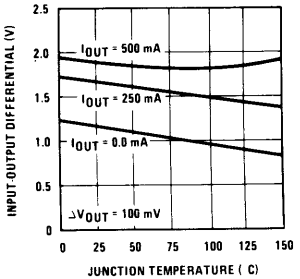

**Ripple Rejection**



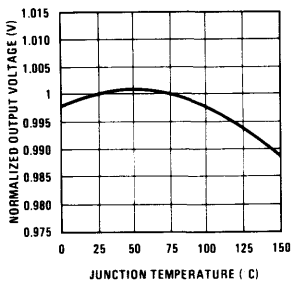

**Ripple Rejection**



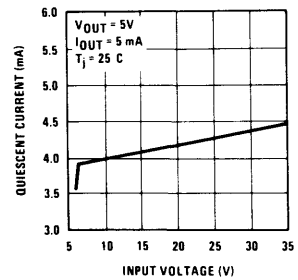

**Dropout Voltage**



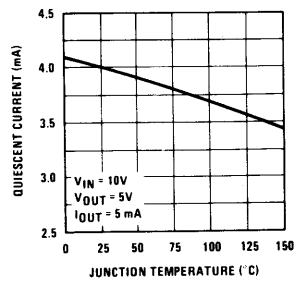

**Output Voltage (Normalized to 1V at $T_J$ = 25° C)**



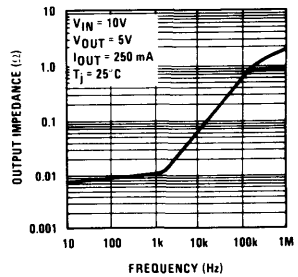

**Quiescent Current**




**Quiescent Current**




**Output Impedance**



National Semiconductor

Voltage Regulators

# LM79XX Series 3-Terminal Negative Regulators

## General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of −5V, −12V, and −15V. These devices need only one external component—a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

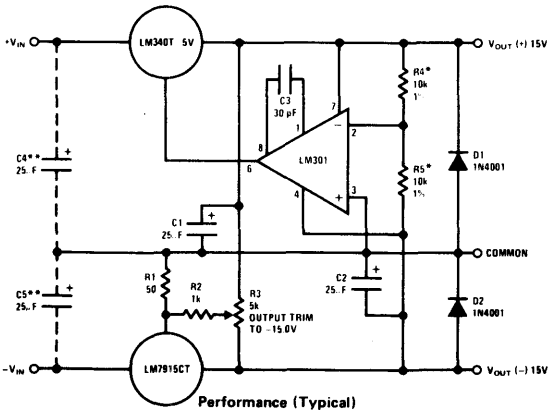
For output voltages other than 5V, 12V and 15V the LM137 series provides an output voltage range from −1.2V to −47V.

## Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 1.5A output current
- 4% preset output voltage

## Typical Applications

**±15V, 1 Amp Tracking Regulators**



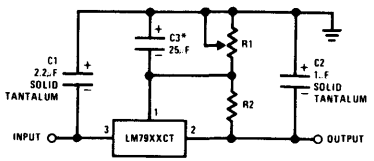

**Performance (Typical)**

| | (−15) | (+15) |
|---|---|---|
| Load Regulation at $\Delta I_L$ = 1A | 40 mV | 2 mV |
| Output Ripple, $C_{IN}$ = 3000µF, $I_L$ = 1A | 100µVrms | 100µVrms |
| Temperature Stability | 50 mV | 50 mV |
| Output Noise 10 Hz ≤ f ≤ 10 kHz | 150µVrms | 150µVrms |

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs

**Necessary only if raw supply filter capacitors are more than 3" from regulators

**Variable Output**



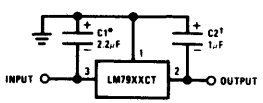

*Improves transient response and ripple rejection. Do not increase beyond 50µF.

$$V_{OUT} = V_{SET}\left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows

| | |
|---|---|
| LM7905CT | 300Ω |
| LM7912CT | 750Ω |
| LM7915CT | 1k |

**Fixed Regulator**

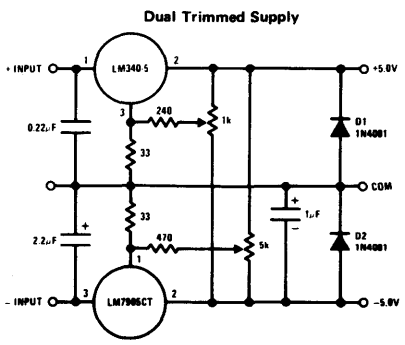



*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25µF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25µF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100µF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

**Dual Trimmed Supply**



## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| ($V_O$ = 5V) | −35V |
| ($V_O$ = 12V and 15V) | −40V |
| Input-Output Differential | |
| ($V_O$ = 5V) | 25V |
| ($V_O$ = 12V and 15V) | 30V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | 0°C to +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 230°C |

## Electrical Characteristics

Conditions unless otherwise noted: $I_{OUT}$ = 500 mA, $C_{IN}$ = 2.2μF, $C_{OUT}$ = 1μF, 0°C ≤ $T_J$ ≤ +125°C, Power Dissipation ≤ 15W.

| PART NUMBER | | | LM7905C | | | UNITS |
|---|---|---|---|---|---|---|
| OUTPUT VOLTAGE | | | 5V | | | |
| INPUT VOLTAGE (unless otherwise specified) | | | −10V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_J$ = 25°C | −4.8 | −5.0 | −5.2 | V |
| | | 5 mA ≤ $I_{OUT}$ ≤ 1A, P ≤ 15W | −4.75 | | −5.25 | V |
| | | (−20 ≤ $V_{IN}$ ≤ −7) | | | | V |
| $\Delta V_O$ | Line Regulation | $T_J$ = 25°C, (Note 2) | | 8 | 50 | mV |
| | | (−25 ≤ $V_{IN}$ ≤ −7) | | | | V |
| | | | | 2 | 15 | mV |
| | | (−12 ≤ $V_{IN}$ ≤ −8) | | | | V |
| $\Delta V_O$ | Load Regulation | $T_J$ = 25°C, (Note 2) | | | | mV |
| | | 5 mA ≤ $I_{OUT}$ ≤ 1.5A | | 15 | 100 | mV |
| | | 250 mA ≤ $I_{OUT}$ ≤ 750 mA | | 5 | 50 | mV |
| $I_Q$ | Quiescent Current | $T_J$ = 25°C | | 1 | 2 | mA |
| $\Delta I_Q$ | Quiescent Current Change | With Line | | | 0.5 | mA |
| | | (−25 ≤ $V_{IN}$ ≤ −7) | | | | V |
| | | With Load, 5 mA ≤ $I_{OUT}$ ≤ 1A | | | 0.5 | mA |
| $V_n$ | Output Noise Voltage | $T_A$ = 25°C, 10 Hz ≤ f ≤ 100 Hz | | 125 | | μV |
| | Ripple Rejection | f = 120 Hz | 54 | 66 | | dB |
| | | (−18 ≤ $V_{IN}$ ≤ −8) | | | | V |
| | Dropout Voltage | $T_J$ = 25°C, $I_{OUT}$ = 1A | | 1.1 | | V |
| $I_{OMAX}$ | Peak Output Current | $T_J$ = 25°C | | 2.2 | | A |
| | Average Temperature Coefficient of Output Voltage | $I_{OUT}$ = 5 mA, 0°C ≤ $T_J$ ≤ 100°C | | 0.4 | | mV/°C |

## Electrical Characteristics (Continued) Conditions unless otherwise noted: $I_{OUT}$ = 500 mA, $C_{IN}$ = 2.2μF, $C_{OUT}$ = 1μF, 0°C ≤ $T_J$ ≤ +125°C, Power Dissipation = 1.5W.

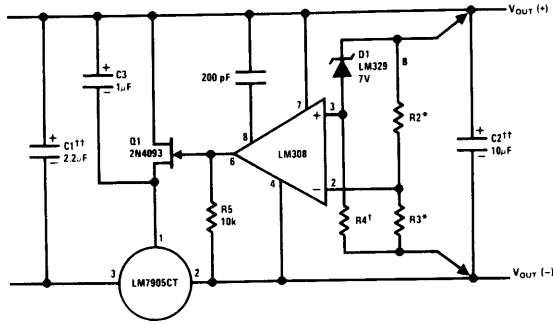
| PART NUMBER | | | LM7912C | | | LM7915C | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|
| OUTPUT VOLTAGE | | | 12V | | | 15V | | | |
| INPUT VOLTAGE (unless otherwise specified) | | | −19V | | | −23V | | | |
| PARAMETER | | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | $T_J$ = 25°C | −11.5 | −12.0 | −12.5 | −14.4 | −15.0 | −15.6 | V |
| | | 5 mA ≤ $I_{OUT}$ ≤ 1A, P ≤ 15W | −11.4 | | −12.6 | −14.25 | | 15.75 | V |
| | | | (−27 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| $\Delta V_O$ | Line Regulation | $T_J$ = 25°C, (Note 2) | | 5 | 80 | | 5 | 100 | mV |
| | | | (−30 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| | | | | 3 | 30 | | 3 | 50 | mV |
| | | | (−22 ≤ $V_{IN}$ ≤ −16) | | | (−26 ≤ $V_{IN}$ ≤ −20) | | | V |
| $\Delta V_O$ | Load Regulation | $T_J$ = 25°C, (Note 2) | | 15 | 200 | | 15 | 200 | mV |
| | | 5 mA ≤ $I_{OUT}$ ≤ 1.5A | | 15 | 200 | | 15 | 200 | mV |
| | | 250 mA ≤ $I_{OUT}$ ≤ 750 mA | | 5 | 75 | | 5 | 75 | mV |
| $I_Q$ | Quiescent Current | $T_J$ = 25°C | | 1.5 | 3 | | 1.5 | 3 | mA |
| $\Delta I_Q$ | Quiescent Current Change | With Line | | | 0.5 | | | 0.5 | mA |
| | | | (−30 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| | | With Load, 5 mA ≤ $I_{OUT}$ ≤ 1A | | | 0.5 | | | 0.5 | mA |
| $V_n$ | Output Noise Voltage | $T_A$ = 25°C, 10 Hz ≤ f ≤ 100 Hz | | 300 | | | 375 | | μV |
| | Ripple Rejection | f = 120 Hz | 54 | 70 | | 54 | 70 | | dB |
| | | | (−25 ≤ $V_{IN}$ ≤ −15) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| | Dropout Voltage | $T_J$ = 25°C, $I_{OUT}$ = 1A | | 1.1 | | | 1.1 | | V |
| $I_{OMAX}$ | Peak Output Current | $T_J$ = 25°C | | 2.2 | | | 2.2 | | A |
| | Average Temperature Coefficient of Output Voltage | $I_{OUT}$ = 5 mA, 0°C ≤ $T_J$ ≤ 100°C | | −0.8 | | | −1.0 | | mV/°C |

**Note 1:** For calculations of junction temperature rise due to power dissipation, thermal resistance junction to ambient ($\theta_{JA}$) is 50°C/W (no heat sink) and 5°C/W (infinite heat sink).

**Note 2:** Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

## Typical Applications (Continued)

**High Stability 1 Amp Regulator**



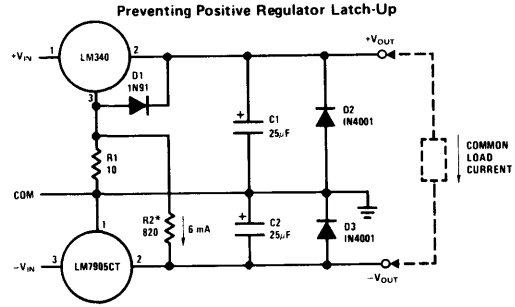

Load and line regulation < 0.01% temperature stability ≤ 0.2%

†Determines Zener current

††Solid tantalum

*Select resistors to set output voltage. 2 ppm/°C tracking suggested

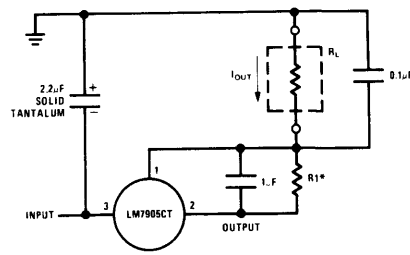
**Preventing Positive Regulator Latch-Up**




R1 and D1 allow the positive regulator to "start-up" when $+V_{IN}$ is delayed relative to $-V_{IN}$ and a heavy load is drawn between the outputs. Without R1 and D1, most three-terminal regulators will not start with heavy (0.1A–1A) load current flowing to the negative regulator, even though the positive output is clamped by D2.

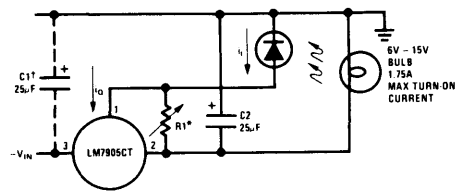
*R2 is optional. Ground pin current from the positive regulator flowing through R1 will increase $+V_{OUT}$ ≈ 60 mV if R2 is omitted.

**Current Source**



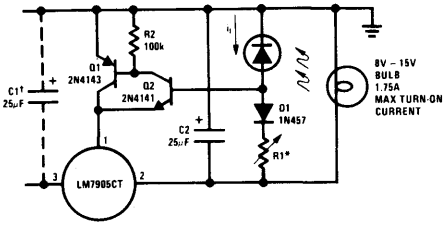

$$*I_{OUT} = 1\ mA + \frac{5V}{R1}$$

**Light Controllers Using Silicon Photo Cells**




*Lamp brightness increases until $i_L = i_Q$ (≈ 1 mA) + 5V/R1.

†Necessary only if raw supply filter capacitor is more than 2" from LM7905CT



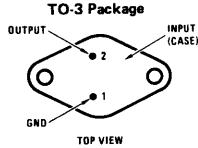

*Lamp brightness increases until $i_L$ = 5V/R1 ($i_L$ can be set as low as 1μA)

†Necessary only if raw supply filter capacitor is more than 2" from LM7905CT

## Connection Diagrams

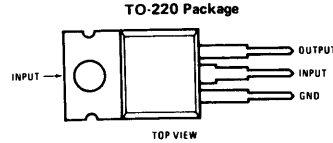
**TO-3 Package**

**Order Numbers:**
**LM7905CK**
**LM7912CK**
**LM7915CK**
**See NS Package KC02A**




TOP VIEW

**TO-220 Package**

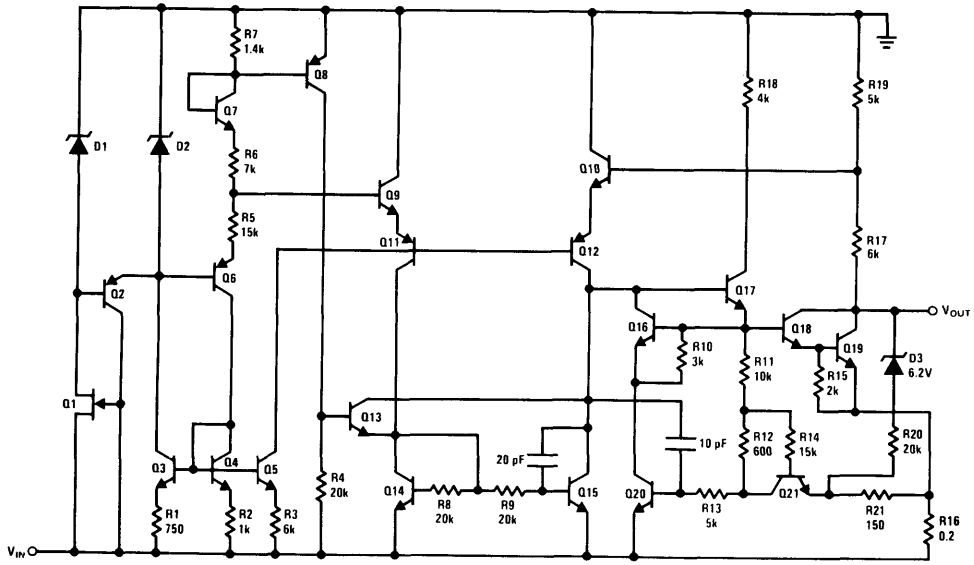



TOP VIEW

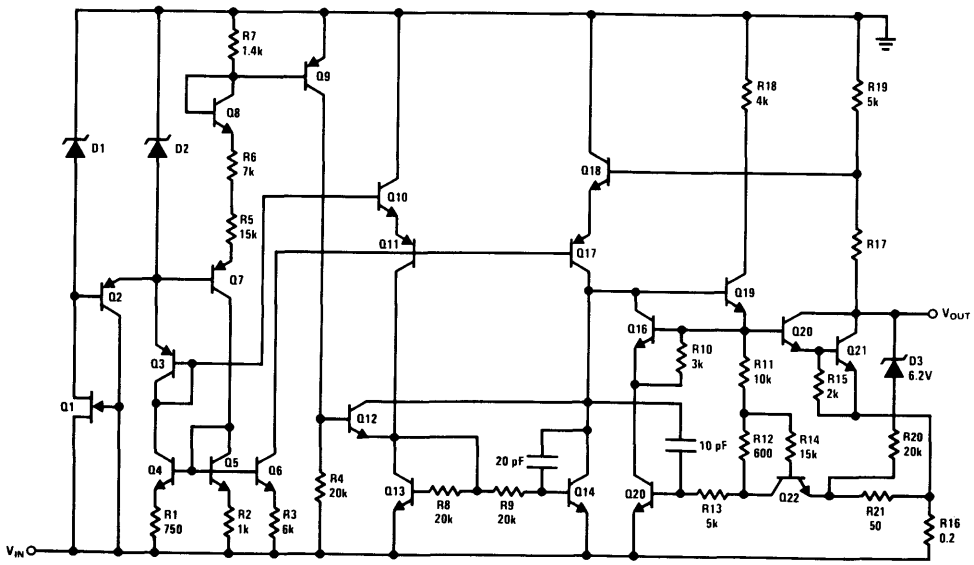
**Order Numbers:**
**LM7905CT**
**LM7912CT**
**LM7915CT**
**See NS Package T03B**

## schematic diagrams

**–5V, –5.2V, –6V, –8V**




**–9V, –12V, –15V, –18V, –24V**



National Semiconductor

# LM79LXXAC Series 3-Terminal Negative Regulators

## General Description

The LM79LXXAC series of 3-terminal negative voltage regulators features fixed output voltages of -5V, -12V, and -15V with output current capabilities in excess of 100 mA. These devices were designed using the latest computer techniques for optimizing the packaged IC thermal/electrical performance. The LM79LXXAC series, even when combined with a minimum output compensation capacitor of 0.1 μF, exhibits an excellent transient response, a maximum line regulation of 0.07% $V_O/V$, and a maximum load regulation of 0.01% $V_O/mA$.

The LM79LXXAC series also includes, as self-protection circuitry: safe operating area circuitry for output transistor power dissipation limiting, a temperature independent short circuit current limit for peak output current limiting, and a thermal shutdown circuit to prevent excessive junction temperature. Although designed primarily as fixed voltage regulators, these devices may be combined with simple external circuitry for boosted and/or adjustable voltages and currents. The LM79LXXAC series is available in the 3-lead TO-92 package.

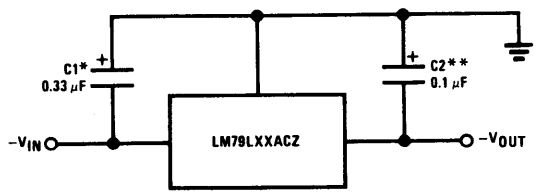
For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

- Preset output voltage error is less than ±5% overload, line and temperature
- Specified at an output current of 100 mA
- Easily compensated with a small 0.1 μF output capacitor
- Internal short-circuit, thermal and safe operating area protection
- Easily adjustable to higher output voltages
- Maximum line regulation less than 0.07% $V_{OUT}/V$
- Maximum load regulation less than 0.01% $V_{OUT}mA$
- TO-92 package

## Typical Applications

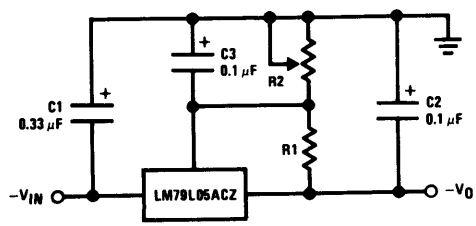
**Fixed Output Regulator**




*Required if the regulator is located far from the power supply filter. A 1 μF aluminum electrolytic may be substituted.

**Required for stability. A 1 μF aluminum electrolytic may be substituted.

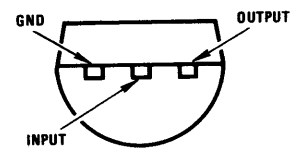
**Adjustable Output Regulator**




$-V_O = -5V - (5V/R1 + I_Q) \cdot R2$,
$5V/R1 > 3\ I_Q$

## Connection Diagram

**TO-92 Plastic Package (Z)**




**BOTTOM VIEW**

**Order Numbers**
**LM79L05ACZ**
**LM79L12ACZ**
**LM79L15ACZ**
**See Package Z03A**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| $V_O$ = −5V, −12V, −15V | −35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | 0°C to +70°C |
| Maximum Junction Temperature | +125°C |
| Storage Temperature Range | −55°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics (Note 2) $T_A$ = 0°C to +70° unless otherwise noted.

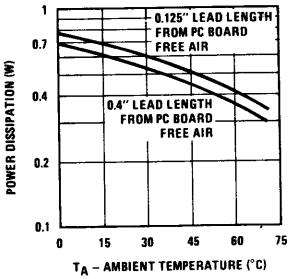
| OUTPUT VOLTAGE | | | −5V | | | −12V | | | −15V | | | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INPUT VOLTAGE (unless otherwise noted) | | | −10V | | | −17V | | | −20V | | | |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | Tj = 25°C, $I_O$ = 100 mA | −5.2 | −5 | −4.8 | −12.5 | −12 | −11.5 | −15.6 | −15 | −14.4 | |
| | | 1 mA ≤ $I_O$ ≤ 100 mA<br>$V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | −5.25<br>(−20 ≤ $V_{IN}$ ≤ −7.5) | | −4.75 | −12.6<br>(−27 ≤ $V_{IN}$ ≤ −14.8) | | −11.4 | −15.75<br>(−30 ≤ $V_{IN}$ ≤ −18) | | −14.25 | V |
| | | 1 mA ≤ $I_O$ ≤ 40 mA<br>$V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | −5.25<br>(−20 ≤ $V_{IN}$ ≤ −7) | | −4.75 | −12.6<br>(−27 ≤ $V_{IN}$ ≤ −14.5) | | −11.4 | −15.75<br>(−30 ≤ $V_{IN}$ ≤ −17.5) | | −14.25 | |
| $\Delta V_O$ | Line Regulation | Tj = 25°C, $I_O$ = 100 mA | | | 60 | | | 45 | | | 45 | mV |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | (−20 ≤ $V_{IN}$ ≤ −7.3) | | | (−27 ≤ $V_{IN}$ ≤ −14.6) | | | (−30 ≤ $V_{IN}$ ≤ −17.7) | | | V |
| | | Tj = 25°C, $I_O$ = 40 mA | | | 60 | | | 45 | | | 45 | mV |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | (−20 ≤ $V_{IN}$ ≤ −7) | | | (−27 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| Δ | Load Regulation | Tj = 25°C<br>1 mA ≤ $I_O$ ≤ 100 mA | | | 50 | | | 100 | | | 125 | mV |
| $\Delta V_O$ | Long Term Stability | $I_O$ = 100 mA | | 20 | | | 48 | | | 60 | | mV/khrs |
| $I_Q$ | Quiescent Current | $I_O$ = 100 mA | | 2 | 6 | | 2 | 6 | | 2 | 6 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 1 mA ≤ $I_O$ ≤ 100 mA | | | 0.3 | | | 0.3 | | | 0.3 | mA |
| | | 1 mA ≤ $I_O$ ≤ 40 mA | | | 0.1 | | | 0.1 | | | 0.1 | |
| | | $I_O$ = 100 mA | | | 0.25 | | | 0.25 | | | 0.25 | mA |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | (−20 ≤ $V_{IN}$ ≤ −7.5) | | | (−27 ≤ $V_{IN}$ ≤ −14.8) | | | (−30 ≤ $V_{IN}$ ≤ −18) | | | V |
| $V_n$ | Output Noise Voltage | Tj = 25°C, $I_O$ = 100 mA<br>f = 10 Hz – 10 kHz | | 40 | | | 96 | | | 120 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_O}$ | Ripple Rejection | Tj = 25°C, $I_O$ = 100 mA<br>f = 120 Hz | 50 | | | 52 | | | 50 | | | dB |
| | Input Voltage Required to Maintain Line Regulation | Tj = 25°C<br>$I_O$ = 100 mA<br>$I_O$ = 40 mA | | | −7.3<br>−7.0 | | | −14.6<br>−14.5 | | | −17.7<br>−17.5 | V |

**Note 1:** Thermal resistance, junction to ambient, of the TO-92 (Z) package is 180°C/W when mounted with 0.40 inch leads on a PC board, and 160°C/W when mounted with 0.25 inch leads on a PC board.

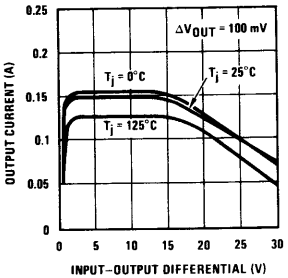
**Note 2:** To ensure constant junction temperature, low duty cycle pulse testing is used.

## Typical Performance Characteristics

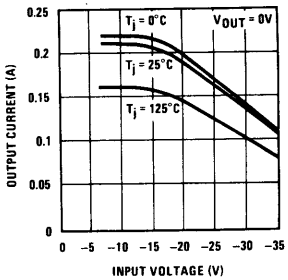
### Maximum Average Power Dissipation (TO-92)



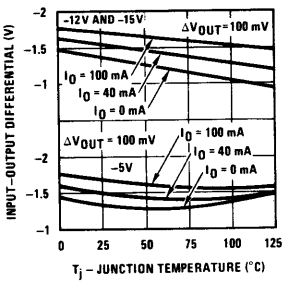

### Peak Output Current



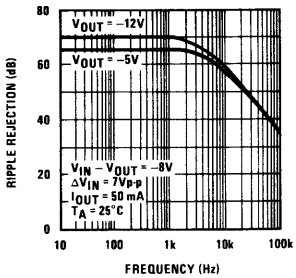

### Short Circuit Output Current



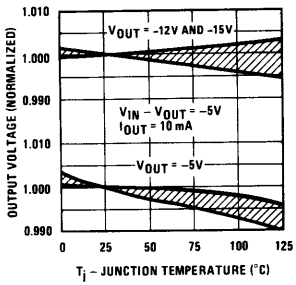

### Dropout Voltage



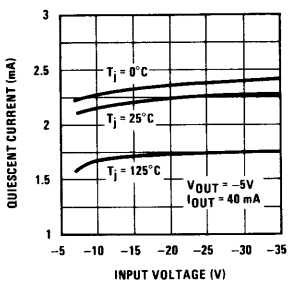

### Ripple Rejection



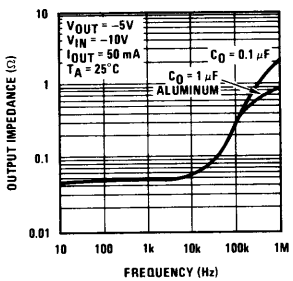

### Output Voltage vs. Temperature (Normalized to 1V @ 25°C)




### Quiescent Current

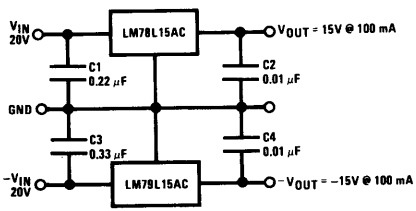



### Output Impedance



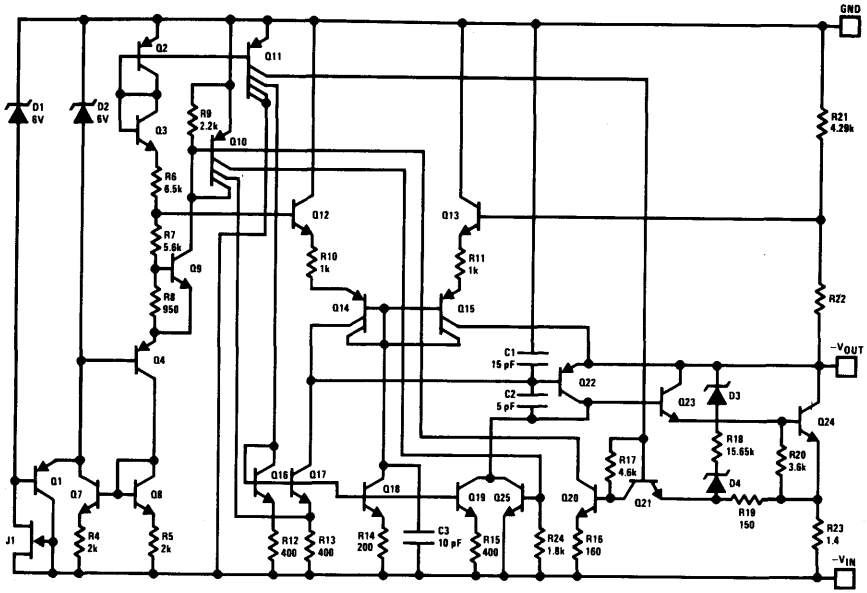

## Typical Applications (Continued)

### ±15V, 100 mA Dual Power Supply

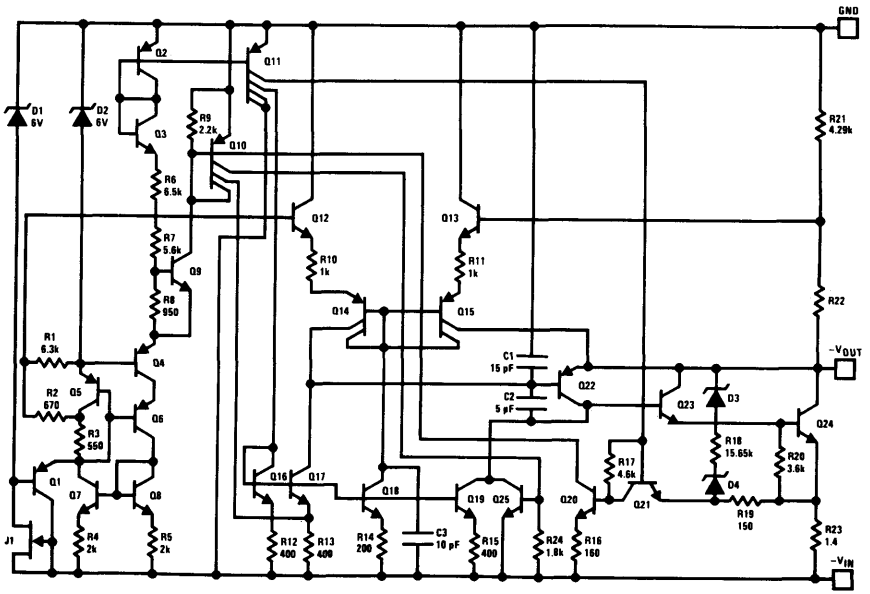


## Schematic Diagrams

-5V




-12V and -15V



National Semiconductor

# LM79MXX Series 3-Terminal Negative Regulators

## General Description

The LM79MXX series of 3-terminal regulators is available with fixed output voltages of -5V, -12V, and -15V. These devices need only one external component—a compensation capacitor at the output. The LM79MXX series is packaged in the TO-202 power package and TO-5 metal can and is capable of supplying 0.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79MXX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

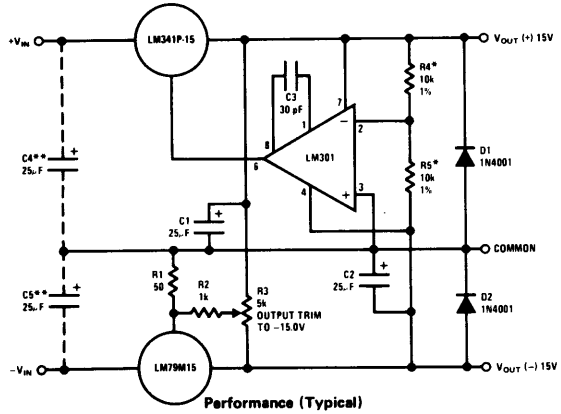
For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 0.5A output current
- 4% preset output voltage

## Typical Applications

**±15V, 1 Amp Tracking Regulators**



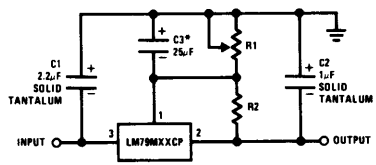

**Performance (Typical)**

| | (−15) | (+15) |
|---|---|---|
| Load Regulation at 0.5A | 40 mV | 2 mV |
| Output Ripple, $C_{IN}$ = 3000μF, $I_L$ = 0.5A | 100μVrms | 100μVrms |
| Temperature Stability | 50 mV | 50 mV |
| Output Noise 10 Hz ≤ f ≤ 10 kHz | 150μVrms | 150μVrms |

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs

**Necessary only if raw supply filter capacitors are more than 3" from regulators

**Variable Output**



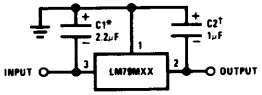

*Improves transient response and ripple rejection. Do not increase beyond 50μF.

$$V_{OUT} = V_{SET}\left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows:

| | |
|---|---|
| LM79M05CP | 300Ω |
| LM79M12CP | 750Ω |
| LM79M15CP | 1k |

**Fixed Regulator**

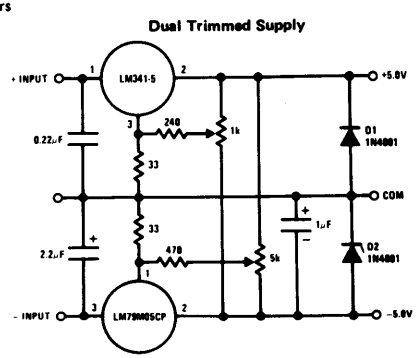



*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

**Dual Trimmed Supply**



## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| ($V_O$ = 5V) | 25V |
| ($V_O$ = 12V and 15V) | −35V |
| Input/Output Differential | |
| ($V_O$ = 5V) | 25V |
| ($V_O$ = 12V and 15V) | 30V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | 0°C to +125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 230°C |

## Electrical Characteristics

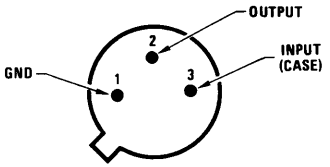
Conditions unless otherwise noted: $I_{OUT}$ = 350 mA, $C_{IN}$ = 2.2μF, $C_{OUT}$ = 1μF, 0°C ≤ Tj ≤ +125°C

| PART NUMBER | | | LM79M05C | | | LM79M12C | | | LM79M15C | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OUTPUT VOLTAGE | | | −5V | | | −12V | | | −15V | | | |
| INPUT VOLTAGE (unless otherwise specified) | | | −10V | | | −19V | | | −23V | | | UNITS |
| | PARAMETER | CONDITIONS | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_O$ | Output Voltage | Tj = 25°C | −4.8 | −5.0 | −5.2 | −11.5 | −12.0 | −12.5 | −14.4 | −15.0 | −15.6 | V |
| | | 5 mA ≤ $I_{OUT}$ ≤ 350 mA | −4.75 | | −5.25 | −11.4 | | −12.6 | −14.25 | | −15.75 | V |
| | | | (−25 ≤ $V_{IN}$ ≤ −7) | | | (−27 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| $\Delta V_O$ | Line Regulation | Tj = 25°C, (Note 2) | | 8 | 50 | | 5 | 80 | | 5 | 80 | mV |
| | | | (−25 ≤ $V_{IN}$ ≤ −7) | | | (−30 ≤ $V_{IN}$ ≤ −14.5) | | | (− ≤ $V_{IN}$ ≤ −17.5) | | | V |
| | | | | 2 | 30 | | 3 | 30 | | 3 | 50 | mV |
| | | | (−18 ≤ $V_{IN}$ ≤ −8) | | | (−25 ≤ $V_{IN}$ ≤ −15) | | | (−28 ≤ $V_{IN}$ ≤ −18) | | | V |
| $\Delta V_O$ | Load Regulation | Tj = 25°C, (Note 2) 5 mA ≤ $I_{OUT}$ ≤ 0.5A | | 30 | 100 | | 30 | 240 | | 30 | 240 | mV |
| $I_Q$ | Quiescent Current | Tj = 25°C | | 1 | 2 | | 1.5 | 3 | | 1.5 | 3 | mA |
| $\Delta I_Q$ | Quiescent Current Change | With Line | | | 0.4 | | | 0.4 | | | 0.4 | mA |
| | | | (−25 ≤ $V_{IN}$ ≤ −8) | | | (−30 ≤ $V_{IN}$ ≤ −14.5) | | | (−30 ≤ $V_{IN}$ ≤ −27) | | | V |
| | | With Load, 5 mA ≤ $I_{OUT}$ ≤ 350 mA | | | 0.4 | | | 0.4 | | | 0.4 | mA |
| $V_n$ | Output Noise Voltage | TA = 25°C, 10 Hz ≤ f ≤ 100 Hz | | 750 | | | 400 | | | 400 | | μV |
| | Ripple Rejection | f = 120 Hz | 54 | 66 | | 54 | 70 | | 54 | 70 | | dB |
| | | | (−18 ≤ $V_{IN}$ ≤ −8) | | | (−25 ≤ $V_{IN}$ ≤ −15) | | | (−30 ≤ $V_{IN}$ ≤ −17.5) | | | V |
| | Dropout Voltage | Tj = 25°C, $I_{OUT}$ = 0.5A | | 1.1 | | | 1.1 | | | 1.1 | | V |
| $I_{OMAX}$ | Peak Output Current | Tj = 25°C | | 800 | | | 800 | | | 800 | | A |
| | Average Temperature Coefficient of Output Voltage | $I_{OUT}$ = 5 mA, 0°C ≤ Tj ≤ 100°C | | 0.4 | | | −0.8 | | | −1.0 | | mV/°C |

**Note 1:** For calculations of junction temperature rise due to power dissipation, thermal resistance junction to ambient ($\theta_{JA}$) is 70°C/W (no heat sink) and 12°C/W (infinite heat sink).

**Note 2:** Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

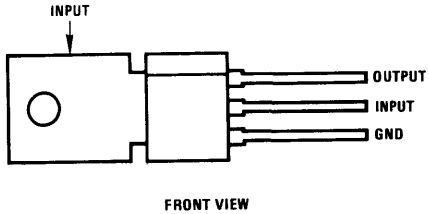
## Connection Diagrams




Metal Can Package TO-5 (H)
Order Number:

LM79M05CH
LM79M12CH
LM79M15CH

See Package H03B




FRONT VIEW

Power Package TO-202 (P)
Order Number:

LM79M05CP
LM79M12CP
LM79M15CP

See Package P03A

For Tab Bend TO-202
Order Number:
LM79M05CP TB
LM79M12CP TB
LM79M15CP TB
See Package P03E

National Semiconductor

# LM1524/LM2524/LM3524 Regulating Pulse Width Modulator

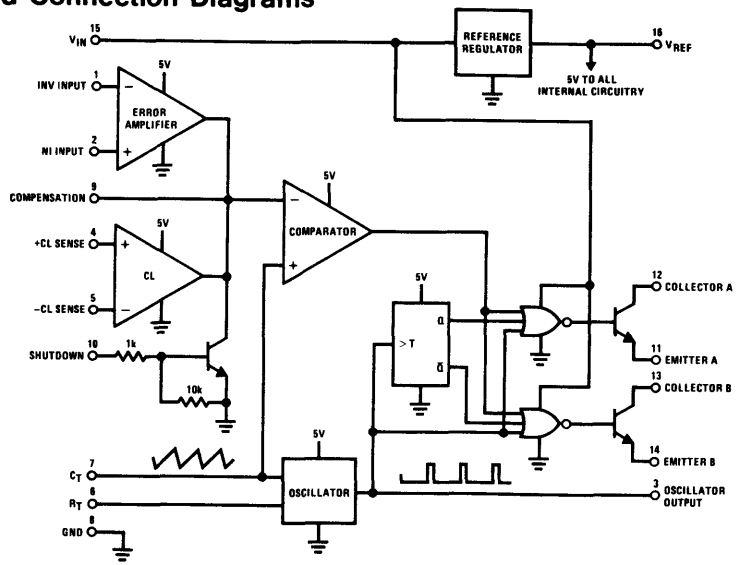
## General Description

The LM1524 series of regulating pulse width modulators contains all of the control circuitry necessary to implement switching regulators of either polarity, transformer coupled DC to DC converters, transformerless polarity converters and voltage doublers, as well as other power control applications. This device includes a 5V voltage regulator capable of supplying up to 50 mA to external circuitry, a control amplifier, an oscillator, a pulse width modulator, a phase splitting flip-flop, dual alternating output switch transistors, and current limiting and shutdown circuitry. Both the regulator output transistor and each output switch are internally current limited and, to limit junction temperature, an internal thermal shutdown circuit is employed. The LM1524 is rated for operation from −55°C to +125°C and is packaged in a hermetic 16-lead DIP (J). The LM2524 and LM3524 are rated for operation from 0°C to +70°C and are packaged in either a hermetic 16-lead DIP (J) or a 16-lead molded DIP (N).

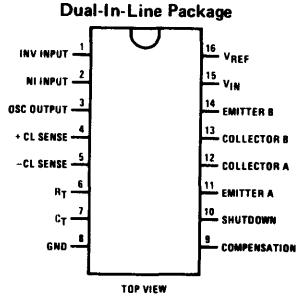
## Features

- Complete PWM power control circuitry
- Frequency adjustable to greater than 100 kHz
- 2% frequency stability with temperature
- Total quiescent current less than 10 mA
- Dual alternating output switches for both push-pull or single-ended applications
- Current limit amplifier provides external component protection
- On-chip protection against excessive junction temperature and output current
- 5V, 50 mA linear regulator output available to user

## Block and Connection Diagrams




Dual-In-Line Package




**Order Number LM1524J, LM2524J or LM3524J**
**See NS Package J16A**

**Order Number LM2524N or LM3524N**
**See NS Package N16A**

## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | 40V |
| Reference Voltage, Forced | 6V |
| Reference Output Current | 50 mA |
| Output Current (Each Output) | 100 mA |
| Oscillator Charging Current (Pin 6 or 7) | 5 mA |
| Internal Power Dissipation (Note 1) | 1W |
| Operating Temperature Range | |
| LM1524 | −55°C to +125°C |
| LM2524/LM3524 | 0°C to +70°C |
| Maximum Junction Temperature | |
| (J Package) | 150°C |
| (N Package) | 125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 300°C |

## Electrical Characteristics

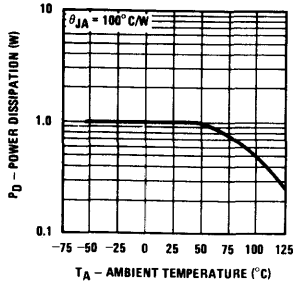
Unless otherwise stated, these specifications apply for $T_A$ = −55°C to +125°C for the LM1524 and 0°C to +70°C for the LM2524 and LM3524, $V_{IN}$ = 20V, and f = 20 kHz. Typical values other than temperature coefficients, are at $T_A$ = 25°C.

| PARAMETER | CONDITIONS | LM1524/LM2524 | | | LM3524 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| **Reference Section** | | | | | | | | |
| Output Voltage | | 4.8 | 5.0 | 5.2 | 4.6 | 5.0 | 5.4 | V |
| Line Regulation | $V_{IN}$ = 8–40V | | 10 | 20 | | 10 | 30 | mV |
| Load Regulation | $I_L$ = 0–20 mA | | 20 | 50 | | 20 | 50 | mV |
| Ripple Rejection | f = 120 Hz, $T_A$ = 25°C | | 66 | | | 66 | | dB |
| Short-Circuit Output Current | $V_{REF}$ = 0, $T_A$ = 25°C | | 100 | | | 100 | | mA |
| Temperature Stability | Over Operating Temperature Range | | 0.3 | 1 | | 0.3 | 1 | % |
| Long Term Stability | $T_A$ = 25°C | | 20 | | | 20 | | mV/khr |
| **Oscillator Section** | | | | | | | | |
| Maximum Frequency | $C_T$ = 0.001 μF, $R_T$ = 2 kΩ | | 350 | | | 350 | | kHz |
| Initial Accuracy | $R_T$ and $C_T$ constant | | 5 | | | 5 | | % |
| Frequency Change with Voltage | $V_{IN}$ = 8–40V, $T_A$ = 25°C | | | 1 | | | 1 | % |
| Frequency Change with Temperature | Over Operating Temperature Range | | | 2 | | | 2 | % |
| Output Amplitude (Pin 3) | $T_A$ = 25°C | | 3.5 | | | 3.5 | | V |
| Output Pulse Width (Pin 3) | $C_T$ = 0.01 μF, $T_A$ = 25°C | | 0.5 | | | 0.5 | | μs |
| **Error Amplifier Section** | | | | | | | | |
| Input Offset Voltage | $V_{CM}$ = 2.5V | | 0.5 | 5 | | 2 | 10 | mV |
| Input Bias Current | $V_{CM}$ = 2.5V | | 2 | 10 | | 2 | 10 | μA |
| Open Loop Voltage Gain | | 72 | 80 | | 60 | 80 | | dB |
| Common-Mode Input Voltage Range | $T_A$ = 25°C | 1.8 | | 3.4 | 1.8 | | 3.4 | V |
| Common-Mode Rejection Ratio | $T_A$ = 25°C | | 70 | | | 70 | | dB |
| Small Signal Bandwidth | $A_V$ = 0 dB, $T_A$ = 25°C | | 3 | | | 3 | | MHz |
| Output Voltage Swing | $T_A$ = 25°C | 0.5 | | 3.8 | 0.5 | | 3.8 | V |
| **Comparator Section** | | | | | | | | |
| Maximum Duty Cycle | % Each Output ON | 45 | | | 45 | | | % |
| Input Threshold (Pin 9) | Zero Duty Cycle | | 1 | | | 1 | | V |
| Input Threshold (Pin 9) | Maximum Duty Cycle | | 3.5 | | | 3.5 | | V |
| Input Bias Current | | | −1 | | | −1 | | μA |
| **Current Limiting Section** | | | | | | | | |
| Sense Voltage | $V_{(Pin\ 2)} - V_{(Pin\ 1)} \geq 50$ mV, Pin 9 = 2V, $T_A$ = 25°C | 190 | 200 | 210 | 180 | 200 | 220 | mV |
| Sense Voltage T.C. | | | 0.2 | | | 0.2 | | mV/°C |
| Common-Mode Voltage | | −0.7 | | 1 | − 0.7 | | 1 | V |
| **Output Section (Each Output)** | | | | | | | | |
| Collector-Emitter Voltage | | 40 | | | 40 | | | V |
| Collector Leakage Current | $V_{CE}$ = 40V | | 0.1 | 50 | | 0.1 | 50 | μA |
| Saturation Voltage | $I_C$ = 50 mA | | 1 | 2 | | 1 | 2 | V |
| Emitter Output Voltage | $V_{IN}$ = 20V, $I_E$ = −250 μA | 17 | 18 | | 17 | 18 | | V |
| Rise Time (10% to 90%) | $R_C$ = 2 kΩ, $T_A$ = 25°C | | 0.2 | | | 0.2 | | μs |
| Fall Time (90% to 10%) | $R_C$ = 2 kΩ, $T_A$ = 25°C | | 0.1 | | | 0.1 | | μs |
| **Total Standby Current** | $V_{IN}$ = 40V, Pins 1, 4, 7, 8, 11 and 14 are grounded, Pin 2 = 2V, All Other Inputs and Outputs Open | | 5 | 10 | | 5 | 10 | mA |

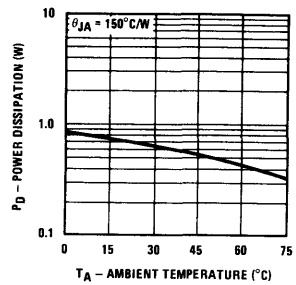
**Note 1:** For operation at elevated temperatures, devices in the J package must be derated based on a thermal resistance of 100°C/W, junction to ambient, and devices in the N package must be derated based on a thermal resistance of 150°C/W, junction to ambient.

## Typical Performance Characteristics

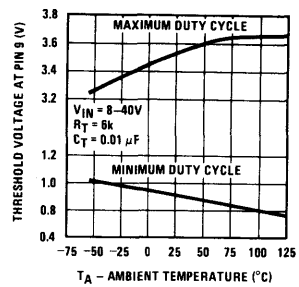
### Maximum Average Power Dissipation (J Package)



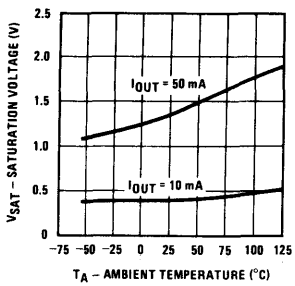

### Maximum Average Power Dissipation (N Package)



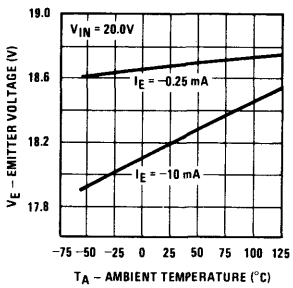

### Maximum and Minimum Duty Cycle Threshold Voltage



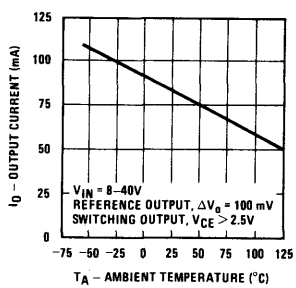

### Output Transistor Saturation Voltage



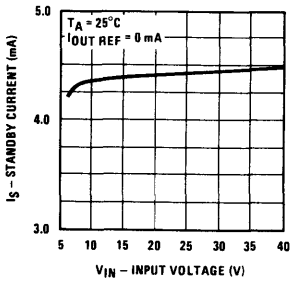

### Output Transistor Emitter Voltage



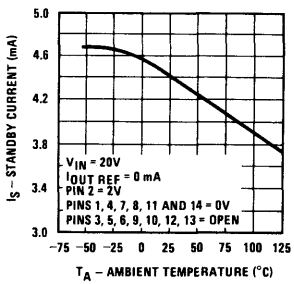

### Reference and Switching Transistor Peak Output Current



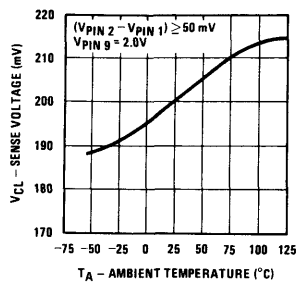

### Standby Current



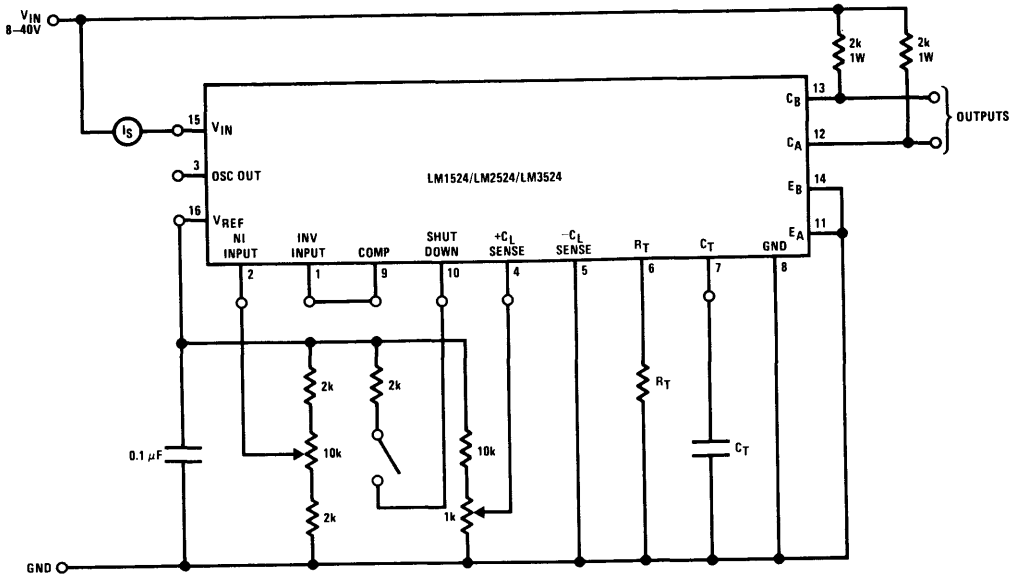

### Standby Current




### Current Limit Sense Voltage ($V_{Pin\ 4} - V_{Pin\ 5}$)



## Test Circuit

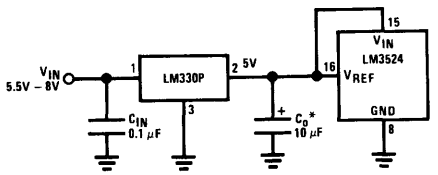



## Functional Description

### INTERNAL VOLTAGE REGULATOR

The LM3524 has on chip a 5V, 50 mA, short circuit protected voltage regulator. This voltage regulator provides a supply for all internal circuitry of the device and can be used as an external reference.

For input voltages of less than 8V the 5V output should be shorted to pin 15, $V_{IN}$, which disables the 5V regulator. With these pins shorted the input voltage must be limited to a maximum of 6V. If input voltages of 6–8V are to be used, a pre-regulator, as shown in *Figure 1*, must be added.




*Minimum $C_O$ of 10 μF required for stability.

FIGURE 1

### OSCILLATOR

The LM3524 provides a stable on-board oscillator. Its frequency is set by an external resistor, $R_T$ and capacitor, $C_T$. A graph of $R_T$, $C_T$ vs oscillator frequency is shown in *Figure 2*. The oscillator's output provides the signals for triggering an internal flip-flop, which directs the PWM information to the outputs, and a blanking pulse to turn off both outputs during transitions to ensure that cross conduction does not occur. The width of the blanking pulse, or dead time, is controlled by the value of $C_T$, as shown in *Figure 3*. The recommended values of $R_T$ are 1.8 kΩ to 100 kΩ, and for $C_T$, 0.001 μF to 0.1 μF.

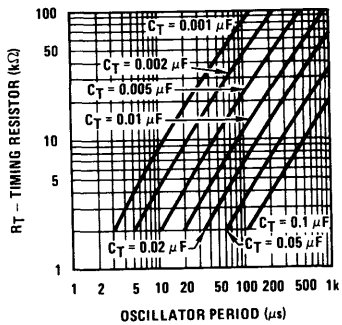



FIGURE 2

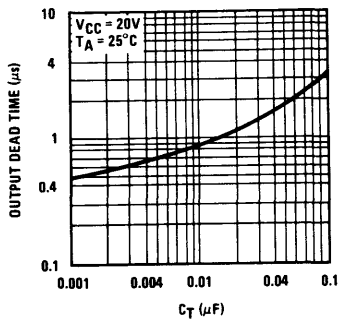



FIGURE 3

## Functional Description (Continued)

### ERROR AMPLIFIER

The error amplifier is a differential input, transconductance amplifier. Its gain, nominally 80 dB, is set by either feedback or output loading. This output loading can be done with either purely resistive or a combination of resistive and reactive components. A graph of the amplifier's gain vs output load resistance is shown in *Figure 4*.

The output of the amplifier, or input to the pulse width modulator, can be overridden easily as its output impedance is very high ($Z_O \simeq 5$ MΩ). For this reason a DC voltage can be applied to pin 9 which will override the error amplifier and force a particular duty cycle to the outputs. An example of this could be a non-regulating motor speed control where a variable voltage was applied to pin 9 to control motor speed. A graph of the output duty cycle vs the voltage on pin 9 is shown in *Figure 5*.

The amplifier's inputs have a common-mode input range of 1.8V–3.4V. The on board regulator is useful for biasing the inputs to within this range.

### CURRENT LIMITING

The function of the current limit amplifier is to override the error amplifier's output and take control of the pulse width. The output duty cycle drops to about 25% when a current limit sense voltage of 200 mV is applied between the $+C_L$ and $-C_L$ terminals. Increasing the sense voltage approximately 5% results in a 0% output duty cycle. Care should be taken to ensure the −0.7V to +1.0V input common-mode range is not exceeded.

### OUTPUT STAGES

The outputs of the LM3524 are NPN transistors, capable of a maximum current of 100 mA. These transistors are driven 180° out of phase and have non-committed open collectors and emitters as shown in *Figure 6*.

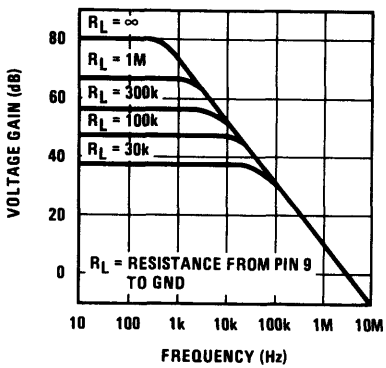



FIGURE 4

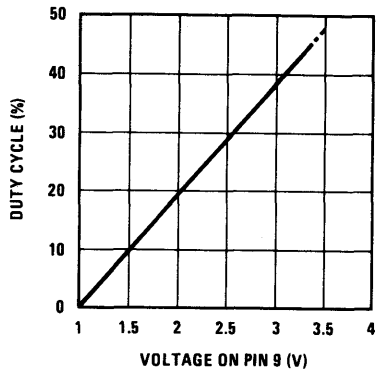



FIGURE 5

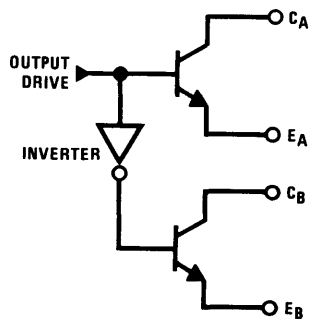
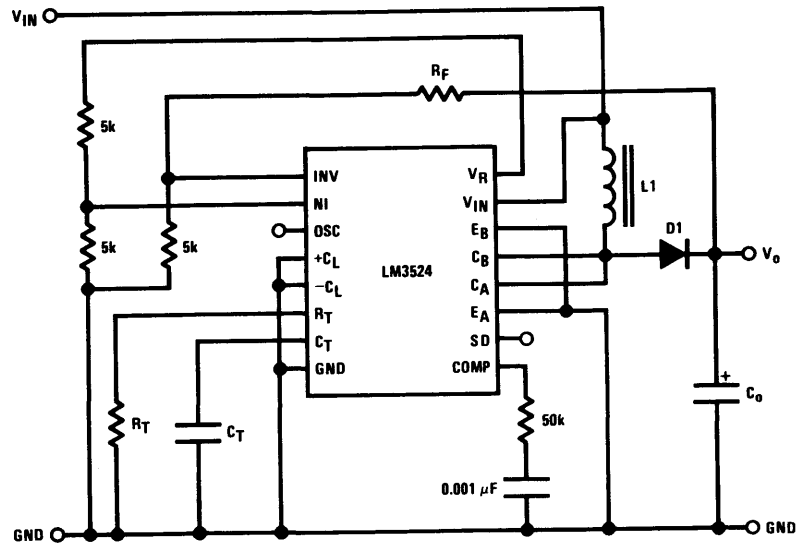



FIGURE 6

## Typical Applications




**DESIGN EQUATIONS**

$$R_F = 5k\left(\frac{V_o}{2.5} - 1\right)$$

$$f_{OSC} \simeq \frac{1}{R_T C_T}$$

$$L1 = \frac{2.5V_{IN}^2 (V_o - V_{IN})}{f_{OSC} I_o V_o^2}$$

$$C_o = \frac{I_o (V_o - V_{IN})}{f_{OSC} \Delta V_o V_o}$$

$$I_{o(MAX)} = I_{IN} \frac{V_{IN}}{V_o}$$

FIGURE 7. Positive Regulator, Step-Up Basic Configuration ($I_{IN(MAX)}$ = 80 mA)

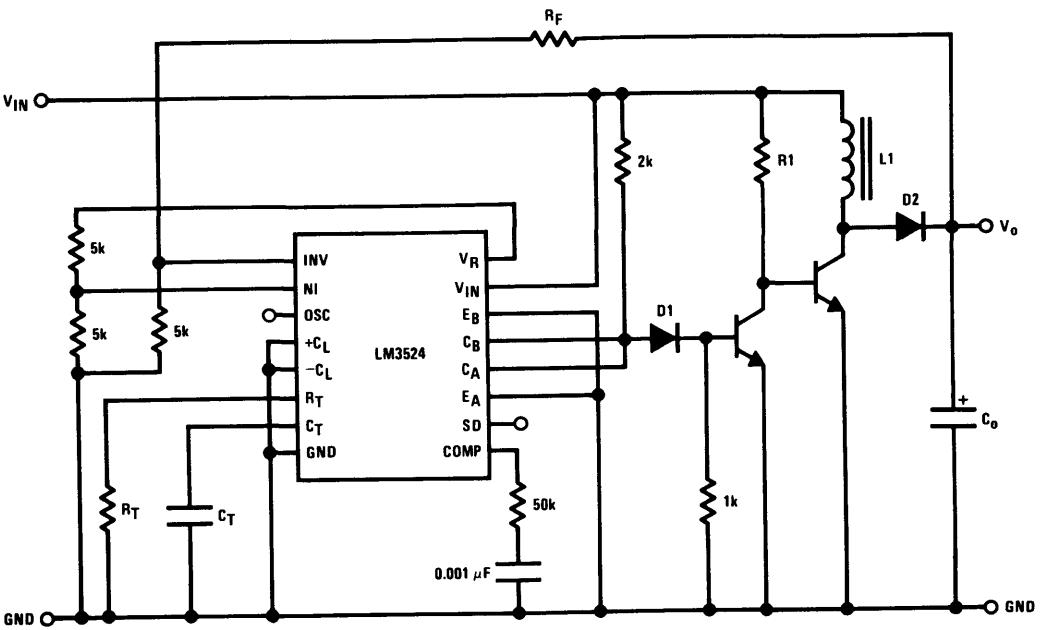
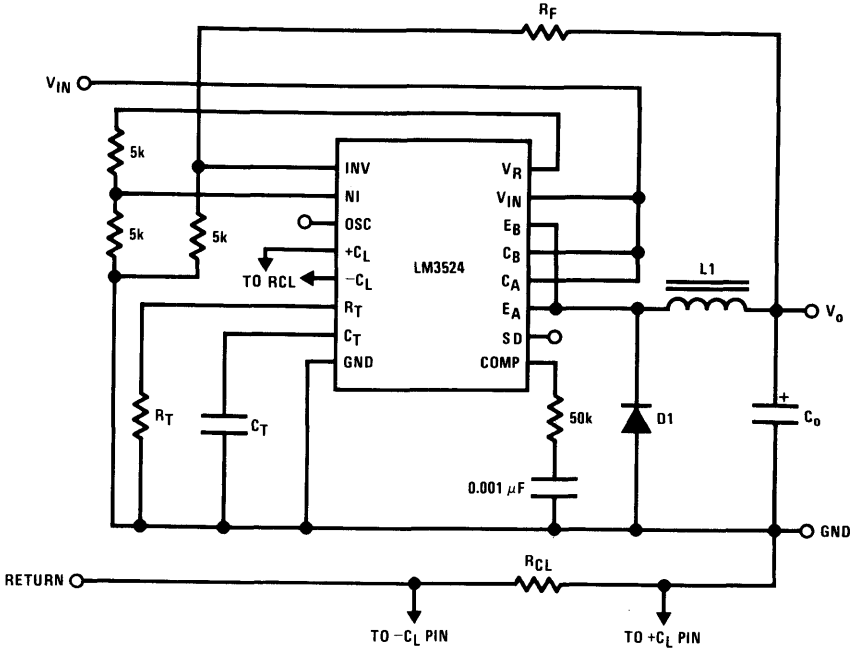



FIGURE 8. Positive Regulator, Step-Up Boosted Current Configuration

## Typical Applications (Continued)




**DESIGN EQUATIONS**

$$R_F = 5\ k\Omega\left(\frac{V_o}{2.5} - 1\right)$$

$$R_{CL} = \frac{\text{CURRENT LIMIT SENSE VOLT}}{I_{o(MAX)}}$$

$$f_{OSC} \simeq \frac{1}{R_T C_T}$$

$$L1 = \frac{2.5V_o (V_{IN} - V_o)}{I_o V_{IN} f_{OSC}}$$

$$C_o = \frac{(V_{IN} - V_o) V_o T^2}{8 \Delta V_o V_{IN} L1}$$

$$I_{o(MAX)} = I_{IN} \frac{V_{IN}}{V_o}$$

FIGURE 9. Positive Regulator, Step-Down Basic Configuration ($I_{IN(MAX)}$ = 80 mA)

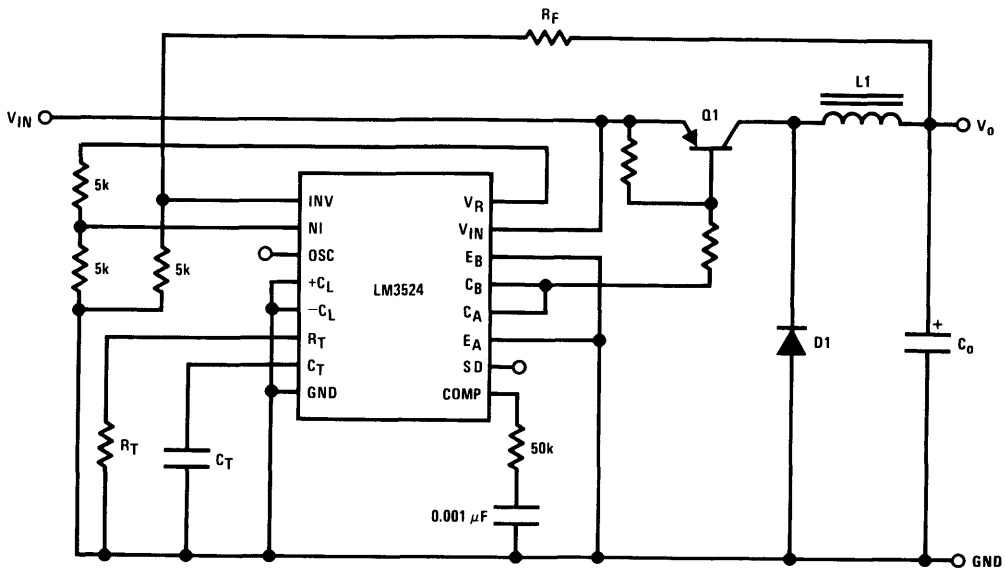
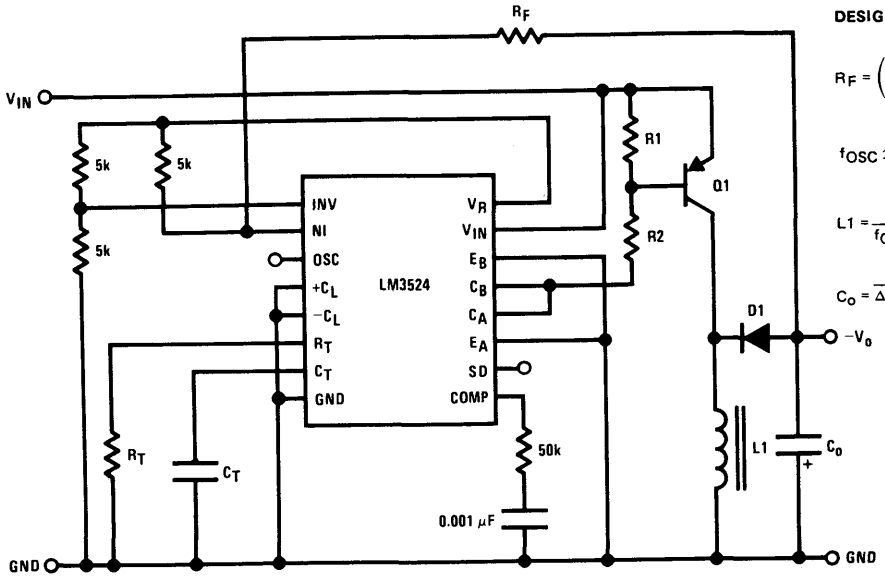



FIGURE 10. Positive Regulator, Step-Down Boosted Current Configuration

## Typical Applications (Continued)




**DESIGN EQUATIONS**

$$R_F = \left(1 - \frac{V_o}{2.5}\right) R1$$

$$f_{OSC} \simeq \frac{1}{R_T C_T}$$

$$L1 = \frac{2.5 V_{IN}\, V_o}{f_{OSC}\,(V_o + V_{IN})\, I_o}$$

$$C_o = \frac{I_o V_o}{\Delta V_o\, f_{OSC}\,(V_o + V_{IN})}$$

FIGURE 11. Boosted Current Polarity Inverter

### BASIC SWITCHING REGULATOR THEORY AND APPLICATIONS

The basic circuit of a step-down switching regulator circuit is shown in *Figure 12*, along with a practical circuit design using the LM3524 in *Figure 15*.

The circuit works as follows: Q1 is used as a switch, which has ON and OFF times controlled by the pulse width modulator. When Q1 is ON, power is drawn from $V_{IN}$ and supplied to the load through L1; $V_A$ is at approximately $V_{IN}$, D1 is reverse biased, and $C_O$ is charging. When Q1 turns OFF the inductor L1 will force $V_A$ negative to keep the current flowing in it, D1 will start conducting and the load current will flow through D1 and L1. The voltage at $V_A$ is smoothed by the L1, $C_O$ filter giving a clean DC output. The current flowing through L1 is equal to the nominal DC load current plus some $\Delta I_L$ which is due to the changing voltage across it. *A good rule of thumb is to set* $\Delta I_{Lp\text{-}p} \simeq 40\% \cdot I_O$.

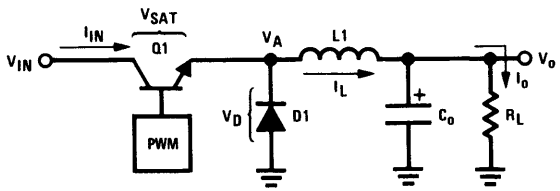



FIGURE 12. Basic Step-Down Switching Regulator

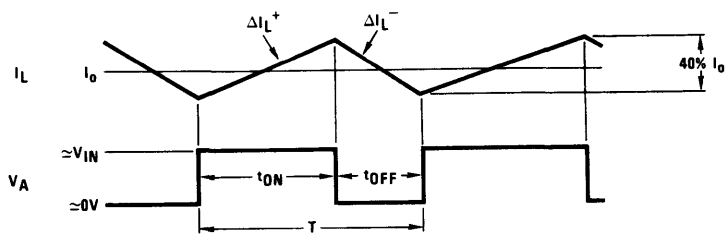



FIGURE 13

## Typical Applications (Continued)

From the relation $V_L = L\frac{di}{dt}$, $\Delta I_L \simeq \frac{V_L T}{L1}$

$$\Delta I_L^+ = \frac{(V_{IN} - V_O)\, t_{ON}}{L1}; \quad \Delta I_L^- = \frac{V_O\, t_{OFF}}{L1}$$

Neglecting $V_{SAT}$, $V_D$, and settling $\Delta I_L^+ = \Delta I_L^-$;

$$\boxed{V_O \simeq V_{IN}\left(\frac{t_{ON}}{t_{OFF} + t_{ON}}\right) = V_{IN}\left(\frac{t_{ON}}{T}\right);}$$

where T = Total Period

The above shows the relation between $V_{IN}$, $V_O$ and duty cycle.

$$I_{IN(DC)} = I_{OUT(DC)}\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right),$$

as Q1 only conducts during $t_{ON}$.

$$P_{IN} = I_{IN(DC)}V_{IN} = (I_{o(DC)})\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right)V_{IN}$$

$$P_O = I_O V_O$$

The efficiency, $\eta$, of the circuit is:

$$\eta MAX = \frac{P_O}{P_{IN}} = \frac{I_O V_O}{I_O\frac{(t_{ON})}{T}V_{IN} + \frac{(V_{SAT}\, t_{ON} + V_{D1} t_{OFF})}{T} I_O}$$

$$= \boxed{\frac{V_O}{V_O + 1}} \text{ for } V_{SAT} = V_{D1} = 1V.$$

$\eta$MAX will be further decreased due to switching losses in Q1. For this reason Q1 should be selected to have the maximum possible $f_T$, which implies very fast rise and fall times.

### CALCULATING INDUCTOR L1

$$t_{ON} \simeq \frac{(\Delta I_L^+) \cdot L1}{(V_{IN} - V_O)}, \quad t_{OFF} = \frac{(\Delta I_L^-) \cdot L1}{V_O}$$

$$t_{ON} + t_{OFF} = T = \frac{(\Delta I_L^+) \cdot L1}{(V_{IN} - V_O)} + \frac{(\Delta I_L^-) \cdot L1}{V_O}$$

$$= \frac{0.4 I_O L1}{(V_{IN} - V_O)} + \frac{0.4 I_O L1}{V_O}$$

Since $\Delta I_L^+ = \Delta I_L^- = 0.4 I_O$

Solving the above for L1

$$\boxed{L1 = \frac{2.5\, V_O(V_{IN} - V_O)}{I_O V_{IN} f}}$$

where: L1 is in Henrys
f is switching frequency in Hz

### CALCULATING OUTPUT FILTER CAPACITOR $C_O$:

*Figure 14* shows L1's current with respect to Q1's $t_{ON}$ and $t_{OFF}$ times. This current must flow to the load and $C_O$. $C_O$'s current will then be the difference between $I_L$, and $I_O$.

$$I_{CO} = I_L - I_O$$

From *Figure 14* it can be seen that current will be flowing into $C_O$ for the second half of $t_{ON}$ through the first half of $t_{OFF}$, or a time , $t_{ON}/2 + t_{OFF}/2$. The current flowing for this time is $\Delta I_L/4$. The resulting $\Delta V_C$ or $\Delta V_O$ is described by:

$$\Delta V_{op\text{-}p} = \frac{1}{C} \cdot \frac{\Delta I_L}{4} \cdot \left(\frac{t_{ON}}{2} + \frac{t_{OFF}}{2}\right)$$

$$= \frac{\Delta I_L}{4C}\left(\frac{t_{ON} + t_{OFF}}{2}\right)$$

Since $\Delta I_L = \frac{V_O(T - t_{ON})}{L1}$ and $t_{ON} = \frac{V_O T}{V_{IN}}$

$$\Delta V_{op\text{-}p} = \frac{V_O\left(T - \frac{V_O T}{V_{IN}}\right)}{4C\, L1}\left(\frac{T}{2}\right) = \frac{(V_{IN} - V_O)\, V_O T^2}{8 V_{IN} C_O L1} \text{ or}$$

$$\boxed{C_O = \frac{(V_{IN} - V_O)V_O\, T^2}{8\Delta V_O V_{IN} L1}}$$

where: C is in farads, T is $\frac{1}{\text{switching frequency}}$,

$\Delta V_O$ is p-p output ripple

*The inductor's current cannot be allowed to fall to zero, as this would cause the inductor to saturate. For this reason some minimum $I_O$ is required as shown below:*

$$I_{o(MIN)} = \frac{(V_{IN} - V_O)\, t_{ON}}{2L1} = \boxed{\frac{(V_{IN} - V_O)\, V_O}{2 f V_{IN} L1}}$$

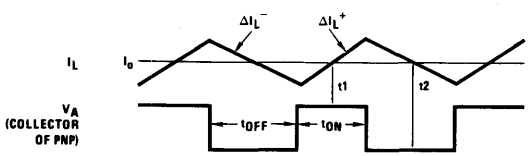
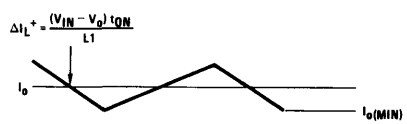



FIGURE 14



## Typical Applications (Continued)

A complete step-down switching regulator schematic, using the LM3524, is illustrated in *Figure 15*. Transistors Q1 and Q2 have been added to boost the output to 1A. The 5V regulator of the LM3524 has been divided in half to bias the error amplifier's non-inverting input to within its common-mode range. Since each output transistor is on for half the period, actually 45%, they have been paralleled to allow longer possible duty cycles, up to 90%. This makes a lower possible input voltage. The output voltage is set by:

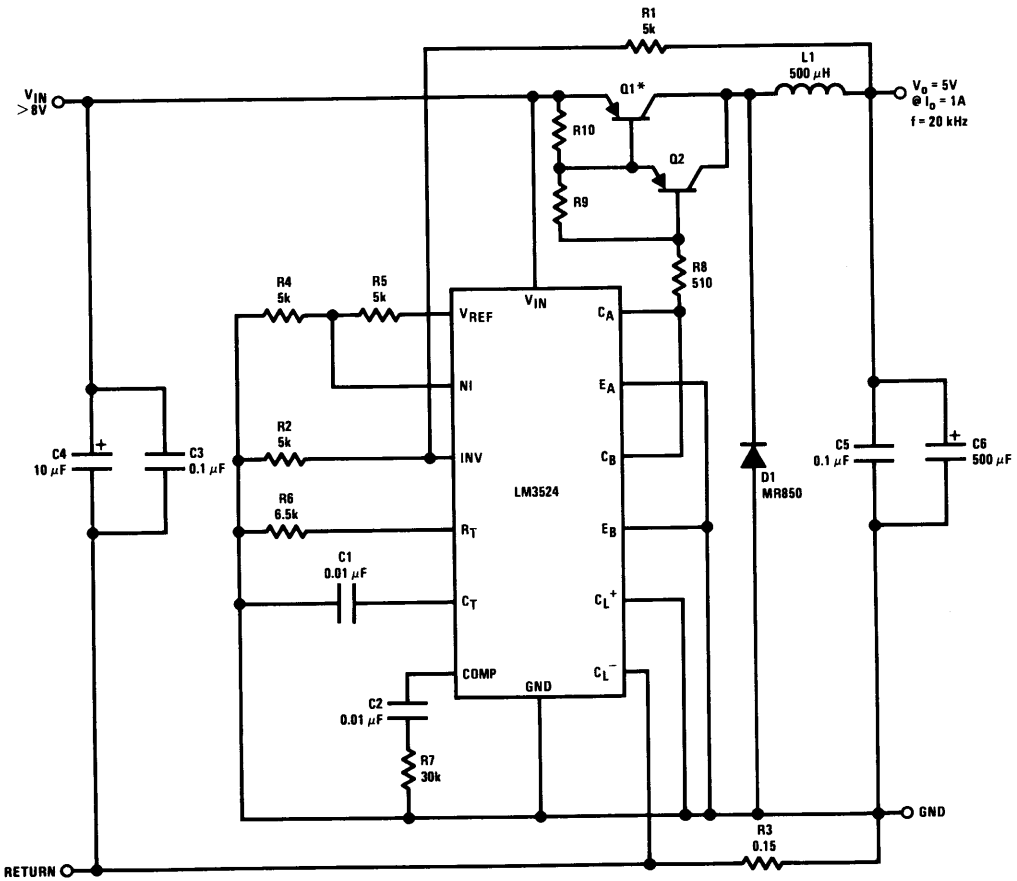
$$V_O = V_{NI}\left(1 + \frac{R1}{R2}\right),$$

where $V_{NI}$ is the voltage at the error amplifier's non-inverting input.

Resistor R3 sets the current limit to:

$$\frac{200\ mV}{R3} = \frac{200\ mV}{0.15} = 1.3A.$$

*Figure 16* and *17* show a PC board layout and stuffing diagram for the 5V, 1A regulator of *Figure 15*. The regulator's performance is listed in Table I.




*Mounted to Staver Heatsink No. V5-1.
Q1 = BD344
Q2 = 2N5023
L1 = > 40 turns No. 22 wire on Ferroxcube No. K300502 Torroid core.

**FIGURE 15. 5V, 1 Amp Step-Down Switching Regulator**

## Typical Applications (Continued)

TABLE I

| PARAMETER | CONDITIONS | TYPICAL CHARACTERISTICS |
|---|---|---|
| Output Voltage | $V_{IN}$ = 10V, $I_O$ = 1A | 5V |
| Switching Frequency | $V_{IN}$ = 10V, $I_O$ = 1A | 20 kHz |
| Short Circuit Current Limit | $V_{IN}$ = 10V | 1.3A |
| Load Regulation | $V_{IN}$ = 10V, $I_O$ = 0.2 − 1A | 3 mV |
| Line Regulation | $\Delta V_{IN}$ = 10 − 20V, $I_O$ = 1A | 6 mV |
| Efficiency | $V_{IN}$ = 10V, $I_O$ = 1A | 80% |
| Output Ripple | $V_{IN}$ = 10V, $I_O$ = 1A | 10 mVp-p |

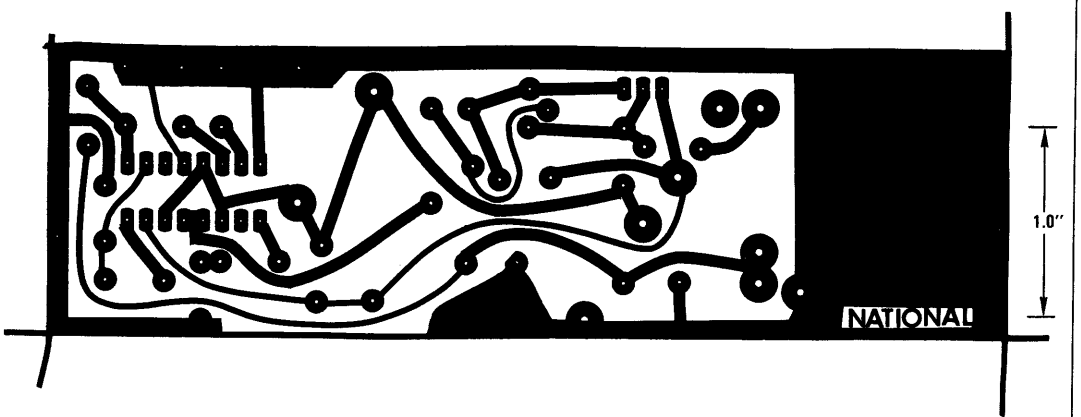



FIGURE 16. 5V, 1 Amp Switching Regulator, Foil Side

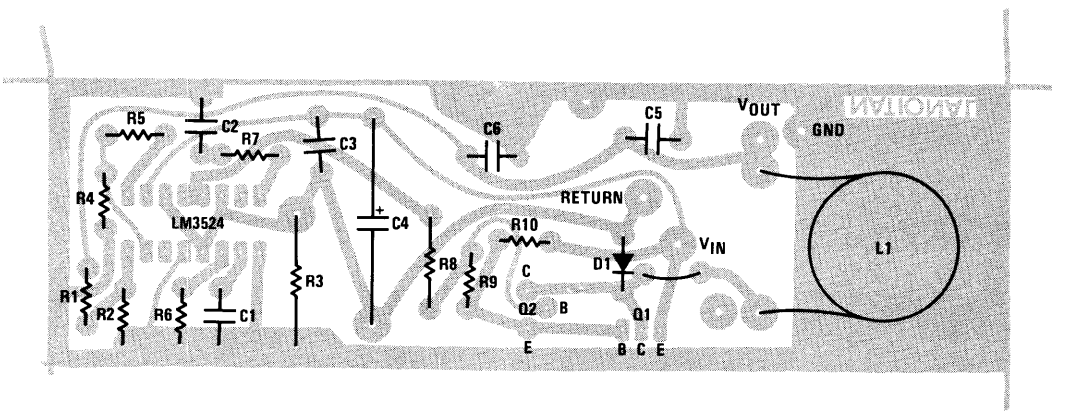



FIGURE 17. Stuffing Diagram, Component Side.

## Typical Applications (Continued)

### THE STEP-UP SWITCHING REGULATOR

*Figure 18* shows the basic circuit for a step-up switching regulator. In this circuit Q1 is used as a switch to alternately apply $V_{IN}$ across inductor L1. During the time, $t_{ON}$, Q1 is ON and energy is drawn from $V_{IN}$ and stored in L1; D1 is reverse biased and $I_O$ is supplied from the charge stored in $C_O$. When Q1 opens, $t_{OFF}$, voltage V1 will rise positively to the point where D1 turns ON. The output current is now supplied through L1, D1 to the load and any charge lost from $C_O$ during $t_{ON}$ is replenished. Here also, as in the step-down regulator, the current through L1 has a DC component plus some $\Delta I_L$. $\Delta I_L$ is again selected to be approximately 40% of $I_L$. *Figure 19* shows the inductor's current in relation to Q1's ON and OFF times.

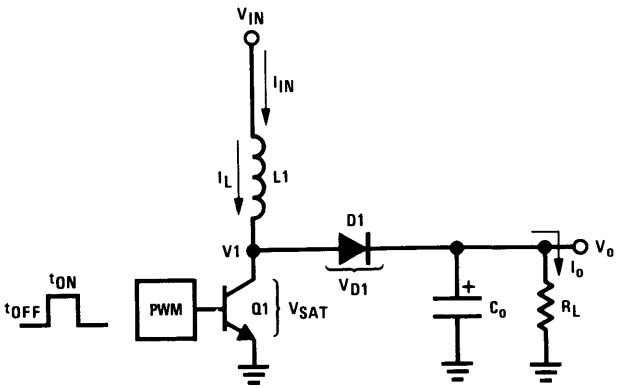



FIGURE 18. Basic Step-Up Switching Regulator

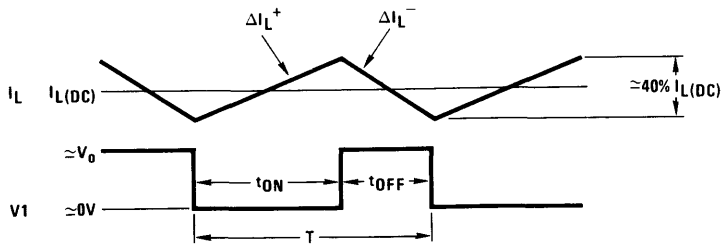



FIGURE 19

## Typical Applications (Continued)

From $\Delta I_L = \frac{V_L T}{L}$, $\Delta I_L^+ \simeq \frac{V_{IN} t_{ON}}{L1}$

and $\Delta I_L^- \simeq \frac{(V_o - V_{IN}) t_{OFF}}{L1}$

Since $\Delta I_L^+ = \Delta I_L^-$, $V_{IN} t_{ON} = V_o t_{OFF} - V_{IN} t_{OFF}$,

and neglecting $V_{SAT}$ and $V_{D1}$

$$\boxed{V_o \simeq V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)}$$

The above equation shows the relationship between $V_{IN}$, $V_o$ and duty cycle.

In calculating input current $I_{IN(DC)}$, which equals the inductor's DC current, assume first 100% efficiency:

$P_{IN} = I_{IN(DC)} V_{IN}$

$P_{OUT} = I_o V_o = I_o \; V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$

for $\eta = 100\%$, $P_{OUT} = P_{IN}$

$I_o \; V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right) = I_{IN(DC)} V_{IN}$

$I_{IN(DC)} = I_o\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$

This equation shows that the input, or inductor, current is larger than the output current by the factor $(1 + t_{ON}/t_{OFF})$. Since this factor is the same as the relation between $V_o$ and $V_{IN}$, $I_{IN(DC)}$ can also be expressed as:

$$\boxed{I_{IN(DC)} = I_o\left(\frac{V_o}{V_{IN}}\right)}$$

So far it is assumed $\eta = 100\%$, where the actual efficiency or $\eta MAX$ will be somewhat less due to the saturation voltage of Q1 and forward on voltage of D1. The internal power loss due to these voltages is the average $I_L$ current flowing, or $I_{IN}$, through either $V_{SAT}$ or $V_{D1}$. For $V_{SAT} = V_{D1} = 1V$ this power loss becomes $I_{IN(DC)}$ (1V). $\eta MAX$ is then:

$$\eta MAX = \frac{P_o}{P_{IN}} = \frac{V_o I_o}{V_o I_o + I_{IN}\,(1V)} = \frac{V_o I_o}{V_o I_o + I_o\left(1 + \frac{t_{ON}}{t_{OFF}}\right)}$$

From $V_o = V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$,

$$\boxed{\eta max = \frac{V_{IN}}{V_{IN} + 1}}$$

This equation assumes only DC losses, however $\eta MAX$ is further decreased because of the switching time of Q1 and D1.

In calculating the output capacitor $C_o$ it can be seen that $C_o$ supplies $I_o$ during $t_{ON}$. The voltage change on $C_o$ during this time will be some $\Delta V_c = \Delta V_o$ or the output ripple of the regulator. Calculation of $C_o$ is:

$\Delta V_o = \frac{I_o t_{ON}}{C_o}$ or $C_o = \frac{I_o t_{ON}}{\Delta V_o}$

From $V_o = V_{IN}\left(\frac{T}{t_{OFF}}\right)$; $t_{OFF} = \frac{V_{IN}}{V_o} T$

where $T = t_{ON} + t_{OFF} = \frac{1}{f}$

$t_{ON} = T - \frac{V_{IN}}{V_o} T = T\left(\frac{V_o - V_{IN}}{V_o}\right)$ therefore:

$$C_o = \frac{I_o T\left(\frac{V_o - V_{IN}}{V_o}\right)}{\Delta V_o} = \boxed{\frac{I_o (V_o - V_{IN})}{f \Delta V_o V_o}}$$

where: $C_o$ is in farads, f is the switching frequency, $\Delta V_o$ is the p-p output ripple

Calculation of inductor L1 is as follows:

$L1 = \frac{V_{IN} t_{ON}}{\Delta I_L^+}$, since during $t_{ON}$,

$V_{IN}$ is applied across L1

$\Delta I_{Lp\text{-}p} = 0.4 I_L = 0.4 I_{IN} = 0.4 I_o\left(\frac{V_o}{V_{IN}}\right)$, therefore:

$$L1 = \frac{V_{IN} t_{ON}}{0.4 I_o\left(\frac{V_o}{V_{IN}}\right)} \text{ and since } t_{ON} = \frac{T(V_o - V_{IN})}{V_o}$$

$$\boxed{L1 = \frac{2.5\, V_{IN}^2 (V_o - V_{IN})}{f\, I_o V_o^2}}$$

where :L1 is in henrys, f is the switching frequency in Hz

## Typical Applications (Continued)

To apply the above theory, a complete step-up switching regulator is shown in *Figure 20*. Since $V_{IN}$ is 5V, $V_{REF}$ is tied to $V_{IN}$. The input voltage is divided by 2 to bias the error amplifier's inverting input. The output voltage is:

$$V_{OUT} = \left(1 + \frac{R2}{R1}\right) \cdot V_{INV} = 2.5 \cdot \left(1 + \frac{R2}{R1}\right)$$

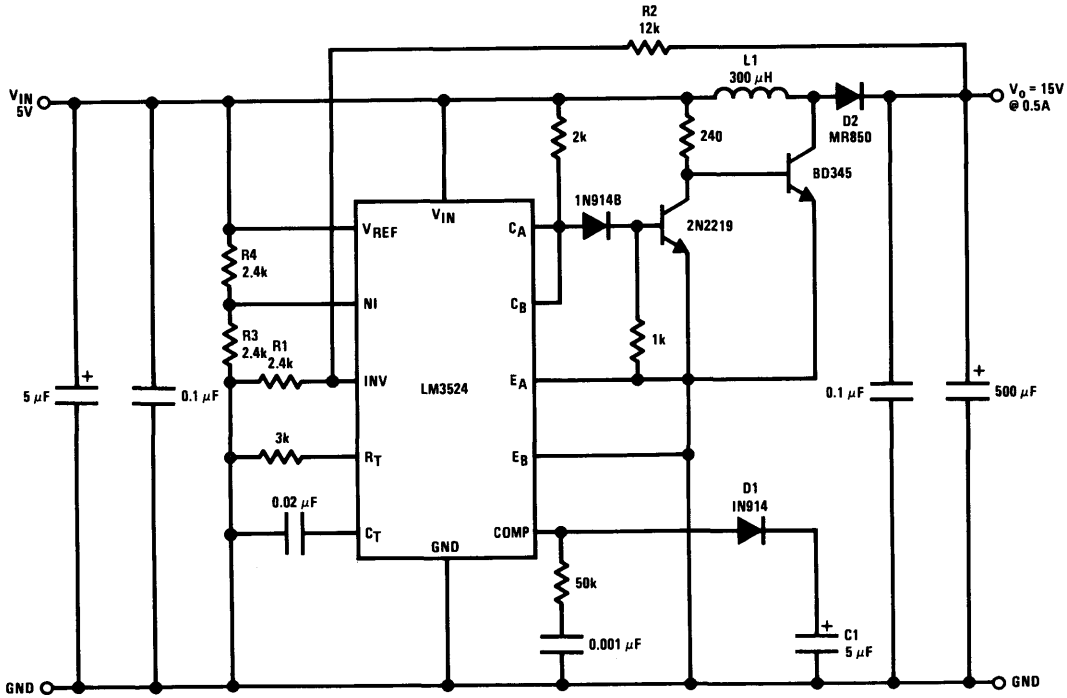
The network D1, C1 forms a slow start circuit.

This holds the output of the error amplifier initially low thus reducing the duty-cycle to a minimum. Without the slow start circuit the inductor may saturate at turn-on because it has to supply high peak currents to charge the output capacitor from 0V. It should also be noted that this circuit has no supply rejection. By adding a reference voltage at the non-inverting input to the error amplifier, see *Figure 21*, the input voltage variations are rejected.

The LM3524 can also be used in inductorless switching regulators. *Figure 22* shows a polarity inverter which if connected to *Figure 20* provides a −15V unregulated output.

### MOTOR SPEED CONTROL

*Figure 23* shows a regulating series DC motor speed control circuit using the LM3524 for the control and drive for the motor and the LM2907 as a speed sensor for the feedback network.




L1 = > 25 turns No. 24 wire on Ferroxcube No. K300502 Torroid core.

**FIGURE 20. 15V, 0.5A Step-Up Switching Regulator**

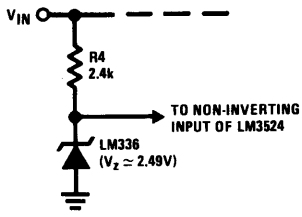



**FIGURE 21**

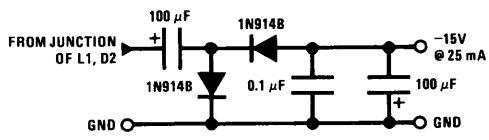



**FIGURE 22**

## Typical Applications (Continued)

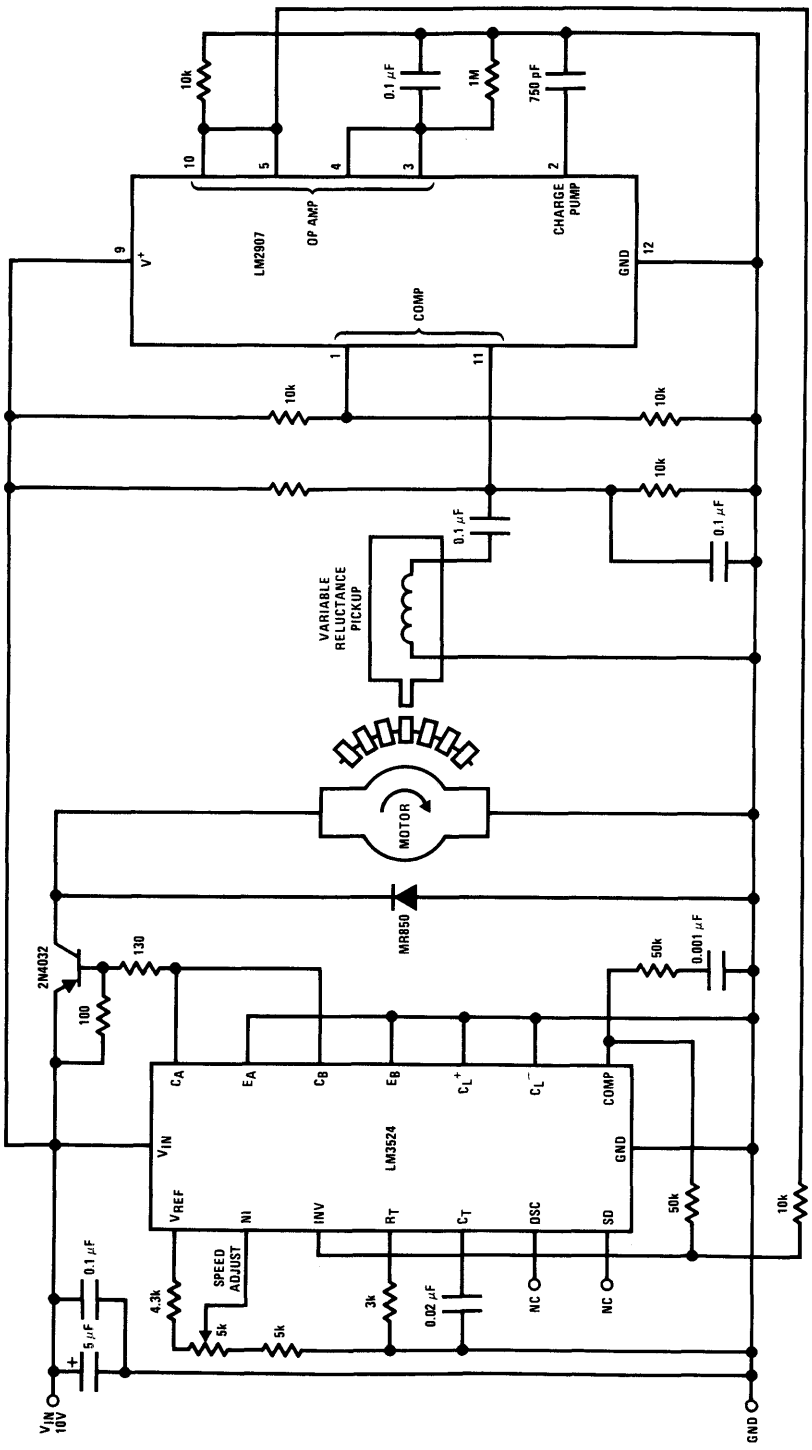



FIGURE 23. Motor Speed Control

National Semiconductor



# LM2930 3-Terminal Positive Regulator

## General Description

The LM2930 3-terminal positive voltage regulator features an ability to source 150mA of output current with an input-output differential of 0.6V or less. Efficient use of low input voltages obtained, for example, from an automotive battery during cold crank conditions, allows 5V circuitry to be properly powered with supply voltages as low as 5.6V. Familiar regulator features such as current limit and thermal overload protection are also provided.

Designed primarily for automotive applications, the LM2930 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (40V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both internal circuits and the load. The LM2930 cannot be harmed by temporary mirror-image insertion.

Fixed outputs of 5V and 8V are available in the plastic TO-202 power package.

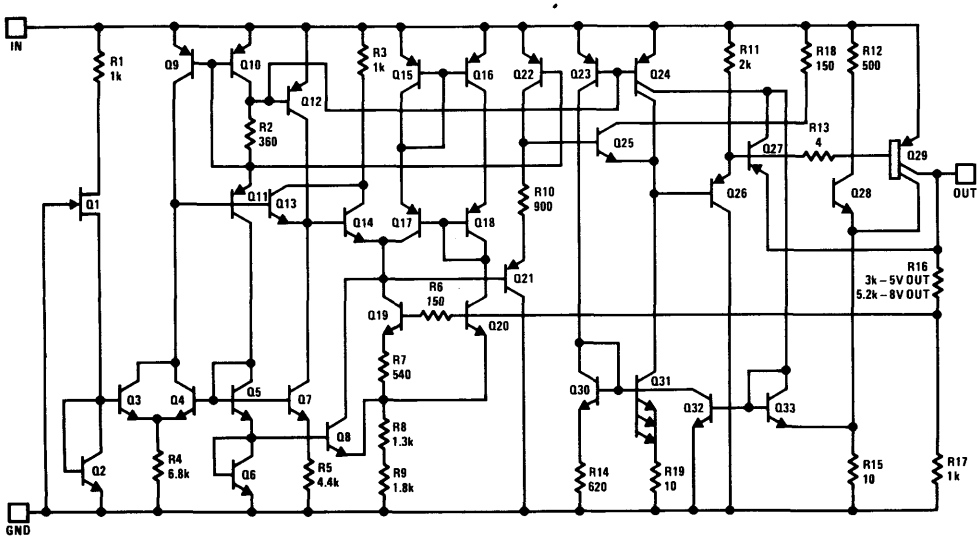
## Features

- Input-output differential less than 0.6V
- Output current in excess of 150mA
- Reverse battery protection
- 40V load dump protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection

## Voltage Range

| | |
|---|---|
| LM2930P-5.0TB | 5V |
| LM2930P-8.0TB | 8V |

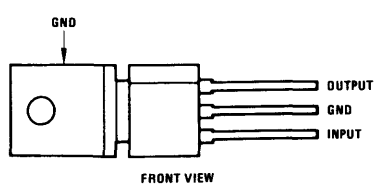
## Schematic and Connection Diagrams




**Order Number**

**LM2930-5.0 TB**
**LM2930-8.0 TB**

**See Package P03E**



## Absolute Maximum Ratings

| | |
|---|---|
| Input Voltage | |
| Operating Range | 26V |
| Overvoltage Protection | 40V |
| Reverse Voltage (100 ms) | −12V |
| Reverse Voltage (DC) | −6V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range | −40°C to +85°C |
| Maximum Junction Temperature | 125°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 230°C |

## Electrical Characteristics (Note 2)

LM2930P-5.0TB ($V_{IN}$ = 14V, $I_O$ = 150 mA, $T_j$ = 25°C, C2 = 10 μF, unless otherwise specified)

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Output Voltage | 6V ≤ $V_{IN}$ ≤ 26V, 5 mA ≤ $I_O$ ≤ 150 mA, −40°C ≤ $T_j$ ≤ +125°C | 4.5 | 5 | 5.5 | V |
| Line Regulation | 9V ≤ $V_{IN}$ ≤ 16V, $I_O$ = 5 mA | | 7 | 25 | mV |
| | 6V ≤ $V_{IN}$ ≤ 26V $I_O$ = 5 mA | | 30 | 80 | mV |
| Load Regulation | 5 mA ≤ $I_O$ ≤ 150 mA | | 14 | 50 | mV |
| Output Impedance | 100 $mA_{DC}$ & 10 mA rms, 100 Hz-10 kHz | | 200 | | mΩ |
| Quiescent Current | $I_O$ = 10 mA | | 4 | 7 | mA |
| | $I_O$ = 150 mA | | 30 | 40 | mA |
| Output Noise Voltage | 10 Hz-100 kHz | | 140 | | μVrms |
| Long Term Stability | | | 20 | | mV/1000 hr |
| Ripple Rejection | $f_O$ = 120 Hz | | 56 | | dB |
| Dropout Voltage | $I_O$ = 150 mA | | 0.3 | 0.6 | V |
| Output Voltage Under Transient Conditions | −12V ≤ $V_{IN}$ ≤ 40V, $R_L$ = 100Ω | | −0.3 | 5.5 | V |

## Electrical Characteristics (Note 2)

LM2930P-8.0TB ($V_{IN}$ = 14V, $I_O$ = 150 mA, $T_j$ = 25°C, C2 = 10 μF, unless otherwise specified)

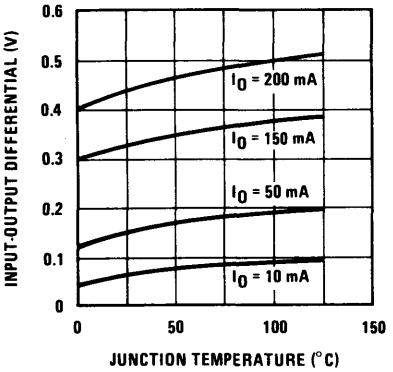
| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Output Voltage | 9.4V ≤ $V_{IN}$ ≤ 26V, 5 mA ≤ $I_O$ ≤ 150 mA, −40°C ≤ $T_j$ ≤ +125°C | 7.2 | 8 | 8.8 | V |
| Line Regulation | 9.4V ≤ $V_{IN}$ ≤ 16V, $I_O$ = 5 mA | | 12 | 50 | mV |
| | 9.4V ≤ $V_{IN}$ ≤ 26V $I_O$ = 5 mA | | 50 | 100 | mV |
| Load Regulation | 5 mA ≤ $I_O$ ≤ 150 mA | | 25 | 50 | mV |
| Output Impedance | 100 $mA_{DC}$ & 10 mA rms, 100 Hz-10 kHz | | 300 | | mΩ |
| Quiescent Current | $I_O$ = 10 mA | | 4 | 7 | mA |
| | $I_O$ = 150 mA | | 30 | 40 | mA |
| Output Noise Voltage | 10 Hz-100 kHz | | 170 | | μVrms |
| Long Term Stability | | | 30 | | mV/1000 hr |
| Ripple Rejection | $f_O$ = 120 Hz | | 52 | | dB |
| Dropout Voltage | $I_O$ = 150 mA | | 0.3 | 0.6 | V |
| Output Voltage Under Transient Conditions | −12V ≤ $V_{IN}$ ≤ 40V, $R_L$ = 100Ω | | −0.3 | 8.8 | V |

**Note 1:** Thermal resistance without a heat sink for junction to case temperature is 12°C/W and for case to ambient temperature is 70°C/W.

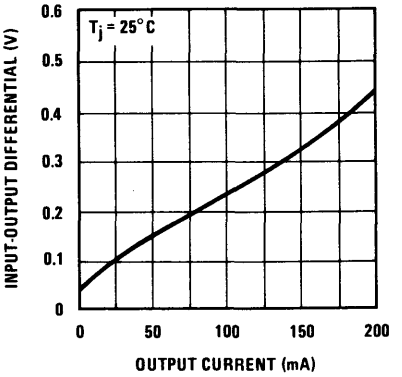
**Note 2:** All characteristics are measured with a capacitor across the input of 0.1 μF and a capacitor across the output of 10 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

## Typical Performance Characteristics

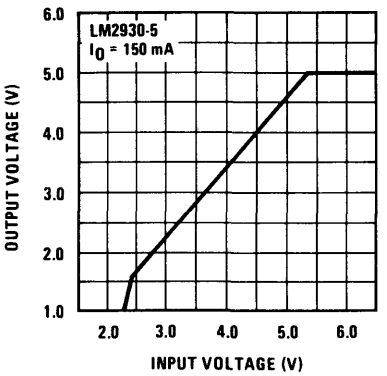
**Dropout Voltage**



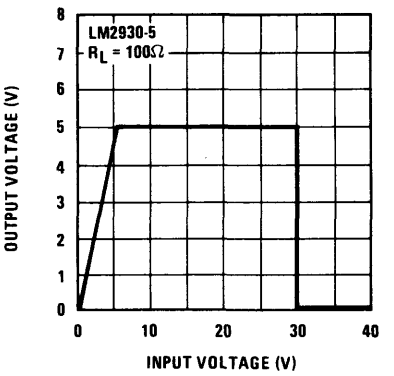

**Dropout Voltage**



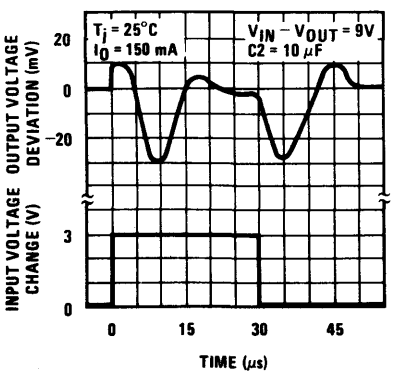

**Low Voltage Behavior**



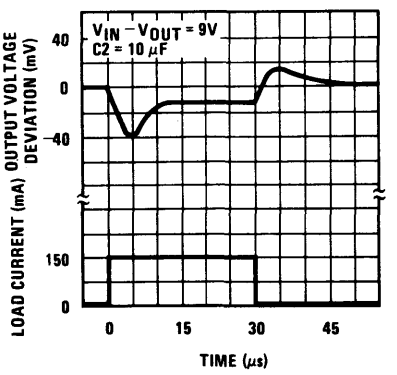

**High Voltage Behavior**




**Line Transient Response**

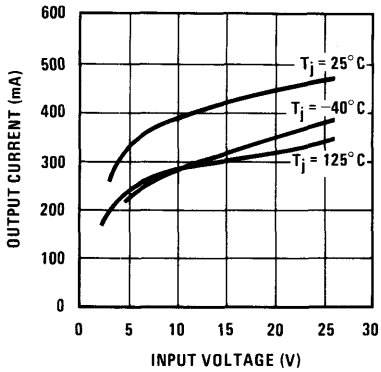



**Load Transient Response**

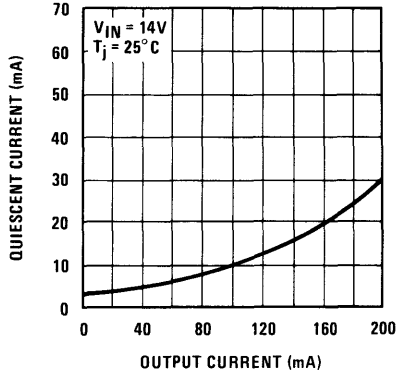


## Typical Performance Characteristics (Continued)

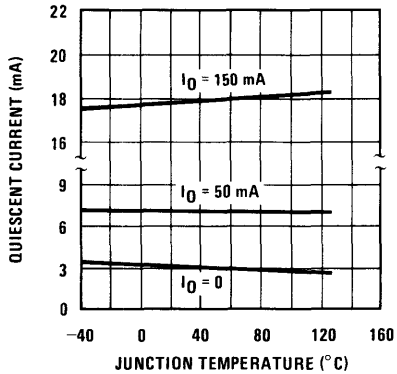
**Peak Output Current**



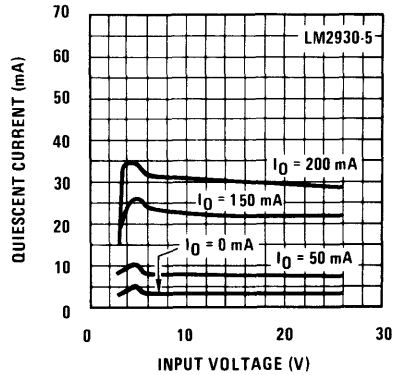

**Quiescent Current**



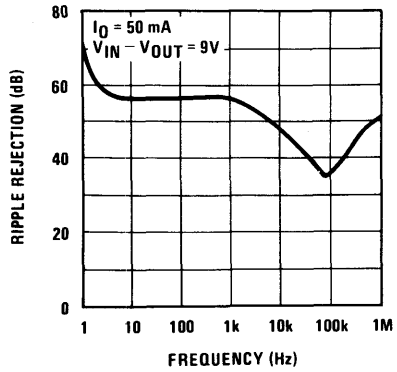

**Quiescent Current**



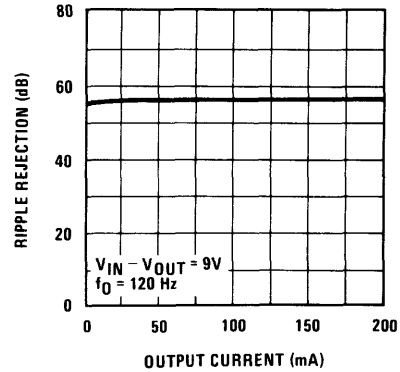

**Quiescent Current**




**Ripple Rejection**

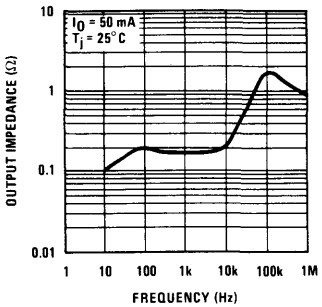



**Ripple Rejection**

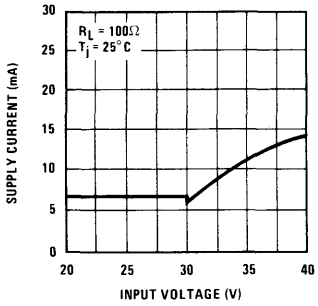


## Typical Performance Characteristics (Continued)

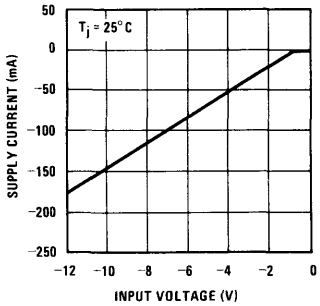
**Output Impedance**



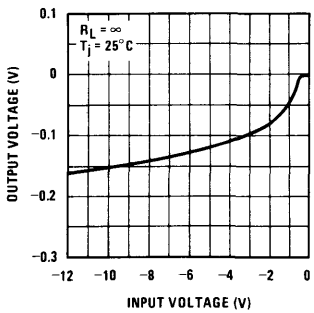

**Overvoltage Supply Current**



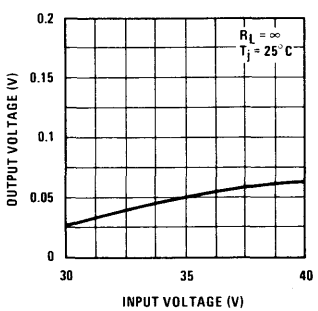

**Reverse Supply Current**



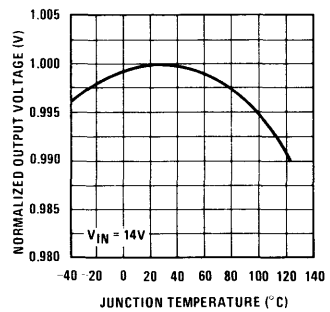

**Output at Reverse Supply**



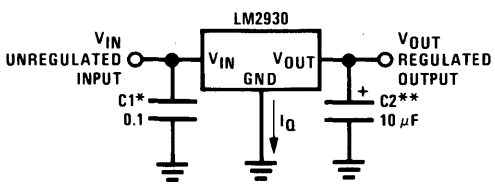

**Output at Overvoltage**




**Output Voltage (Normalized to 1V at $T_j$ = 25°C)**




## Typical Application




* Required if regulator is located far from power supply filter

** C2 must be at least 10 μF to maintain stability. May be increased without bound. Locate as close as possible to regulator.

## Definition of Terms

**Dropout Voltage:** The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

**Input Voltage:** The DC voltage applied to the input terminals with respect to ground.

**Input-Output Differential:** The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

**Line Regulation:** The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

**Load Regulation:** The change in output voltage for a change in load current at constant chip temperature.

**Long Term Stability:** Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

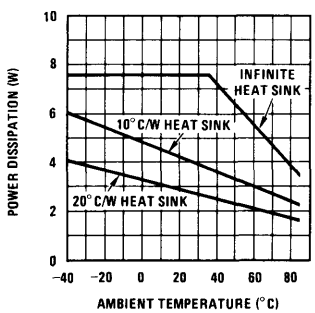
**Output Noise Voltage:** The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

**Quiescent Current:** That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

**Ripple Rejection:** The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

**Temperature Stability of $V_O$:** The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

**Maximum Power Dissipation**



# Notes

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