TEXAS INSTRUMENTS

# LM1086-MIL 1.5-A Low Dropout Positive Voltage Regulator

## 1 Features

- Available in Fixed 1.8-V, 2.5-V, 3.3-V, 5-V Versions
- Available in Adjustable Version
- Current Limiting and Thermal Protection
- 2% Output Accuracy
- Output Current 1.5 A
- Line Regulation 0.015% (Typical)
- Load Regulation 0.1% (Typical)
- Maximum Input Voltage up to 29 V
- Minimum Adjustable Output Voltage Down to 1.25 V
- Stable with Ceramic Output Capacitor with ESR
- Temperature Range : –40°C to +125°C

## 2 Applications

- High-Efficiency Linear Regulators
- Battery Chargers
- Post Regulation for Switching Supplies
- Constant Current Regulators
- Microprocessor Supplies
- Audio Amplifiers Supplies
- Fire Alarm Control

## 3 Description

The LM1086-MIL is a regulator with a maximum dropout of 1.5 V at 1.5 A of load current. The device has the same pin-out as TI's industry standard LM317.

Two resistors are required to set the output voltage of the adjustable output voltage version of the LM1086-MIL. Fixed output voltage versions integrate the adjust resistors. Typically, no input capacitor is needed unless the device is situated more than 6 inches from the input filter capacitors. Output capacitor can be replaced with ceramic and appropriate ESR.

The LM1086-MIL circuit includes a zener trimmed bandgap reference, current limiting, and thermal shutdown. Because the LM1086-MIL regulator is floating and detects 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. Exceeding the maximum input-to-output deferential will result in short-circuiting the output. By connecting a fixed resistor between the adjustment pin and output, the LM1086-MIL can be also used as a precision current regulator.
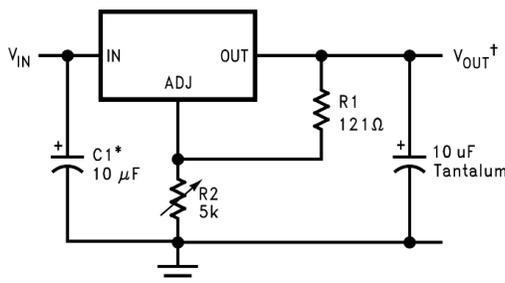
For applications requiring greater output current, refer to LM1084 for the 5-A version, and the LM1085 for the 3-A version.

### Device Information[1]

| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| LM1086-MIL | WSON (8) | 4.00 mm × 4.00 mm |
| | DDPAK/TO-263 (3) | 10.18 mm × 8.41 mm |
| | TO-220 (3) | 14.986 mm × 10.16 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.

### Typical Application



*NEEDED IF DEVICE IS FAR FROM FILTER CAPACITORS

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

# Table of Contents

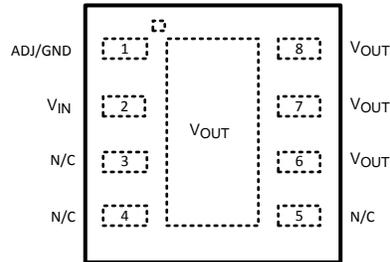## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

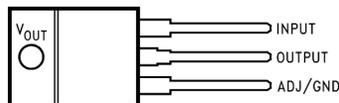| DATE | REVISION | NOTES |
|---|---|---|
| June 2017 | * | Initial release |

# 5 Pin Configuration and Functions

**NGN Package**
**8-Pin WSON**
**Top View**



**NDE Package**
**3-Pin TO-220**
**Top View**



**KTT Package**
**3-Pin DDPAK/TO-263**
**Top View**
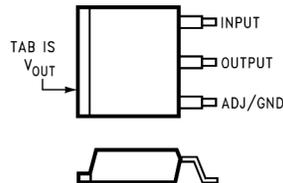


## Pin Functions

| PIN | | | I/O | DESCRIPTION |
|---|---|---|---|---|
| NAME | NUMBER | | | |
| | KTT/NDE | NGN | | |
| ADJ/GND | 1 | 1 | — | Adjust pin for the adjustable output voltage version. Ground pin for the fixed output voltage versions. |
| $V_{IN}$ | 3 | 2 | I | Input voltage pin for the regulator. |
| $V_{OUT}$ | 2, TAB | 6, 7, 8, PAD | O | Output voltage pin for the regulator. |
| N/C | | 3, 4, 5 | — | No connection |

# 6 Specifications

## 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) [1][2]

|  |  | MIN | MAX | UNIT |
|---|---|---|---|---|
| Maximum input-to-output voltage differential | LM1086-MIL-ADJ |  | 29 | V |
|  | LM1086-MIL-1.8 |  | 27 | V |
|  | LM1086-MIL-2.5 |  | 27 | V |
|  | LM1086-MIL-3.3 |  | 27 | V |
|  | LM1086-MIL-5 |  | 25 | V |
| Power dissipation[3] |  | Internally Limited |  |  |
| Junction temperature ($T_J$)[4] |  |  | 150 | °C |
| Storage temperature, $T_{stg}$ |  | −65 | 150 | °C |

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) If Military/Aerospace specified devices are required, contact the Texas Instruments Sales Office/Distributors for availability and specifications.
(3) Power dissipation is kept in a safe range by current limiting circuitry. Refer to *Overload Recovery* in *Application and Implementation*. The value $R_{\theta JA}$ for the WSON package is specifically dependent on PCB trace area, trace material, and the number of thermal vias. For improved thermal resistance and power dissipation for the WSON package, refer to *AN-1187 Leadless Leadframe Package (LLP)*
(4) The maximum power dissipation is a function of $T_{J(MAX)}$ , $R_{\theta JA}$, and $T_A$. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A) / R_{\theta JA}$. All numbers apply for packages soldered directly into a PC board. Refer to *Thermal Considerations*.

## 6.2 ESD Ratings

|  |  |  | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1] | ±2000 | V |

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

## 6.3 Recommended Operating Conditions

|  |  | MIN | MAX | UNIT |
|---|---|---|---|---|
| **JUNCTION TEMPERATURE RANGE ($T_J$)**[1] |  |  |  |  |
| C grade | Control section | 0 | 125 | °C |
|  | Output section | 0 | 150 | °C |
| I grade | Control section | −40 | 125 | °C |
|  | Output section | −40 | 150 | °C |

(1) The maximum power dissipation is a function of $T_{J(MAX)}$ , $R_{\theta JA}$, and $T_A$. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A) / R_{\theta JA}$. All numbers apply for packages soldered directly into a PC board. Refer to *Thermal Considerations*.

## 6.4 Thermal Information

|  |  | LM1086-MIL | | | |
|---|---|---|---|---|---|
| **THERMAL METRIC**[1] |  | **KTT** | **NDE** | **NGN** | **UNIT** |
|  |  | **3 PINS** | **3 PINS** | **8 PINS** |  |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 40.8 | 23.0 | 35.9 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 42.3 | 16.1 | 24.2 | °C/W |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 23.3 | 4.5 | 13.2 | °C/W |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 10.2 | 2.4 | 0.2 | °C/W |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 22.3 | 2.5 | 13.3 | °C/W |
| $R_{\theta JC(bot)}$ | Junction-to-case (bottom) thermal resistance: control section/output section | 1.5/4 | 1.5/4 | 2.9 | °C/W |

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

## 6.5 Electrical Characteristics

Typicals and limits appearing in normal type apply for $T_J$ = 25°C unless specified otherwise.

| PARAMETER | | TEST CONDITIONS | $T_J$ = 25°C | | | $T_J$ over the entire range for operation (see *Recommended Operating Conditions*) | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | MIN[1] | TYP[2] | MAX[1] | |
| $V_{REF}$ | Reference voltage | LM1086-MIL-ADJ, $I_{OUT}$ = 10 mA, $V_{IN} - V_{OUT}$ = 3 V, 10 mA ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 1.5 V ≤ $V_{IN} - V_{OUT}$ ≤ 15 V [3] | 1.238 | 1.25 | 1.262 | 1.225 | 1.250 | 1.27 | V |
| $V_{OUT}$ | Output voltage[3] | LM1086-MIL-1.8, $I_{OUT}$ = 0 mA, $V_{IN}$ = 5 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 3.3 V ≤ $V_{IN}$ ≤ 18 V | 1.782 | 1.8 | 1.818 | 1.764 | 1.8 | 1.836 | V |
| | | LM1086-MIL-2.5, $I_{OUT}$ = 0 mA, $V_{IN}$ = 5 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 4.0 V ≤ $V_{IN}$ ≤ 18 V | 2.475 | 2.5 | 2.525 | 2.450 | 2.5 | 2.55 | V |
| | | LM1086-MIL-3.3, $I_{OUT}$ = 0 mA, $V_{IN}$ = 5 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 4.75 V ≤ $V_{IN}$ ≤ 18 V | 3.267 | 3.3 | 3.333 | 3.235 | 3.3 | 3.365 | V |
| | | LM1086-MIL-5, $I_{OUT}$ = 0 mA, $V_{IN}$ = 8 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 6.5 V ≤ $V_{IN}$ ≤ 20 V | 4.950 | 5 | 5.05 | 4.9 | 5 | 5.1 | V |
| $\Delta V_{OUT}$ | Line regulation[4] | LM1086-MIL-ADJ, $I_{OUT}$ =10 mA, 1.5 V ≤ ($V_{IN} - V_{OUT}$) ≤ 15 V | | 0.015% | 0.2% | | 0.035% | 0.2% | |
| | | LM1086-MIL-1.8, $I_{OUT}$ = 0 mA, 3.3 V ≤ $V_{IN}$ ≤ 18 V | | 0.3 | 6 | | 0.6 | 6 | mV |
| | | LM1086-MIL-2.5, $I_{OUT}$ = 0 mA, 4.0 V ≤ $V_{IN}$ ≤ 18 V | | 0.3 | 6 | | 0.6 | 6 | mV |
| | | LM1086-MIL-3.3, $I_{OUT}$ = 0 mA, 4.5 V ≤ $V_{IN}$ ≤ 18 V | | 0.5 | 10 | | 1 | 10 | mV |
| | | LM1086-MIL-5, $I_{OUT}$ = 0 mA, 6.5 V ≤ $V_{IN}$ ≤ 20 V | | 0.5 | 10 | | 1 | 10 | mV |

(1) All limits are specified by testing or statistical analysis.
(2) Typical values represent the most likely parametric norm.
(3) $I_{FULL\ LOAD}$ is defined in the current limit curves. The $I_{FULL\ LOAD}$ Curve defines current limit as a function of input-to-output voltage. Note that 15 W power dissipation for the LM1086-MIL is only achievable over a limited range of input-to-output voltage.
(4) Load and line regulation are measured at constant junction temperature, and are specified up to the maximum power dissipation of 15 W. Power dissipation is determined by the input/output differential and the output current. Ensured maximum power dissipation will not be available over the full input/output range.

## Electrical Characteristics (continued)

Typicals and limits appearing in normal type apply for $T_J$ = 25°C unless specified otherwise.

| PARAMETER | | TEST CONDITIONS | $T_J$ = 25°C | | | $T_J$ over the entire range for operation (see *Recommended Operating Conditions*) | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | MIN[1] | TYP[2] | MAX [1] | |
| $\Delta V_{OUT}$ | Load regulation[4] | LM1086-MIL-ADJ, ($V_{IN}$-$V_{OUT}$) = 3 V, 10 mA ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$ | | 0.1% | 0.3% | | 0.2% | 0.4% | |
| | | LM1086-MIL-1.8, 2.5, $V_{IN}$ = 5 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$ | | 3 | 12 | | 6 | 20 | mV |
| | | LM1086-MIL-3.3, $V_{IN}$ = 5 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$ | | 3 | 15 | | 7 | 25 | mV |
| | | LM1086-MIL-5, $V_{IN}$ = 8 V, 0 ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$ | | 5 | 20 | | 10 | 35 | mV |
| | Dropout voltage[5] | LM1086-MIL-ADJ, 1.8, 2.5, 3.3, 5, $\Delta V_{REF}$, $\Delta V_{OUT}$ = 1%, $I_{OUT}$ = 1.5 A | | | | | 1.3 | 1.5 | V |
| $I_{LIMIT}$ | Current limit | LM1086-MIL-ADJ, $V_{IN}$ − $V_{OUT}$ = 5 V, $V_{IN}$ − $V_{OUT}$ = 25 V | | | | 1.5 | 2.7 | | A |
| | | | | | | 0.05 | 0.15 | | |
| | | LM1086-MIL-1.8,2.5, 3.3, $V_{IN}$ = 8 V | | | | 1.5 | 2.7 | | A |
| | | LM1086-MIL-5, $V_{IN}$ = 10 V | | | | 1.5 | 2.7 | | A |
| | Minimum load current[6] | LM1086-MIL-ADJ, $V_{IN}$ −$V_{OUT}$ = 25 V | | | | | 5 | 10 | mA |
| | Quiescent current | LM1086-MIL-1.8, 2.5, $V_{IN}$ ≤ 18 V | | | | | 5 | 10 | mA |
| | | LM1086-MIL-3.3, $V_{IN}$ ≤ 18 V | | | | | 5 | 10 | mA |
| | | LM1086-MIL-5, $V_{IN}$ ≤ 20 V | | | | | 5 | 10 | mA |
| | Thermal regulation | $T_A$ = 25°C, 30-ms pulse | | 0.008 | 0.04 | | | | %/W |
| | Ripple rejection | $f_{RIPPLE}$ = 120 Hz, $C_{OUT}$ = 25 μF Tantalum, $I_{OUT}$ = 1.5 A | | | | 60 | 75 | | dB |
| | | LM1086-MIL-ADJ, $C_{ADJ}$ = 25 μF, ($V_{IN}$− $V_O$) = 3 V | | | | | | | |
| | | LM1086-MIL-1.8, 2.5, $V_{IN}$ = 6 V | | | | 60 | 72 | | dB |
| | | LM1086-MIL-3.3, $V_{IN}$= 6.3 V | | | | 60 | 72 | | dB |
| | | LM1086-MIL-5 $V_{IN}$ = 8 V | | | | 60 | 68 | | dB |
| | Adjust pin current | LM1086-MIL | | 55 | | | | 120 | μA |
| | Adjust pin current change | 10 mA ≤ $I_{OUT}$ ≤ $I_{FULL\ LOAD}$, 1.5 V ≤ ($V_{IN}$ − $V_{OUT}$) ≤ 15 V | | | | | 0.2 | 5 | μA |
| | Temperature stability | | | | | | 0.5% | | |
| | Long-term stability | $T_A$ = 125°C, 1000 Hrs | | 0.3% | 1% | | | | |
| | RMS Noise (% of $V_{OUT}$) | 10 Hz ≤ f≤ 10 kHz | | 0.003% | | | | | |

(5) Dropout voltage is specified over the full output current range of the device.
(6) The minimum output current required to maintain regulation.

Product Folder Links: *LM1086-MIL*
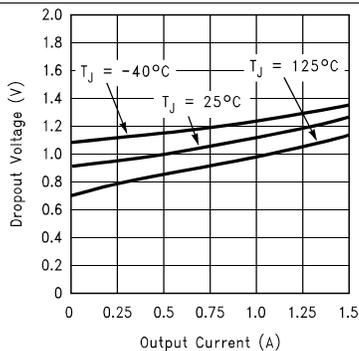
## 6.6 Typical Characteristics



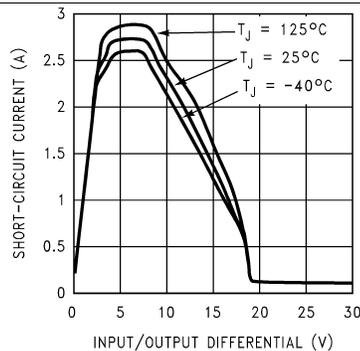**Figure 1. Dropout Voltage vs Output Current**



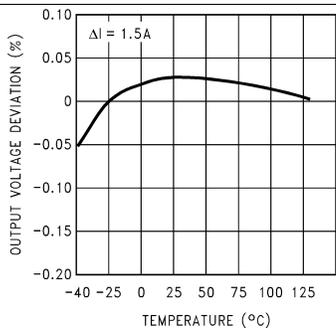**Figure 2. Short-Circuit Current vs Input/Output Difference**



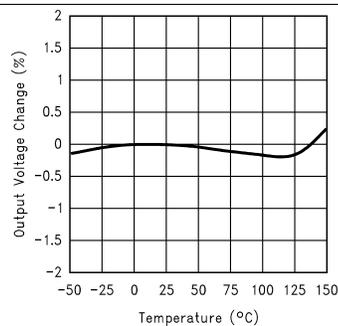**Figure 3. Load Regulation vs Temperature**



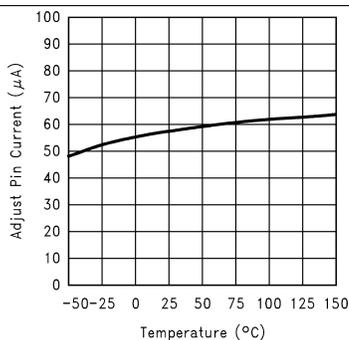**Figure 4. Percent Change in Output Voltage vs Temperature**
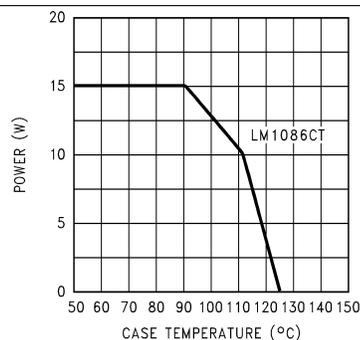


**Figure 5. Adjust Pin Current vs Temperature**



**Figure 6. Maximum Power Dissipation vs Temperature**

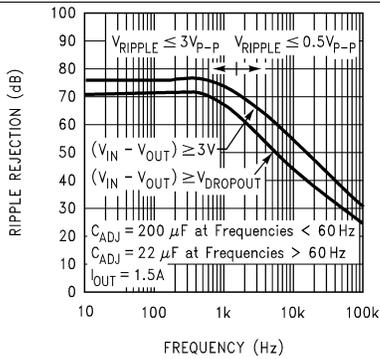## Typical Characteristics (continued)



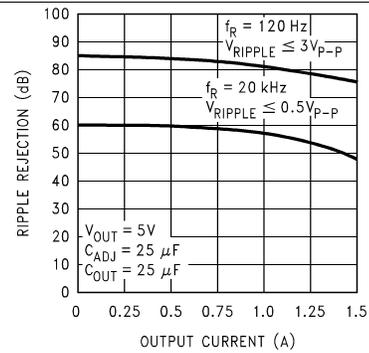**Figure 7. Ripple Rejection vs Frequency (LM1086-MIL-ADJ)**



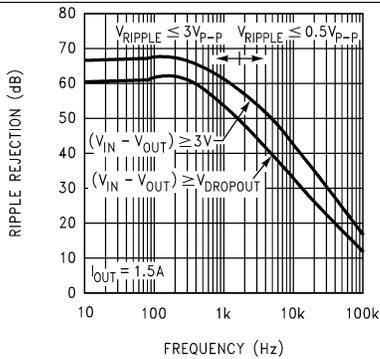**Figure 8. Ripple Rejection vs Output Current (LM1086-MIL-ADJ)**
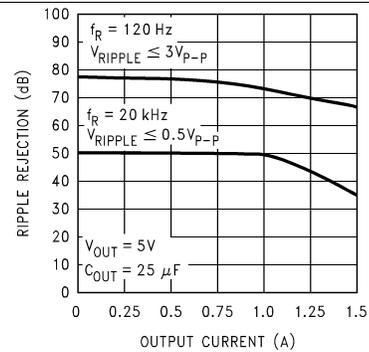


**Figure 9. Ripple Rejection vs Frequency (LM1086-MIL-5)**
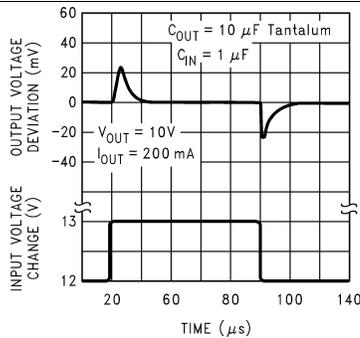


**Figure 10. Ripple Rejection vs Output Current (LM1086-MIL-5)**
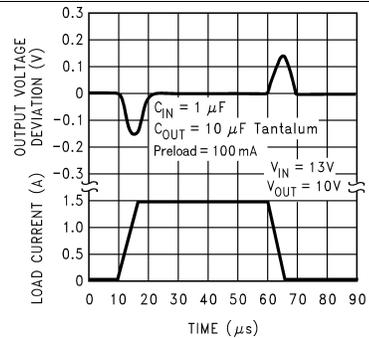


**Figure 11. Line Transient Response**



**Figure 12. Load Transient Response**

Product Folder Links: *LM1086-MIL*

# 7 Detailed Description

## 7.1 Overview

A basic functional diagram for the LM1086-MIL-ADJ (excluding protection circuitry) is shown in Figure 13. The topology is basically that of the LM317 except for the pass transistor. Instead of a Darlingtion NPN with its two diode voltage drop, the LM1086-MIL uses a single NPN. This results in a lower dropout voltage. The structure of the pass transistor is also known as a quasi LDO. The advantage of a quasi LDO over a PNP LDO is its inherently lower quiescent current. The LM1086-MIL is specified to provide a minimum dropout voltage of 1.5 V over temperature, at full load.
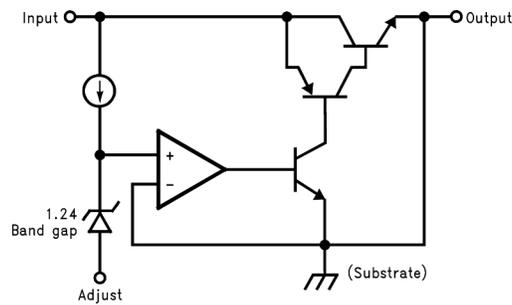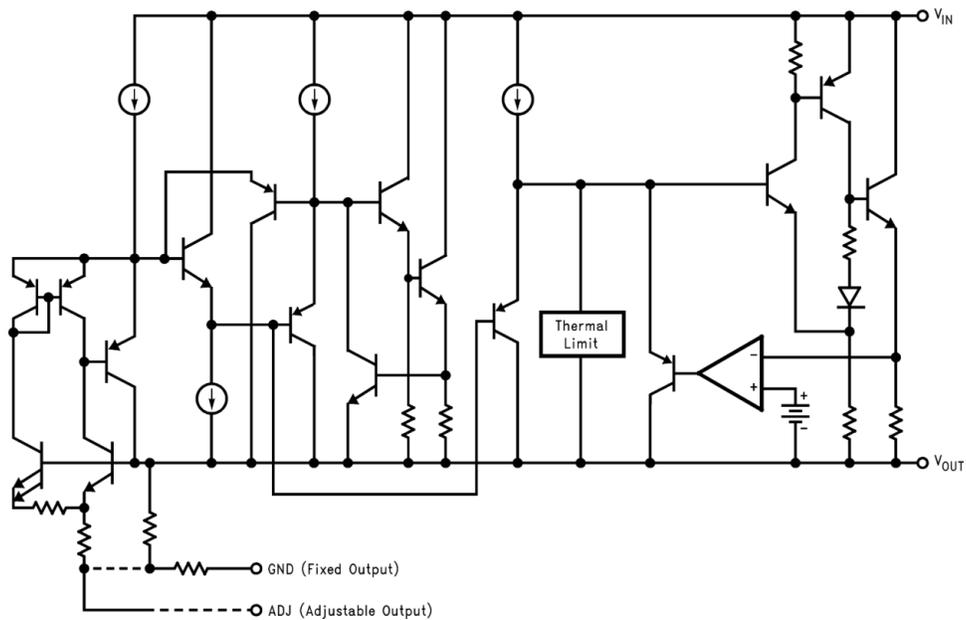
**Figure 13. Basic Functional Block Diagram**

## 7.2 Functional Block Diagram

## 7.3 Feature Description

### 7.3.1 Ripple Rejection

Ripple rejection is a function of the open loop gain within the feedback loop (refer to Figure 13 and Figure 16). The LM1086-MIL exhibits 75 dB of ripple rejection (typical). When adjusted for voltages higher than $V_{REF}$, the ripple rejection decreases as function of adjustment gain: (1 + R1 / R2) or $V_O / V_{REF}$. Therefore, a 5-V adjustment decreases ripple rejection by a factor of four (−12 dB); output ripple increases as adjustment voltage increases.

However, the adjustable version allows this degradation of ripple rejection to be compensated. The adjust terminal can be bypassed to ground with a capacitor ($C_{ADJ}$). The impedance of the $C_{ADJ}$ must be equal to or less than R1 at the desired ripple frequency. This bypass capacitor prevents ripple from being amplified as the output voltage is increased.

$$1 / (2\pi \times f_{RIPPLE} \times C_{ADJ}) \leq R_1 \tag{1}$$

### 7.3.2 Load Regulation

The LM1086-MIL regulates the voltage that appears between its output and ground pins, or between its output and adjust pins. In some cases, line resistances can introduce errors to the voltage across the load. To obtain the best load regulation, a few precautions are needed.

Figure 14 shows a typical application using a fixed output regulator. Rt1 and Rt2 are the line resistances. $V_{LOAD}$ is less than the $V_{OUT}$ by the sum of the voltage drops along the line resistances. In this case, the load regulation seen at the $R_{LOAD}$ would be degraded from the data sheet specification. To improve this, the load should be tied directly to the output terminal on the positive side and directly tied to the ground terminal on the negative side.
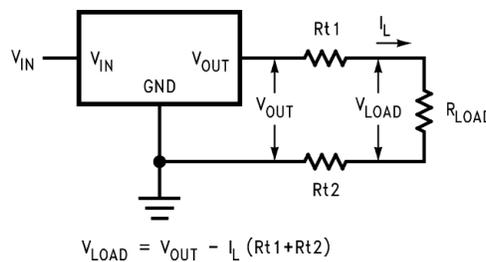


$$V_{LOAD} = V_{OUT} - I_L (Rt1 + Rt2)$$

**Figure 14. Typical Application Using Fixed Output Regulator**

When the adjustable regulator is used (Figure 15), the best performance is obtained with the positive side of the resistor R1 tied directly to the output terminal 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 5-V regulator with 0.05-Ω resistance between the regulator and load has a load regulation due to line resistance of 0.05 Ω × $I_L$. If R1 (= 125 Ω) is connected near the load the effective line resistance will be 0.05 Ω (1 + R2 / R1) or in this case, it is 4 times worse. In addition, the ground side of the resistor R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.



$$V_{LOAD} = V_{REF} (R1 + R2)/R1 - I_L Rt1$$
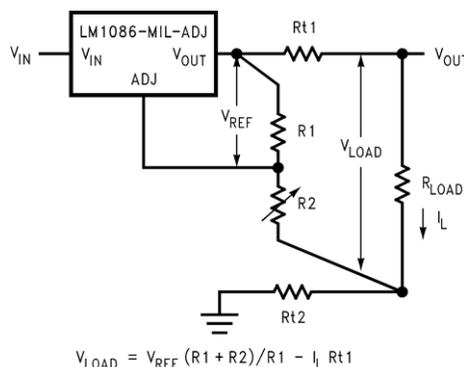
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**Figure 15. Best Load Regulation Using Adjustable Output Regulator**

## Feature Description (continued)

### 7.3.3 Overload Recovery

Overload recovery refers to the ability of the regulator to recover from a short-circuited output. A key factor in the recovery process is the current limiting used to protect the output from drawing too much power. The current-limiting circuit reduces the output current as the input-to-output differential increases. Refer to short-circuit curve in *Typical Characteristics*.

During normal start-up, the input-to-output differential is small because the output follows the input. But, if the output is shorted, then the recovery involves a large input to output differential. Sometimes during this condition the current limiting circuit is slow in recovering. If the limited current is too low to develop a voltage at the output, the voltage will stabilize at a lower level. Under these conditions it may be necessary to recycle the power of the regulator in order to get the smaller differential voltage and thus adequate start up conditions. Refer to *Typical Characteristics* for the short circuit current vs input differential voltage.

## 7.4 Device Functional Modes

### 7.4.1 Output Voltage

The LM1086-MIL adjustable version develops a 1.25-V reference voltage, ($V_{REF}$), between the output and the ADJ pin. As shown in Figure 16, this voltage is applied across resistor R1 to generate a constant current I1. This constant current then flows through R2. The resulting voltage drop across R2 adds to the reference voltage to sets the desired output voltage.

The current $I_{ADJ}$ from the adjustment terminal introduces an output error . But since it is small (120 µA maximum), it becomes negligible when R1 is in the 100-Ω range.

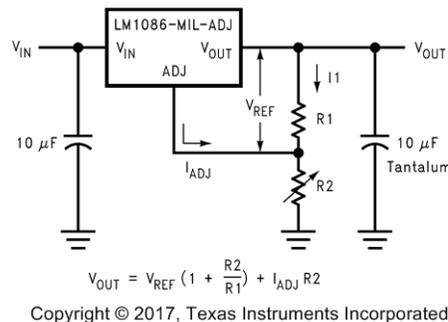For fixed voltage devices, R1 and R2 are integrated inside the devices.



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

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**Figure 16. Basic Adjustable Regulator**

### 7.4.2 Stability Consideration

Stability consideration primarily concerns the phase response of the feedback loop. In order for stable operation, the loop must maintain negative feedback. The LM1086-MIL requires a certain amount series resistance with capacitive loads. This series resistance introduces a zero within the loop to increase phase margin and thus increase stability. The equivalent series resistance (ESR) of solid tantalum or aluminum electrolytic capacitors is used to provide the appropriate zero (approximately 500 kHz).

Aluminum electrolytics are less expensive than tantalum capacitors, but their ESR varies exponentially at cold temperatures requiring close examination when choosing the desired transient response over temperature. Tantalums are a convenient choice because their ESR varies less than 2:1 over temperature.

The recommended load/decoupling capacitance is a 10-µF tantalum or a 50-µF aluminum. These values assure stability for the majority of applications.

The adjustable versions allows an additional capacitor to be used at the ADJ pin to increase ripple rejection. If this is done increase the output capacitor to 22 µF for tantalum or to 150 µF for aluminum.

Capacitors other than tantalum or aluminum can be used at the adjust pin and the input pin. A 10-µF capacitor is a reasonable value at the input. See *Ripple Rejection* regarding the value for the ADJ pin capacitor.

## Device Functional Modes (continued)

Large output capacitance is desirable for applications that entail large changes in load current (microprocessors, for example). The higher the capacitance, the larger the available charge per demand. It is also desirable to provide low ESR to reduce the change in output voltage:

$$\Delta V = \Delta I \times ESR \qquad (2)$$

It is common practice to use several tantalum and ceramic capacitors in parallel to reduce this change in the output voltage by reducing the overall ESR.

Output capacitance can be increased indefinitely to improve transient response and stability.

### 7.4.3 Protection Diodes

Under normal operation, the LM1086-MIL regulator does not need any protection diode. With the adjustable device, the internal resistance between the adjustment and output terminals limits the current. No diode is needed to divert the current around the regulator even with a capacitor on the ADJ pin. The ADJ pin can take a transient signal of ±25 V with respect to the output voltage without damaging the device.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor discharges into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and rate of decrease of $V_{IN}$. In the LM1086-MIL regulator, the internal diode between the output and input pins can withstand microsecond surge currents of 10 A to 20 A. With an extremely large output capacitor (≥ 1000 µf), and with input instantaneously shorted to ground, the regulator could be damaged. In this case, an external diode is recommended between the output and input pins to protect the regulator, shown in Figure 17.
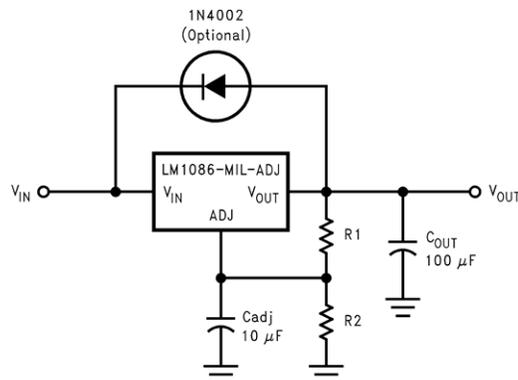


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**Figure 17. Regulator with Protection Diode**

# 8  Application and Implementation

**NOTE**

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## 8.1  Application Information

The LM1086-MIL is versatile in its applications, including uses in programmable output regulation and local on-card regulation. By connecting a fixed resistor between the ADJ and OUTPUT terminals, the LM1086-MIL can function as a precision current regulator. An optional output capacitor can be added to improve transient response. The ADJ pin can be bypassed to achieve very high ripple-rejection ratios, which are difficult to achieve with standard three-terminal regulators. Note that, in the following applications if ADJ is mentioned, it makes use of the adjustable version of the part, however, if GND is mentioned, it is the fixed-voltage version of the part.

## 8.2  Typical Applications

### 8.2.1  1.2-V to 15-V Adjustable Regulator

This part can be used as a simple low drop out regulator to enable a variety of output voltages needed for demanding applications. By using an adjustable R2 resistor a variety of output voltages can be made possible as shown in Figure 18 based on the LM1086-MIL-ADJ.
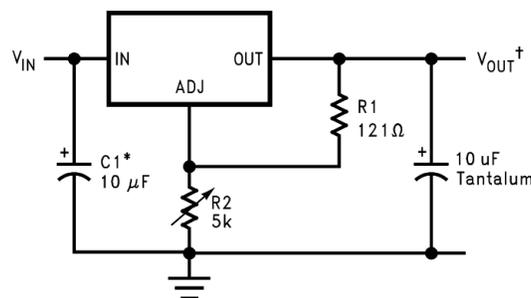


*NEEDED IF DEVICE IS FAR FROM FILTER CAPACITORS

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

**Figure 18. 1.2-V to 15-V Adjustable Regulator**

#### 8.2.1.1  Design Requirements

The device component count is very minimal, employing two resistors as part of a voltage divider circuit and an output capacitor for load regulation.

#### 8.2.1.2  Detailed Design Procedure

The voltage divider for this part is set based Figure 18, where R1 is the upper feedback resistor R2 is the lower feedback resistor.

## Typical Applications (continued)

### 8.2.1.3  Application Curve
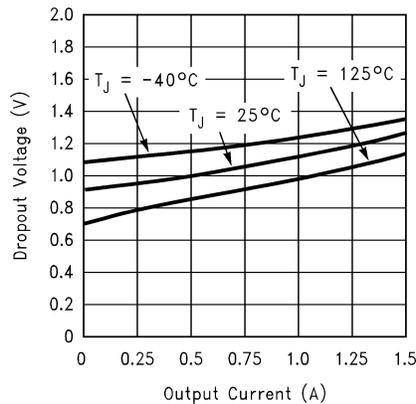


### 8.3  Other Applications

### 8.3.1  Adjustable at 5 V

The application shown in Figure 19 outlines a simple 5-V output application made possible by the LM1086-MIL-ADJ. This application can provide 1.5 A at high efficiencies and very low dropout.
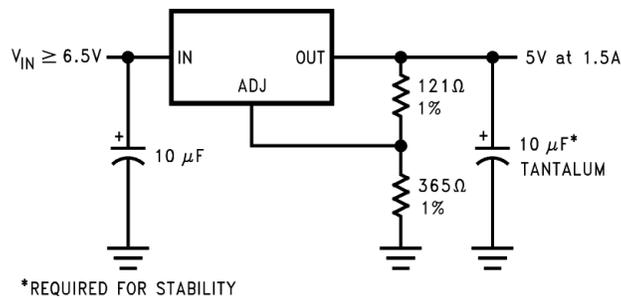


**Figure 19.  Adjustable at 5 V**

### 8.3.2  5-V Regulator with Shutdown

A variation of the 5-V output regulator application with shutdown control is shown in Figure 20 based on the LM1086-MIL-ADJ. It uses a simple NPN transistor on the ADJ pin to block or sink the current on the ADJ pin. If the TTL logic is pulled high, the NPN transistor is activated and the device is disabled, outputting approximately 1.25 V. If the TTL logic is pulled low, the NPN transistor is unbiased and the regulator functions normally.
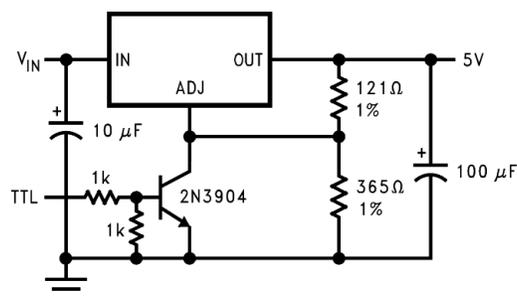


**Figure 20.  5-V Regulator with Shutdown**

## Other Applications (continued)

### 8.3.3 Battery Charger

The LM1086-MIL-ADJ can be used as a battery charger to regulate the charging current required by the battery bank as shown in Figure 21. In this application the LM1086-MIL acts as a constant voltage, constant current part by sensing the voltage potential across the battery and compensating it to the current voltage. To maintain this voltage, the regulator delivers the maximum charging current required to charge the battery. As the battery approaches the fully charged state, the potential drop across the sense resistor, $R_S$ reduces and the regulator throttles back the current to maintain the float voltage of the battery.
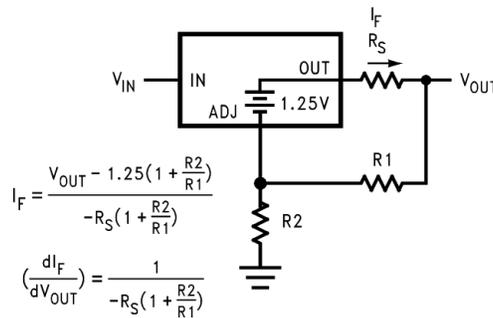


$$I_F = \frac{V_{OUT} - 1.25\left(1 + \frac{R2}{R1}\right)}{-R_S\left(1 + \frac{R2}{R1}\right)}$$

$$\left(\frac{dI_F}{dV_{OUT}}\right) = \frac{1}{-R_S\left(1 + \frac{R2}{R1}\right)}$$

**Figure 21. Battery Charger**

### 8.3.4 Adjustable Fixed Regulator

A simple adjustable, fixed-range-output regulator can be made possible by placing a variable resistor on the ground of the device as shown in Figure 22 based on the fixed output voltage LM1086-MIL-5. The GND pin has a small quiescent current of 5 mA typical. Increasing the resistance on the GND pin increases the voltage potential across the resistor. This potential is then mirrored on to the output to increase the total output voltage by the potential drop across the GND resistor.
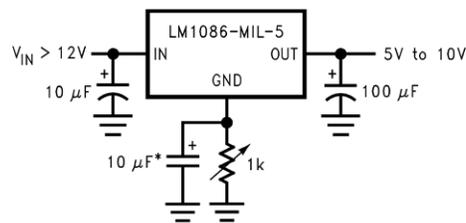


*OPTIONAL IMPROVES RIPPLE REJECTION
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**Figure 22. Adjustable Fixed Regulator**

### 8.3.5 Regulator With Reference

A fixed output voltage version of the LM1086-MIL-5 can be employed to provide an output rail and a reference rail at the same time as shown in Figure 23. This simple application makes use of a reference diode, the LM136-5, to regulate the GND voltage to a fixed 5 V based on the quiescent current generated by the GND pin. This voltage is then added onto the output to generate a total of 10 V out.
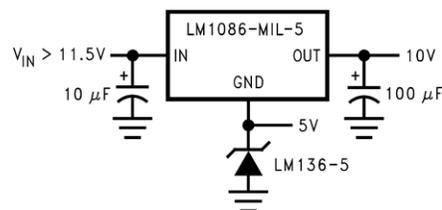


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**Figure 23. Regulator With Reference**

## Other Applications (continued)

### 8.3.6 High-Current Lamp-Driver Protection

A simple constant-current source with protection can be designed by controlling the impedance between the lamp and ground. The LM1086-MIL-ADJ shown in Figure 24 makes use of an external TTL or CMOS input to drive the NPN transistor. This pulls the output of the regulator to a few tenths of a volt and puts the part into current limit. Releasing the logic will reduce the current flow across the lamp into the normal operating current thereby protecting the lamp during start-up.
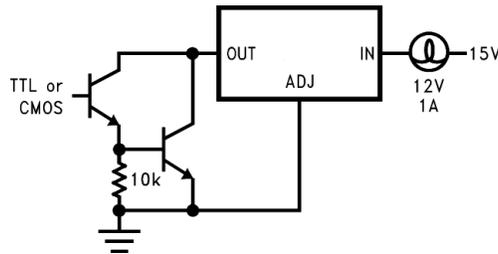
**Figure 24. High Current Lamp Driver Protection**

### 8.3.7 Battery-Backup-Regulated Supply

A regulated battery-backup supply can be generated by using two fixed output voltage versions of the part as shown in Figure 25. The top regulator supplies the line voltage during normal operation, however when the input is not available, the second regulator derives power from the battery backup and regulates it to 5 V based on the LM1086-MIL-5. The diodes prevent the rails from back feeding into the supply and batteries.
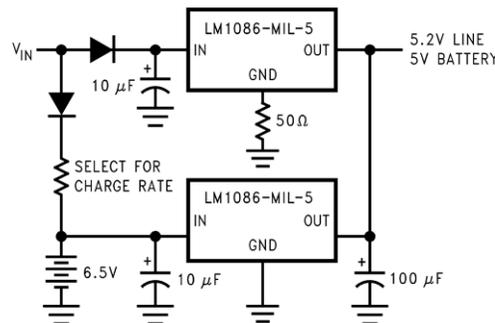
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**Figure 25. Battery Backup Regulated Supply**

Product Folder Links: *LM1086-MIL*

## Other Applications (continued)

### 8.3.8 Ripple Rejection Enhancement

A very simple ripple rejection circuit is shown in Figure 26 using the LM1086-MIL-ADJ. The capacitor C1 smooths out the ripple on the output by cleaning up the feedback path and preventing excess noise from feeding back into the regulator. Please remember $X_{C1}$ should be approximately equal to R1 at the ripple frequency.
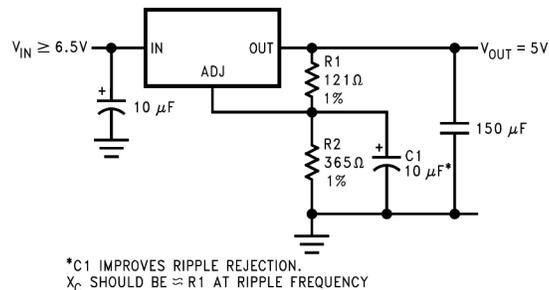
**Figure 26. Ripple Rejection Enhancement**

### 8.3.9 Automatic Light Control

A common streetlight control or automatic light control circuit is designed in Figure 27 based on the LM1086-MIL-ADJ. The photo transistor conducts in the presence of light and grounds the ADJ pin preventing the lamp from turning on. However, in the absence of light, the LM1086-MIL regulates the voltage to 1.25 V between OUT and ADJ, ensuring the lamp remains on.
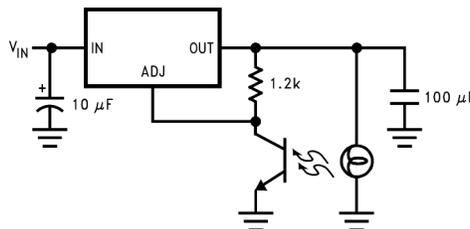
**Figure 27. Automatic Light Control**

### 8.3.10 Remote Sensing

Remote sensing is a method of compensating the output voltage to a very precise degree by sensing the output and feeding it back through the feedback. The circuit implementing this is shown in Figure 28 using the LM1086-MIL-ADJ. The output of the regulator is fed into a voltage follower to avoid any loading effects and the output of the op-amp is injected into the top of the feedback resistor network. This has the effect of modulating the voltage to a precise degree without additional loading on the output.
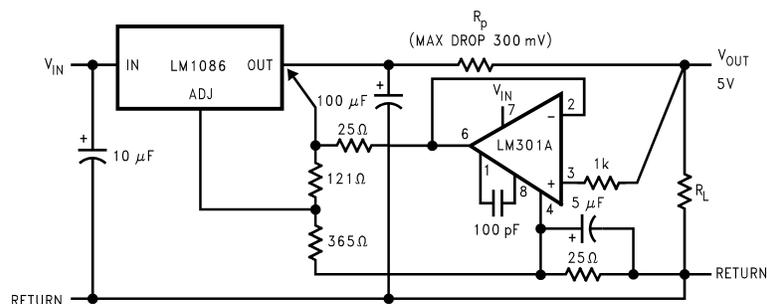
**Figure 28. Remote Sensing**

# 9 Power Supply Recommendations

The linear regulator input supply must be well regulated and kept at a voltage level such that the maximum input-to-output voltage differential allowed by the device is not exceeded. The minimum dropout voltage ($V_{IN} - V_{OUT}$) should be met with extra headroom when possible in order to keep the output well regulated. Pace a 10-µF or higher capacitor at the input to bypass noise.

# 10 Layout

## 10.1 Layout Guidelines

For the best overall performance, follow these layout guidelines. Place all circuit components on the same side of the circuit board and as near as practical to the respective linear regulator pins connections. Keep traces short and wide to reduce the amount of parasitic elements into the system. The actual width and thickness of traces depends on the current carrying capability and heat dissipation required by the end system. An array of plated vias can be placed on the pad area underneath the TAB to conduct heat to any inner plane areas or to a bottom-side copper plane.
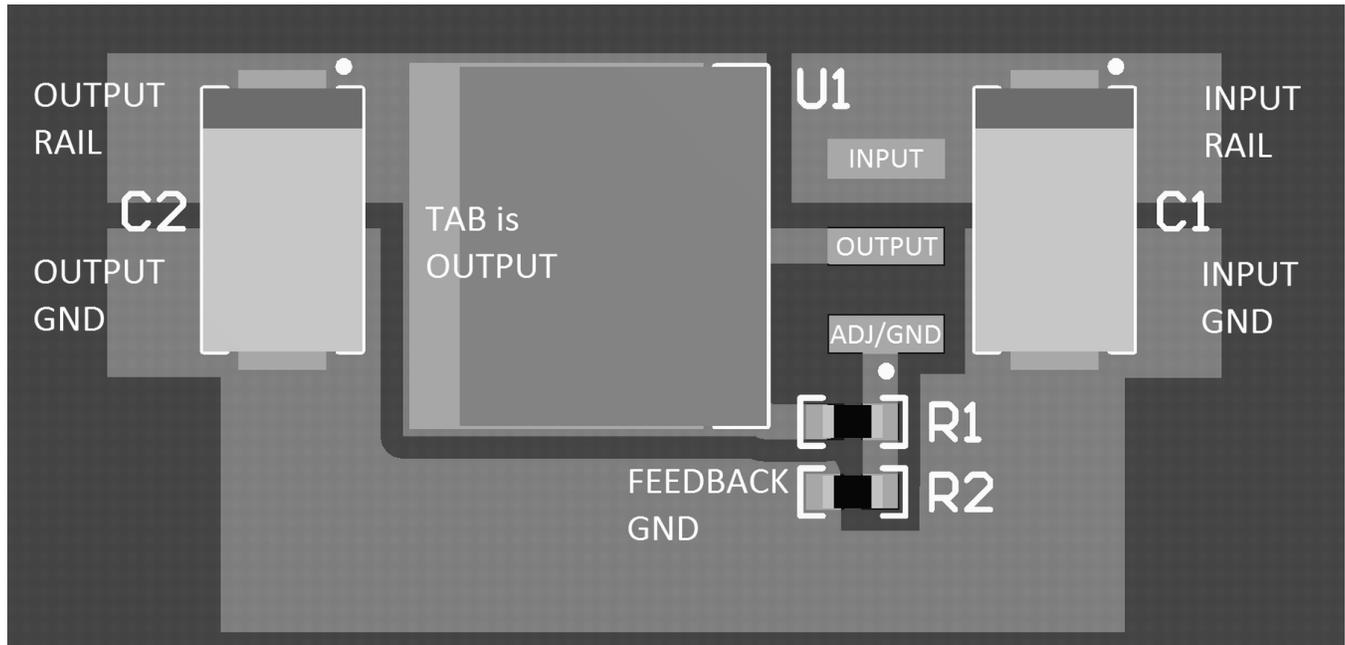
## 10.2 Layout Example



**Figure 29. Layout Example**

## 10.3 Thermal Considerations

ICs heats up when in operation, and power consumption is one factor in how hot it gets. The other factor is how well the heat is dissipated. Heat dissipation is predictable by knowing the thermal resistance between the IC and ambient ($R_{\theta JA}$). Thermal resistance has units of temperature per power (°C/W). The higher the thermal resistance, the hotter the IC.

The LM1086-MIL specifies the thermal resistance for each package as junction to case ($R_{\theta JC}$). In order to get the total resistance to ambient ($R_{\theta JA}$), two other thermal resistance must be added, one for case to heat-sink ($R_{\theta CH}$) and one for heatsink to ambient ($R_{\theta HA}$). The junction temperature can be predicted as follows:

$$T_J = T_A + P_D (\theta_{JC} + R_{\theta CH} + R_{\theta HA}) = T_A + P_D R_{\theta JA}$$

where

- $T_J$ is junction temperature
- $T_A$ is ambient temperature
- $P_D$ is the power consumption of the device                                                              (3)

Device power consumption is calculated as follows:

$$I_{IN} = I_L + I_G \tag{4}$$
$$P_D = (V_{IN} - V_{OUT}) I_L + V_{IN}I_G \tag{5}$$

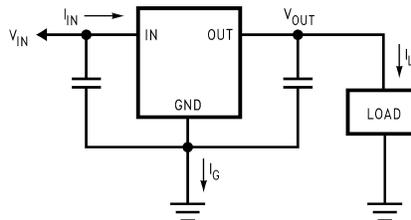Figure 30 shows the voltages and currents which are present in the circuit.



**Figure 30. Power Dissipation Diagram**

Once the devices power is determined, the maximum allowable ($R_{\theta JA\ (max)}$) is calculated as:

$$R_{\theta JA\ (max)} = T_{R(max)}/P_D = T_{J(max)} - T_{A(max)}/P_D$$

The LM1086-MIL has different temperature specifications for two different sections of the device: the control section and the output section. The *Thermal Information* table shows the junction to case thermal resistances for each of these sections, while the maximum junction temperatures ($T_{J(max)}$) for each section is listed in the *Absolute Maximum Ratings* section of the data sheet. $T_{J(max)}$ is 125°C for the control section, while $T_{J(max)}$ is 150°C for the output section.

Calculate $R_{\theta JA\ (max)}$ separately for each section as follows:

$$R_{\theta JA} \text{ (maximum, control section)} = (125°C - T_{A(max)})/P_D \tag{6}$$
$$R_{\theta JA} \text{ (maximum, output section)} = (150°C - T_{A(max)})/P_D \tag{7}$$

The required heat sink is determined by calculating its required thermal resistance ($R_{\theta HA\ (max)}$).

$$R_{\theta HA\ (max)} = R_{\theta JA\ (max)} - (R_{J\theta C} + R_{\theta CH}) \tag{8}$$

($R_{\theta HA\ (max)}$) should also be calculated twice as follows:

$$(R_{\theta HA\ (max)}) = R_{\theta JA} \text{ (maximum, control section)} - (R_{\theta JC} \text{ (CONTROL SECTION)} + R_{\theta CH}) \tag{9}$$
$$(R_{\theta HA\ (max)}) = R_{J\theta A}\text{(maximum, output section)} - (R_{\theta JC} \text{ (OUTPUT SECTION)} + R_{\theta CH}) \tag{10}$$

If thermal compound is used, $R_{\theta CH}$ can be estimated at 0.2°C/W. If the case is soldered to the heat sink, then a $R_{\theta CH}$ can be estimated as 0°C/W.

After, $R_{\theta HA\ (max)}$ is calculated for each section, choose the lower of the two $R_{\theta HA\ (max)}$ values to determine the appropriate heat sink.

## Thermal Considerations (continued)

If PC board copper is going to be used as a heat sink, then Figure 31 can be used to determine the appropriate area (size) of copper foil required.
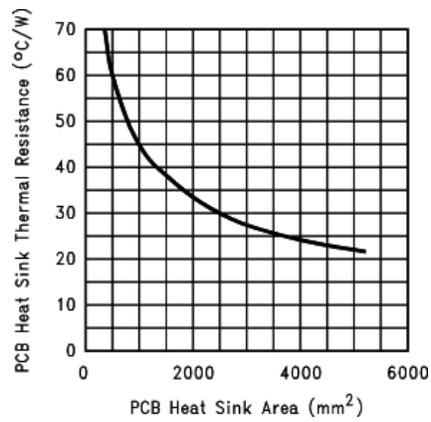


**Figure 31. Heat Sink Thermal Resistance vs Area**

# 11 Device and Documentation Support

## 11.1 Documentation Support

### 11.1.1 Related Documentation

For related documentation see the following:

AN-1187 Leadless Leadframe Package (LLP)

## 11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

## 11.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

## 11.4 Trademarks

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## 11.5 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## 11.6 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

# 12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

![Texas Instruments logo]

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LM1086-ADJ MDC | ACTIVE | DIESALE | Y | 0 | 130 | RoHS & Green | Call TI | Level-1-NA-UNLIM | -40 to 85 | | Samples |

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

**(2)** **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

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

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