

## 1.5A Low Dropout Positive Regulators Adjustable and Fixed 5V, 12V

### FEATURES

- Three Terminal Adjustable or Fixed 5V, 12V
- Output Current of 1.5A, (0.5A for LT1086H)
- Operates Down to 1V Dropout
- Guaranteed Dropout Voltage at Multiple Current Levels
- 0.015% Line Regulation
- 0.1% Load Regulation
- 100% Thermal Limit Burn-In

### APPLICATIONS

- High Efficiency Linear Regulators
- Post Regulators for Switching Supplies
- Constant Current Regulators
- Battery Chargers

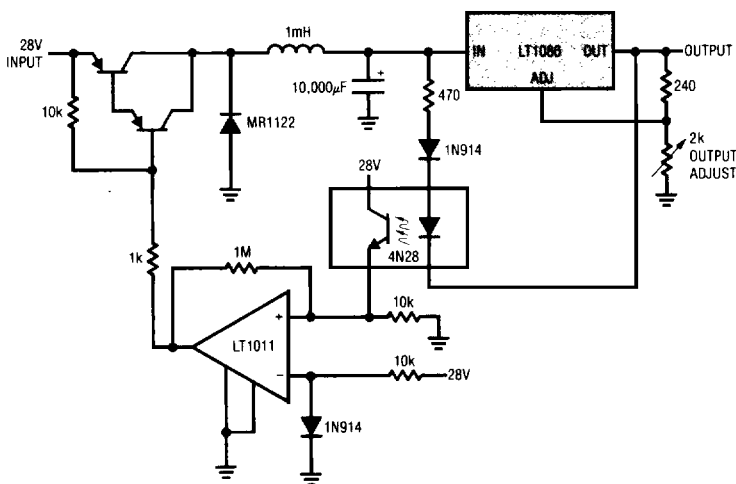
### DESCRIPTION

The LT1086 is designed to provide 1.5A with higher efficiency than currently available devices. All internal circuitry is designed to operate down to 1V input to output differential and the dropout voltage is fully specified as a function of load current. Dropout is guaranteed at a maximum of 1.5V at maximum output current, decreasing at lower load currents. On-chip trimming adjusts the reference/output voltage to 1%. Current limit is also trimmed, minimizing the stress on both the regulator and power source circuitry under overload conditions.

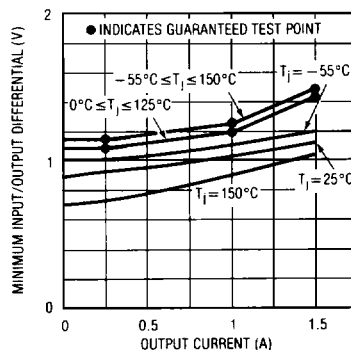
The LT1086 is pin compatible with older 3 terminal adjustable regulators. A 10 $\mu$ F output capacitor is required on these new devices; however, this is usually included in most regulator designs.

Unlike PNP regulators, where up to 10% of the output current is wasted as quiescent current, the LT1086 quiescent current flows into the load, increasing efficiency.

High Efficiency Regulator



LT1086 Dropout Voltage



## ABSOLUTE MAXIMUM RATINGS

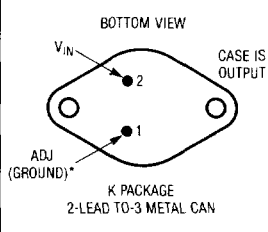
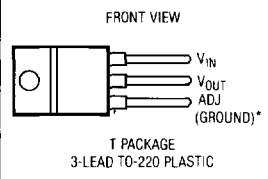
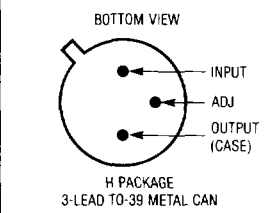
Power Dissipation .....	Internally Limited
Input Voltage* .....	30V
Operating Input Voltage	
Adj. Devices .....	25V
-5V Devices .....	20V
-12V Devices .....	25V
Operating Junction Temperature Range	
"M" Grades	
Control Section .....	-55°C to 150°C
Power Transistor .....	-55°C to 200°C
"C" Grades	
Control Section .....	0°C to 125°C
Power Transistor .....	0°C to 150°C
Storage Temperature .....	-65°C to 150°C
Lead Temperature (Soldering, 10 sec) .....	300°C

\*Although the devices maximum operating voltage is limited, (20V for a -5V device, and 25V for adjustable and -12 devices) the devices are guaranteed to withstand transient input voltages up to 30V. For input voltages greater than the maximum operating input voltage some degradation of specifications will occur. For -5 and -12 devices operating at input/output voltage differentials greater than 15V, a minimum external load of 5mA is required to maintain regulation.

## PRECONDITIONING

100% Thermal Limit Burn-In

## PACKAGE/ORDER INFORMATION

 <p>BOTTOM VIEW</p> <p>FRONT VIEW</p> <p>K PACKAGE 2-LEAD TO-3 METAL CAN</p>	ORDER PART NUMBER	
	LT1086MK	LT1086CK
	LT1086MK-5	LT1086CK-5
	LT1086MK-12	LT1086CK-12
 <p>FRONT VIEW</p> <p>T PACKAGE 3-LEAD TO-220 PLASTIC</p>	LT1086CT LT1086CT-5 LT1086CT-12	
 <p>BOTTOM VIEW</p> <p>H PACKAGE 3-LEAD TO-39 METAL CAN</p>	LT1086MH	

\*FOR FIXED VERSIONS

## ELECTRICAL CHARACTERISTICS (See Note 1)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Reference Voltage LT1086, LT1086H	$I_{OUT} = 10mA$ , $T_J = 25^\circ C$ , $(V_{IN} - V_{OUT}) = 3V$ (K Package Only)	1.238	1.250	1.262	V
	$10mA \leq I_{OUT} \leq 1.5A$ , (0.5A for LT1086H) $1.5V \leq (V_{IN} - V_{OUT}) \leq 15V$	1.225	1.250	1.270	V
Output Voltage LT1086-5	$I_{OUT} = 0mA$ , $T_J = 25^\circ C$ $V_{IN} = 8V$ (K Package Only)	4.950	5.000	5.050	V
	$0 \leq I_{OUT} \leq 1.5A$ , $6.5V \leq V_{IN} \leq 20V$	4.900	5.000	5.100	V
LT1086-12	$I_{OUT} = 0mA$ , $T_J = 25^\circ C$ $V_{IN} = 15V$ (K Package Only)	11.880	12.000	12.120	V
	$0V \leq I_{OUT} \leq 1.5A$ , $13.5V \leq V_{IN} \leq 25V$	11.760	12.000	12.240	V
Line Regulation LT1086, LT1086H	$I_{LOAD} = 10mA$ , $1.5V \leq (V_{IN} - V_{OUT}) \leq 15V$ , $T_J = 25^\circ C$		0.015	0.2	%
			0.035	0.2	%
LT1086-5	$I_{OUT} = 0mA$ , $T_J = 25^\circ C$ , $6.5V \leq V_{IN} \leq 20V$		0.5	10	mV
			1.0	10	mV
LT1086-12	$I_{OUT} = 0mA$ , $T_J = 25^\circ C$ , $13.5V \leq V_{IN} \leq 25V$		1.0	25	mV
			2.0	25	mV

## ELECTRICAL CHARACTERISTICS (See Note 1)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Load Regulation LT1086, LT1086H	$(V_{IN} - V_{OUT}) = 3V$ , $10mA \leq I_{OUT} \leq 1.5A$ , (0.5A for LT1086H) $T_j = 25^{\circ}C$ (Notes 1, 2)	●		0.1 0.2	0.3 0.4	% %
LT1086-5	$V_{IN} = 8V$ , $0 \leq I_{OUT} \leq 1.5A$ , $T_j = 25^{\circ}C$ (Notes 1, 2)	●		5 10	20 35	mV mV
LT1086-12	$V_{IN} = 15V$ , $0 \leq I_{OUT} \leq 1.5A$ , $T_j = 25^{\circ}C$ (Notes 1, 2)	●		12 24	36 72	mV mV
Dropout Voltage ( $V_{IN} - V_{OUT}$ ) LT1086	$\Delta V_{REF} = 1\%$ , $I_{OUT} = 1.5A$ (Note 3)	●		1.3	1.5	V
LT1086H	$\Delta V_{REF} = 1\%$ , $I_{OUT} = 0.5A$ (Note 3)	●		0.95	1.25	V
LT1086-5	$\Delta V_{OUT} = 50mV$ , $I_{OUT} = 1.5A$ (Note 3)	●		1.3	1.5	V
LT1086-12	$\Delta V_{OUT} = 120mV$ , $I_{OUT} = 1.5A$ (Note 3)	●		1.3	1.5	V
Current Limit LT1086, LT1086-5, LT1086-12	$(V_{IN} - V_{OUT}) = 5V$	●	1.5	1.6	2.5	A
	$(V_{IN} - V_{OUT}) = 25V$	●	0.050	0.10		A
LT1086H	$(V_{IN} - V_{OUT}) = 5V$	●	0.5	0.7	1.2	A
	$(V_{IN} - V_{OUT}) = 25V$	●	0.020	0.075		A
Minimum Load Current LT1086, LT1086H	$(V_{IN} - V_{OUT}) = 25V$ (Note 4)	●		5	10	mA
Quiescent Current LT1086-5	$V_{IN} \leq 20V$	●		5	10	mA
LT1086-12	$V_{IN} \leq 25V$	●		5	10	mA
Thermal Regulation	$T_A = 25^{\circ}C$ , 30ms Pulse			0.008	0.04	%/W
Ripple Rejection  LT1086, LT1086H	$f = 120Hz$ , $C_{OUT} = 25\mu F$ Tantalum $I_{OUT} = 1.5A$ , ( $I_{OUT} = 0.5A$ for LT1086H) $C_{ADJ} = 25\mu F$ , $(V_{IN} - V_{OUT}) = 3V$	●	60	75		dB
LT1086-5	$V_{IN} = 8V$	●	60	68		dB
LT1086-12	$V_{IN} = 15V$	●	54	60		dB
Adjust Pin Current LT1086, LT1086H	$T_j = 25^{\circ}C$	●		55	120	$\mu A$ $\mu A$
Adjust Pin Current Change LT1086, LT1086H	$10mA \leq I_{OUT} \leq 1.5A$ , (0.5A for LT1086H) $1.5V \leq (V_{IN} - V_{OUT}) \leq 15V$	●		0.2	5	$\mu A$
Temperature Stability		●		0.5		%
Long Term Stability	$T_A = 125^{\circ}C$ , 1000 Hrs.			0.3	1	%
RMS Output Noise (% of $V_{OUT}$ )	$T_A = 25^{\circ}C$ $10Hz \leq f \leq 10kHz$			0.003		%
Thermal Resistance Junction to Case	K Package: Control Circuitry/Power Transistor T Package: Control Circuitry/Power Transistor H Package: Control Circuitry/Power Transistor				1.7/4.0 1.5/4.0 15/20	$^{\circ}C/W$ $^{\circ}C/W$ $^{\circ}C/W$

The ● denotes the specifications which apply over the full operating temperature range.

**Note 1:** See thermal regulation specifications for changes in output voltage due to heating effects. Load and line regulation are measured at a constant junction temperature by low duty cycle pulse testing. Load regulation is measured at the output lead  $\approx 1/8"$  from the package.

**Note 2:** Line and load regulation are guaranteed up to the maximum power dissipation of 15W for the LT1086, LT1086-5 and LT1086-12, and 3W for the LT1086H. Power dissipation is determined by the input/output differential

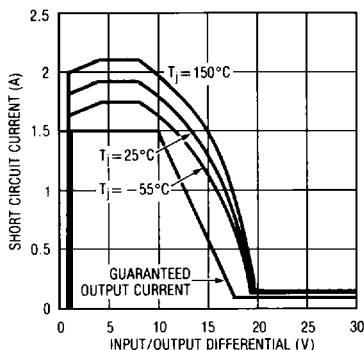
and the output current. Guaranteed maximum power dissipation will not be available over the full input/output voltage range. See Short Circuit Current Curve for available output current.

**Note 3:** Dropout voltage is specified over the full output current range of the device. Test points and limits are shown on the Dropout Voltage curve.

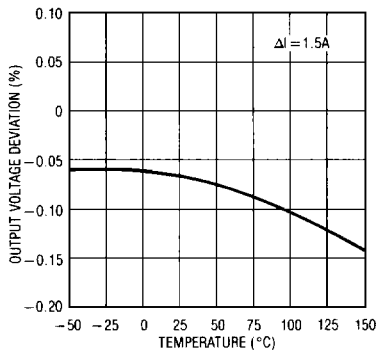
**Note 4:** Minimum load current is defined as the minimum output current required to maintain regulation. At 25V input/output differential the device is guaranteed to regulate if the output current is greater than 10mA.

## TYPICAL PERFORMANCE CHARACTERISTICS

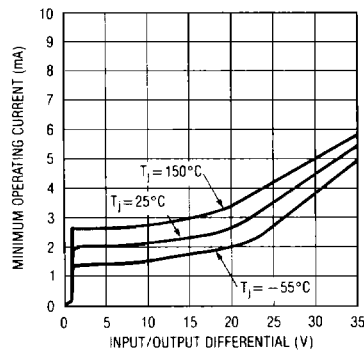
LT1086 Short Circuit Current



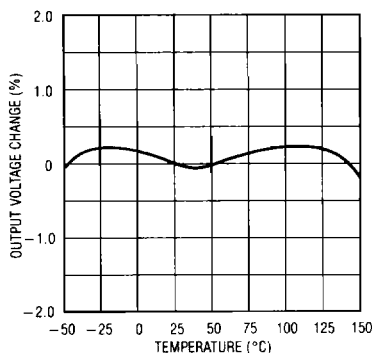
LT1086 Load Regulation



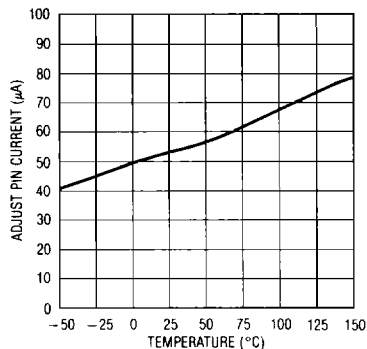
Minimum Operating Current  
(Adjustable Device)



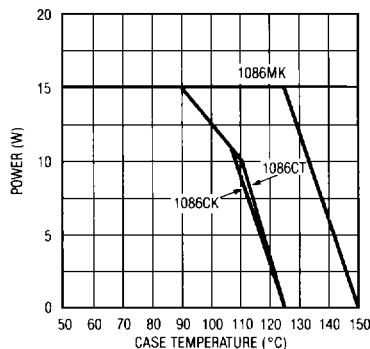
Temperature Stability



Adjust Pin Current

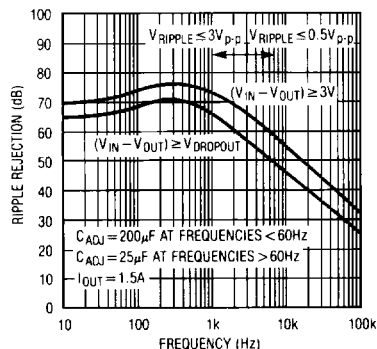


LT1086 Maximum Power  
Dissipation\*

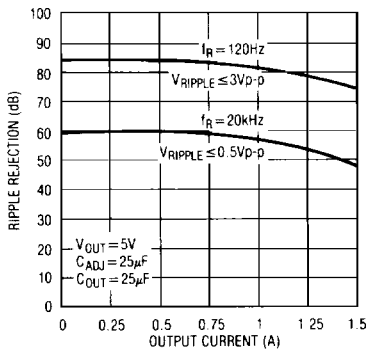


\*AS LIMITED BY MAXIMUM JUNCTION TEMPERATURE

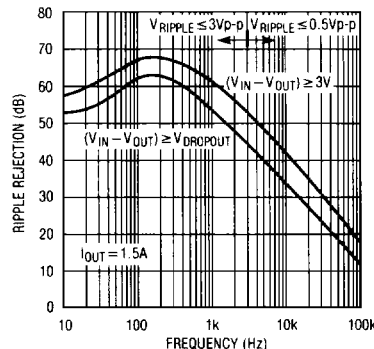
LT1086 Ripple Rejection



LT1086 Ripple Rejection vs  
Current

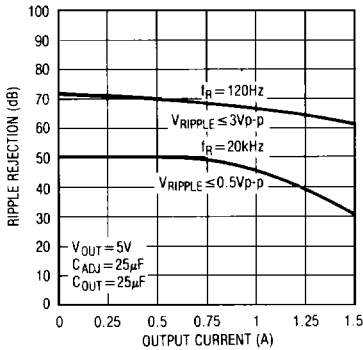


LT1086-5 Ripple Rejection

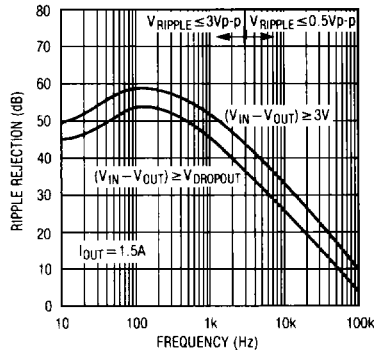


## TYPICAL PERFORMANCE CHARACTERISTICS

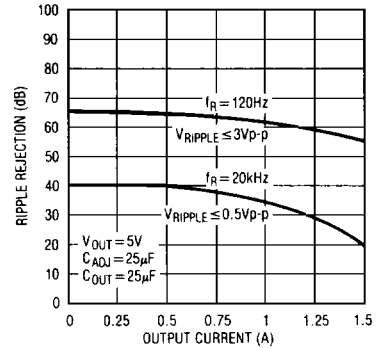
LT1086-5 Ripple Rejection vs Current



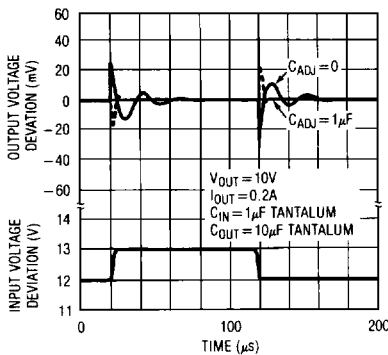
LT1086-12 Ripple Rejection



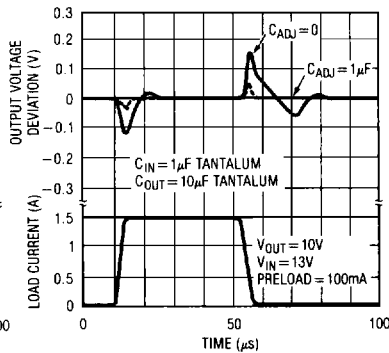
LT1086-12 Ripple Rejection vs Current



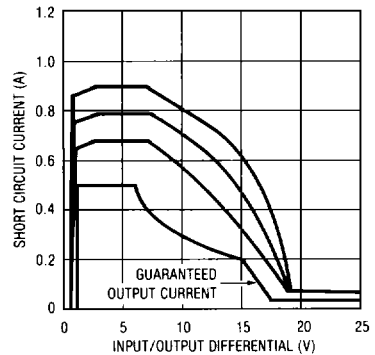
LT1086 Line Transient Response



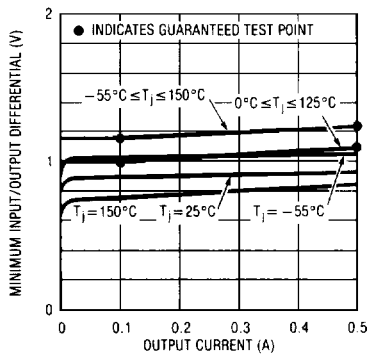
LT1086 Load Transient Response



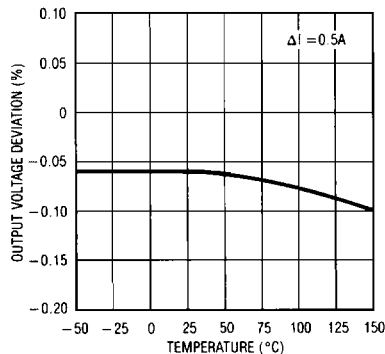
LT1086H Short Circuit Current



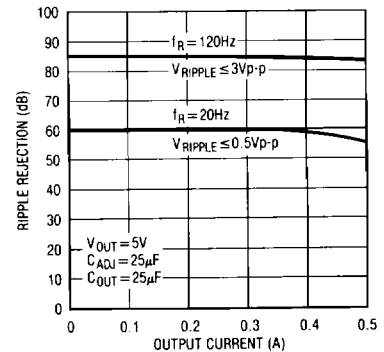
LT1086H Dropout Voltage



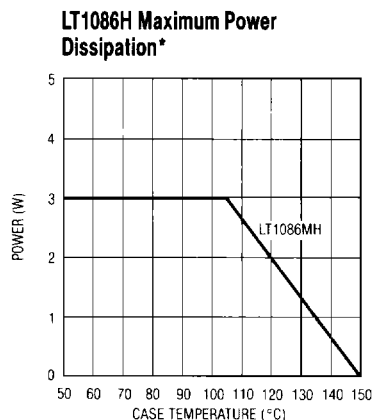
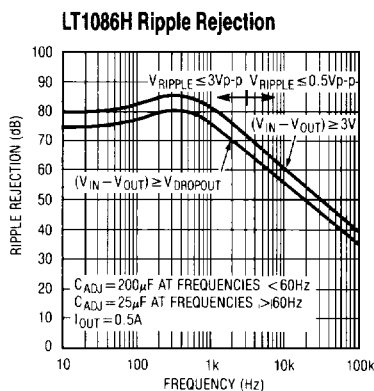
LT1086H Load Regulation



LT1086H Ripple Rejection vs Current



## TYPICAL PERFORMANCE CHARACTERISTICS



\*AS LIMITED BY MAXIMUM JUNCTION TEMPERATURE

## APPLICATION HINTS

The LT1086 family of three terminal regulators is easy to use and has all the protection features that are expected in high performance voltage regulators. They are short circuit protected, have safe area protection as well as thermal shutdown to turn off the regulator should the temperature exceed about  $165^{\circ}\text{C}$  at the sense point.

These regulators are pin compatible with older three terminal adjustable devices, offer lower dropout voltage and more precise reference tolerance. Further, the reference stability with temperature is improved over older types of regulators. The only circuit difference between using the LT1086 family and older regulators is that they require an output capacitor for stability.

### Stability

The circuit design used in the LT1086 family requires the use of an output capacitor as part of the device frequency compensation. For all operating conditions, the addition of  $150\mu\text{F}$  aluminum electrolytic or a  $22\mu\text{F}$  solid tantalum on the output will ensure stability. Normally, capacitors much smaller than this can be used with the LT1086. Many different types of capacitors with widely varying characteristics are available. These capacitors differ in capacitor tolerance (sometimes ranging up to  $\pm 100\%$ ), equivalent series resistance, and capacitance temperature coefficient. The  $150\mu\text{F}$  or  $22\mu\text{F}$  values given will ensure stability.

When using the LT1086 the adjustment terminal can be bypassed to improve ripple rejection. When the adjustment terminal is bypassed the requirement for an output capacitor increases. The values of  $22\mu\text{F}$  tantalum or  $150\mu\text{F}$  aluminum cover all cases of bypassing the adjustment terminal. For fixed voltage devices or adjustable devices without an adjust pin bypass capacitor, smaller output capacitors can be used with equally good results and the table below shows approximately what size capacitors are needed to ensure stability.

### Recommended Capacitor Values

Input	Output	Adjustment
$10\mu\text{F}$	$10\mu\text{F}$ Tantalum, $50\mu\text{F}$ Aluminum	None
$10\mu\text{F}$	$22\mu\text{F}$ Tantalum, $150\mu\text{F}$ Aluminum	$20\mu\text{F}$

Normally, capacitor values on the order of  $100\mu\text{F}$  are used in the output of many regulators to ensure good transient response with heavy load current changes. Output capacitance can be increased without limit and larger values of output capacitor further improve stability and transient response of the LT1086 regulators.

Another possible stability problem that can occur in monolithic IC regulators is current limit oscillations. These can occur because, in current limit, the safe area

## APPLICATION HINTS

protection exhibits a negative impedance. The safe area protection decreases the current limit as the input-to-output voltage increases. That is the equivalent of having a negative resistance since increasing voltage causes current to decrease. Negative resistance during current limit is not unique to the LT1086 series and has been present on all power IC regulators. The value of the negative resistance is a function of how fast the current limit is folded back as input-to-output voltage increases. This negative resistance can react with capacitors or inductors on the input to cause oscillation during current limiting. Depending on the value of series resistance, the overall circuitry may end up unstable. Since this is a system problem, it is not necessarily easy to solve; however it does not cause any problems with the IC regulator and can usually be ignored.

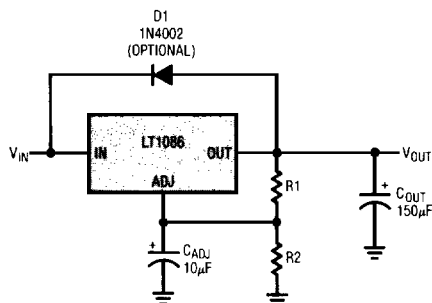
### Protection Diodes

In normal operation, the LT1086 family does not need any protection diodes. Older adjustable regulators required protection diodes between the adjustment pin and the output and from the output to the input to prevent overstressing the die. The internal current paths on the LT1086 adjustment pin are limited by internal resistors. Therefore, even with capacitors on the adjustment pin, no protection diode is needed to ensure device safety under short circuit conditions.

Diodes between input and output are usually not needed. The internal diode between the input and the output pins of the LT1086 family can handle microsecond surge currents of 10A to 20A. Even with large output capacitances, it is very difficult to get those values of surge currents in normal operations. Only with high value of output capacitors, such as 1000 $\mu$ F to 5000 $\mu$ F and with the input pin instantaneously shorted to ground, can damage occur. A crowbar circuit at the input of the LT1086 can generate those kinds of currents, and a diode from output to input is then recommended. Normal power supply cycling or even plugging and unplugging in the system will not generate current large enough to do any damage.

The adjustment pin can be driven on a transient basis  $\pm 25$ V, with respect to the output without any device

degradation. Of course, as with any IC regulator, exceeding the maximum input to output voltage differential causes the internal transistors to break down and none of the protection circuitry is functional.



### Overload Recovery

Like any of the IC power regulators, the LT1086 has safe area protection. The safe area protection decreases the current limit as input-to-output voltage increases and keeps the power transistor inside a safe operating region for all values of input-to-output voltage. The LT1086 protection is designed to provide some output current at all values of input-to-output voltage up to the device breakdown.

When power is first turned on, as the input voltage rises, the output follows the input, allowing the regulator to start up into very heavy loads. During the start-up, as the input voltage is rising, the input-to-output voltage differential remains small, allowing the regulator to supply large output currents. With high input voltage, a problem can occur wherein removal of an output short will not allow the output voltage to recover. Older regulators, such as the 7800 series, also exhibited this phenomenon, so it is not unique to the LT1086.

The problem occurs with a heavy output load when the input voltage is high and the output voltage is low, such as immediately after a removal of a short. The load line for such a load may intersect the output current curve at two points. If this happens, there are two stable output operating points for the regulator. With this double intersection, the power supply may need to be cycled down to zero and brought up again to make the output recover.

## APPLICATION HINTS

### Ripple Rejection

For the LT1086 the typical curves for ripple rejection reflect values for a bypassed adjustment pin. This curve will be true for all values of output voltage. For proper bypassing, and ripple rejection approaching the values shown, the impedance of the adjust pin capacitor, at the ripple frequency should equal the value of  $R_1$ , (normally 100 $\Omega$ -120 $\Omega$ ). The size of the required adjust pin capacitor is a function of the input ripple frequency. At 120Hz the adjust pin capacitor should be 13 $\mu$ F if  $R_1 = 100\Omega$ . At 10kHz only 0.16 $\mu$ F is needed.

For circuits without an adjust pin bypass capacitor, the ripple rejection will be a function of output voltage. The output ripple will increase directly as a ratio of the output voltage to the reference voltage ( $V_{OUT}/V_{REF}$ ). For example, with the output voltage equal to 5V, and no adjust pin capacitor, the output ripple will be higher by the ratio of 5V/1.25V or 4 times larger. Ripple rejection will be degraded by 12dB from the value shown on the LT1086 curve. Typical curves are provided for -5 and -12 devices since the adjust pin is not available.

### Output Voltage

The LT1086 develops a 1.25V reference voltage between the output and the adjust terminal (see Figure 1). By placing a resistor,  $R_1$ , between these two terminals, a constant current is caused to flow through  $R_1$  and down through  $R_2$  to set the overall output voltage. Normally this current is chosen to be the specified minimum load current of 10mA. Because  $I_{ADJ}$  is very small and constant when compared with the current through  $R_1$ , it represents a small error and can usually be ignored. For fixed voltage devices  $R_1$  and  $R_2$  are included in the device.

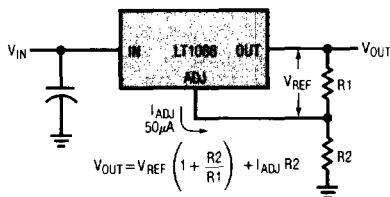


Figure 1. Basic Adjustable Regulator

### Load Regulation

Because the LT1086 is a three-terminal device, it is not possible to provide true remote load sensing. Load regulation will be limited by the resistance of the wire connecting the regulator to the load. The data sheet specification for load regulation is measured at the bottom of the package. Negative side sensing is a true Kelvin connection, with the bottom of the output divider returned to the negative side of the load. Although it may not be immediately obvious, best load regulation is obtained when the top of the resistor divider, ( $R_1$ ), is connected *directly* to the case *not to the load*. This is illustrated in Figure 2. If  $R_1$  were connected to the load, the effective resistance between the regulator and the load would be

$$R_p \times \frac{R_2 + R_1}{R_1}, R_p = \text{Parasitic Line Resistance.}$$

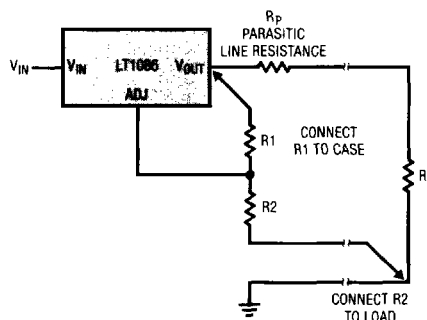


Figure 2. Connections for Best Load Regulation

Connected as shown,  $R_p$  is not multiplied by the divider ratio.  $R_p$  is about 0.004 $\Omega$  per foot using 16 gauge wire. This translates to 4mV/ft at 1A load current, so it is important to keep the positive lead between regulator and load as short as possible, and use large wire or PC board traces.

Note that the resistance of the package leads for the H package  $\approx 0.06\Omega/\text{in}$ . While it is usually not possible to connect the load directly to the package, it is possible to connect larger wire or PC traces close to the case to avoid voltage drops that will degrade load regulation.

For fixed voltage devices the top of  $R_1$  is internally Kelvin connected, and the ground pin can be used for negative side sensing.



## APPLICATION HINTS

### Thermal Considerations

The LT1086 series of regulators have internal power and thermal limiting circuitry designed to protect the device under overload conditions. For continuous normal load conditions however, maximum junction temperature ratings must not be exceeded. It is important to give careful consideration to all sources of thermal resistance from junction to ambient. This includes junction to case, case to heat sink interface, and heat sink resistance itself. New thermal resistance specifications have been developed to more accurately reflect device temperature and ensure safe operating temperatures. The data section for these new regulators provides a separate thermal resistance and maximum junction temperature for both the *Control Section* and the *Power Transistor*. Previous regulators, with a single junction to case thermal resistance specification, used an average of the two values provided here and therefore could allow excessive junction temperatures under certain conditions of ambient temperature and heat sink resistance. To avoid this possibility, calculations should be made for both sections to ensure that both thermal limits are met.

For example, using a LT1086CK (TO-3, Commercial) and assuming:

$$\begin{aligned} V_{IN} (\text{max continuous}) &= 9V, V_{OUT} = 5V, I_{OUT} = 1A, \\ T_{AMBIENT} &= 75^{\circ}\text{C}, \theta_{HEAT\ SINK} = 3^{\circ}\text{C/W}, \\ \theta_{CASE\text{-}TO\text{-}HEAT\text{-}SINK} &= 0.2^{\circ}\text{C/W for K package with thermal compound.} \end{aligned}$$

Power dissipation under these conditions is equal to:

$$P_D = (V_{IN} - V_{OUT}) (I_{OUT}) = 4W$$

Junction temperature will be equal to:

$$T_j = T_{AMBIENT} + P_D (\theta_{HEAT\text{-}SINK} + \theta_{CASE\text{-}TO\text{-}HEAT\text{-}SINK} + \theta_{jc})$$

For the Control Section:

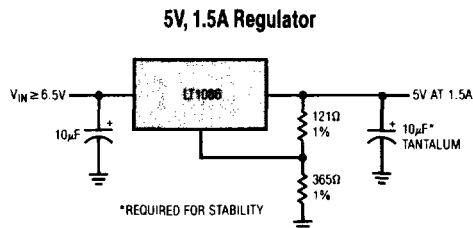
$$\begin{aligned} T_j &= 75^{\circ}\text{C} + 4W (3^{\circ}\text{C/W} + 0.2^{\circ}\text{C/W} + 1.7^{\circ}\text{C/W}) = 95^{\circ}\text{C} \\ 95^{\circ}\text{C} &< 125^{\circ}\text{C} = T_{jmax} \text{ (Control Section)} \\ &\text{Commercial Range} \end{aligned}$$

For the Power Transistor:

$$\begin{aligned} T_j &= 75^{\circ}\text{C} + 4W (3^{\circ}\text{C/W} + 0.2^{\circ}\text{C/W} + 4^{\circ}\text{C/W}) = 103.8^{\circ}\text{C} \\ 103.8^{\circ}\text{C} &< 150^{\circ}\text{C} = T_{jmax} \text{ (Power Transistor)} \\ &\text{Commercial Range} \end{aligned}$$

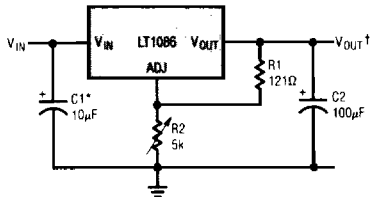
In both cases the junction temperature is below the maximum rating for the respective sections, ensuring reliable operation.

Junction to case thermal resistance for the K and T packages is specified from the I.C. junction to the bottom of the case directly below the die. This is the lowest resistance path for heat flow. While this is also the lowest resistance path for the H package, most available heat sinks for this package are of the clip-on type that attach to the cap of the package. The datasheet specification for thermal resistance for the H package is therefore written to reflect this. In all cases proper mounting is required to ensure the best possible heat flow from the die to the heat sink. Thermal compound at the case-to-heat sink interface is strongly recommended. In the case of the H package, mounting the device so that heat can flow out the bottom of the case will significantly lower thermal resistance ( $\approx$  a factor of 2). If the case of the device must be electrically isolated, a thermally conductive spacer can be used, as long as its added contribution to thermal resistance is considered. Note that the case of all devices in this series is electrically connected to the output.



## TYPICAL APPLICATIONS

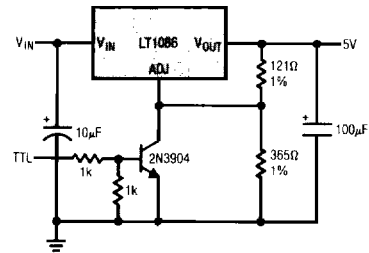
### 1.2V-15V Adjustable Regulator



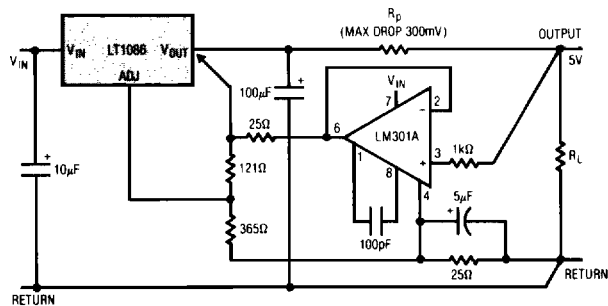
\*NEEDED IF DEVICE IS FAR FROM FILTER CAPACITORS

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

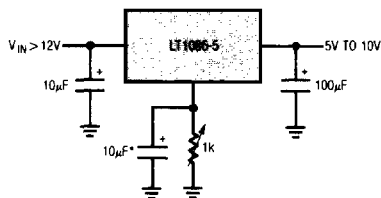
### 5V Regulator with Shutdown



## Remote Sensing

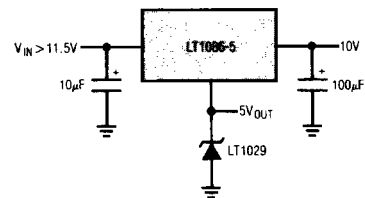


## Adjusting Output Voltage of Fixed Regulators

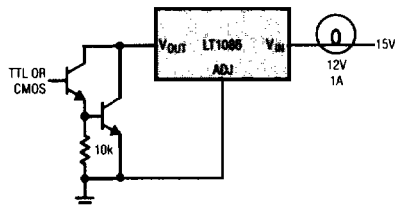


\*OPTIONAL IMPROVES RIPPLE REJECTION

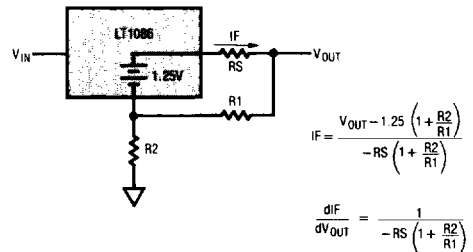
### Regulator with Reference



## Protected High Current Lamp Driver



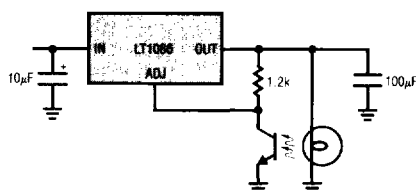
## Battery Charger



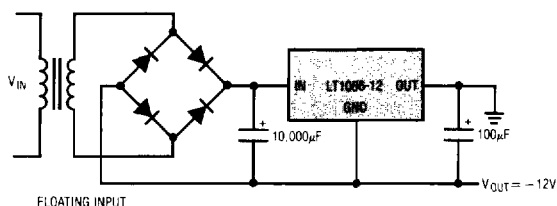


## TYPICAL APPLICATIONS

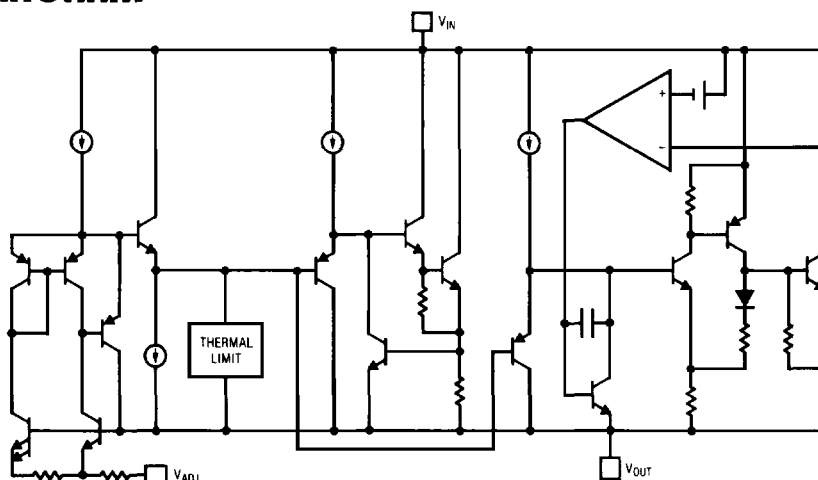
Automatic Light Control



Low Dropout Negative Supply



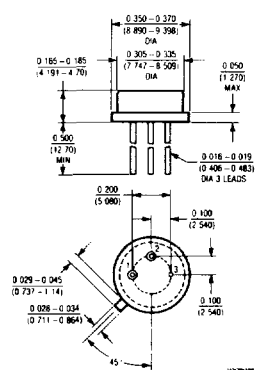
## BLOCK DIAGRAM



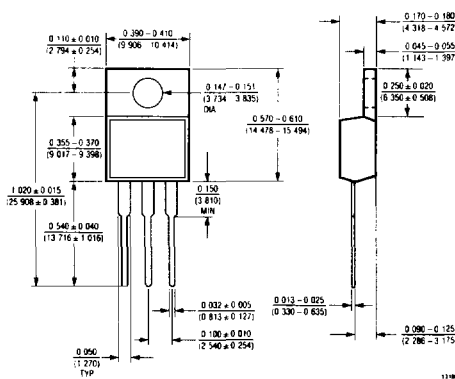
## PACKAGE DESCRIPTIONS

Dimensions in inches (millimeters) unless otherwise noted.

H Package  
3-Lead TO-39 Metal Can



T Package  
3-Lead TO-220 Plastic



K Package  
2-Lead TO-3 Metal Can

