High Input Voltage
Adjustable 3-Terminal Linear Regulator

Features

- ❏ **12V to 450V input voltage range**
- ❏ Adjustable 1.20V to 440V output regulation
- ❏ 5% output voltage tolerance
- ❏ Output current limiting
- ❏ 10μA typical ADJ current
- ❏ Internal junction temperature limiting

Applications

- ❏ Off-line SMPS startup circuits
- ❏ Adjustable high voltage constant current source
- ❏ Industrial Controls
- ❏ Motor controls
- ❏ Battery chargers
- ❏ Power supplies

General Description

The Supertex LR8 is a high voltage, low output current, adjustable linear regulator. It has a wide operating input voltage range of 12V to 450V. The output voltage can be adjusted from 1.20V to 440V provided that the input voltage is at least 10V greater than the output voltage. The output voltage can be adjusted by means of two external resistors R1 and R2 as shown in the typical application circuits. The LR8 regulates the voltage difference between V_{OUT} and ADJ pins to a nominal value of 1.20V. The 1.20V is amplified by the external resistor ratio R1 and R2. An internal constant bias current of typically 10μA is connected to the ADJ pin. This increases V_{OUT} by a constant voltage of 10μA times R2.

The LR8 has current limiting and temperature limiting. The output current limit is typically 20mA and the minimum temperature limit is 125°C. An output short circuit current will therefore be limited to 20mA. When the junction temperature reaches its temperature limit, the output current and/or output voltage will decrease to keep the junction temperature from exceeding its temperature limit. For SMPS start-up circuit applications, the LR8 turns off when an external voltage greater than the output voltage of the LR8 is applied to V_{OUT} of the LR8. To maintain stability, a bypass capacitor of 1.0μF or larger and a minimum DC output current of 500μA are required.

The device is available in TO-92, TO-243AA (SOT-89), and TO-252 (D-PAK) packages.

LR8 Block Diagram and Typical Application
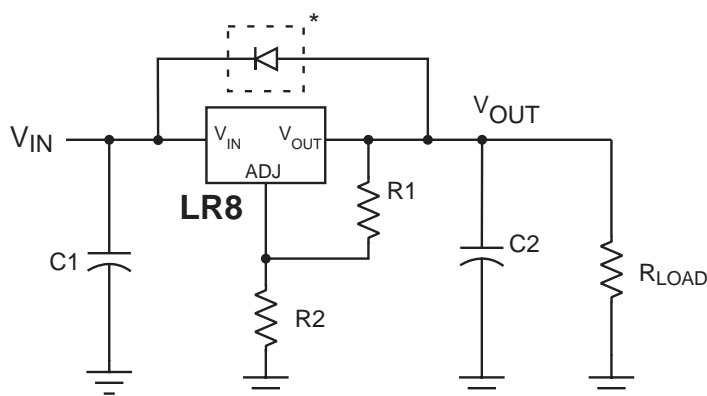
*Required for conditions where V_{IN} is less than V_{OUT}.

Ordering Information

Package Options		
TO-92	**TO-243AA***	**TO-252**
LR8N3	LR8N8	LR8K4

* Same as SOT-89. Product supplied on 2000 piece carrier tape reels.
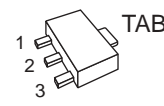
Product marking for TO-243AA:

LR8✻

where ✻ = 2-week alpha date code
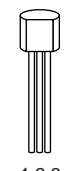
Absolute Maximum Ratings

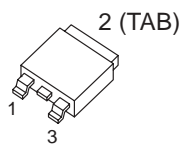|	
V_{IN} Input Voltage	-0.5V to +480V*
Output Voltage Range	-0.5V to +470V
Operating Ambient Temperature Range	-40°C to +85°C
Operating Junction Temperature Range	-40°C to +125°C
Storage Temperature Range	-65°C to +150°C

*Voltages referenced to ADJ.

Pin Configurations

TO-243AA (SOT-89)   TO-92   TO-252 (D-PAK)

	V_{IN}	V_{OUT}	ADJ
TO-92	1	2	3
TO-243AA	1	2 TAB	3
TO-252	1	2 (TAB)	3

Electrical Characteristics

Test conditions unless otherwise specified: -40°C < T_A < 85°C.

Symbol	Parameter	Min	Typ	Max	Units	Test Conditions
V_{IN} - V_{OUT}	Input to Output Voltage Difference	12		450	V	
V_{OUT}	Overall Output Voltage Regulation	1.14	1.20	1.26	V	12V<V_{IN}<400V, R1=2.4KΩ, R2=0
V_{OUT}	Overall Output Voltage Regulation	375	400	425	V	R1=2.4KΩ, R2=782KΩ
ΔV_{OUT}	Line Regulation		0.003	0.01	%/V	15V<V_{IN}<400V, V_{OUT}=5V, I_{OUT}=0.5mA
ΔV_{OUT}	Load Regulation		1.4	3.0	%	V_{IN}=15V, V_{OUT}=5V, 0.5mA<I_{OUT}<10mA
ΔV_{OUT}	Temperature Regulation	-1		+1	%	V_{IN}=15V, V_{OUT}=5V, I_{OUT}=10mA, -40°C<T_A<85°C
I_{OUT}	Output Current Limit	10		30	mA	T_J < 85°C, V_{IN} - V_{OUT} = 10V
I_{OUT}	Output Current Limit			0.5	mA	T_J > 125°C, V_{IN} - V_{OUT} = 450V
I_{OUT}	Minimum Output Current		0.3	0.5	mA	Includes R1 and load current
I_{ADJ}	Adjust Output Current	5	10	15	μA	
C2	Minimum Output Load Capacitance	1			μF	
DV_{OUT}/DV_{IN}	Ripple Rejection Ratio	50	60		dB	120Hz, V_{OUT} = 5V
T_{LIMIT}	Junction Temperature Limit	125			°C	

Thermal Characteristics

Package	Power Dissipation @ T_A=25°C	θ_{JC} °C/W	θ_{JA} °C/W
TO-92	0.74W	125	170
TO-243AA	1.6W	15	78†
TO-252	2.5W	6.25	50†

† Mounted on FR4 board, 25mm x 25mm x 1.57mm.
  Significant P_D increase possible on ceramic substrate.

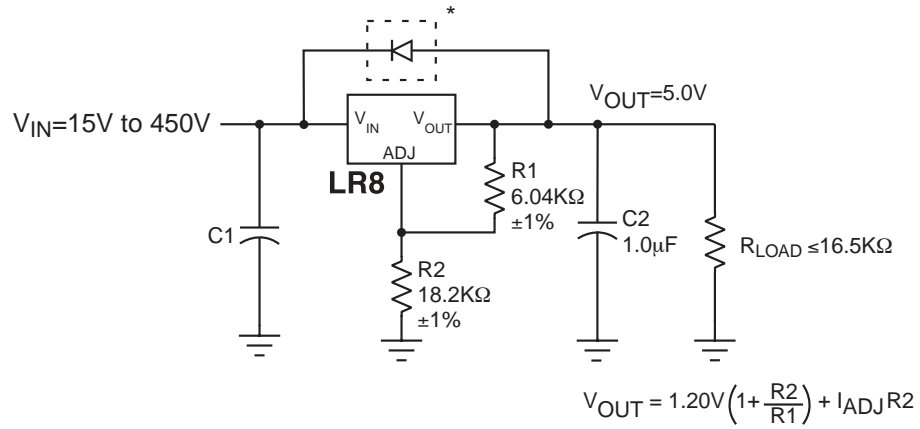## Functional Block Diagram
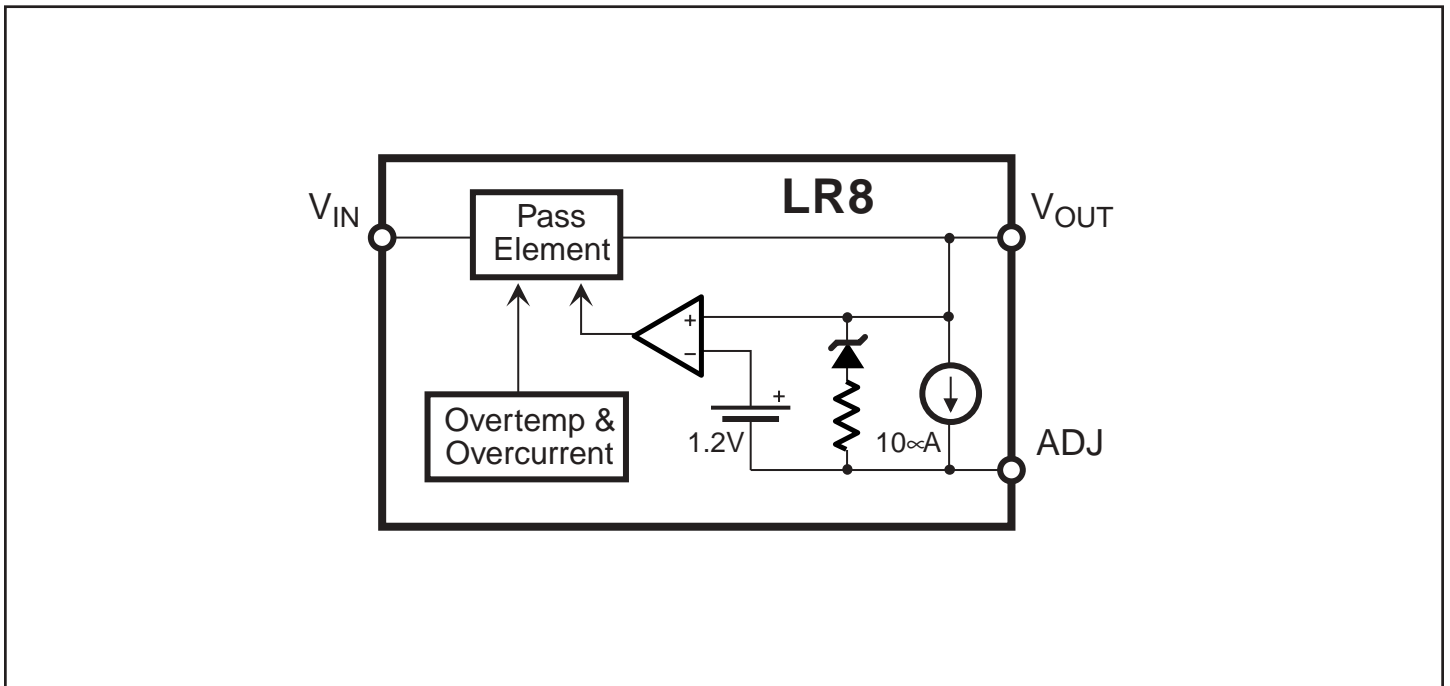
Typical Application Circuits

Figure 1: High Input Voltage, 5.0V Output Linear Regulator

$$V_{OUT} = 1.20V\left(1+\frac{R2}{R1}\right) + I_{ADJ}R2$$
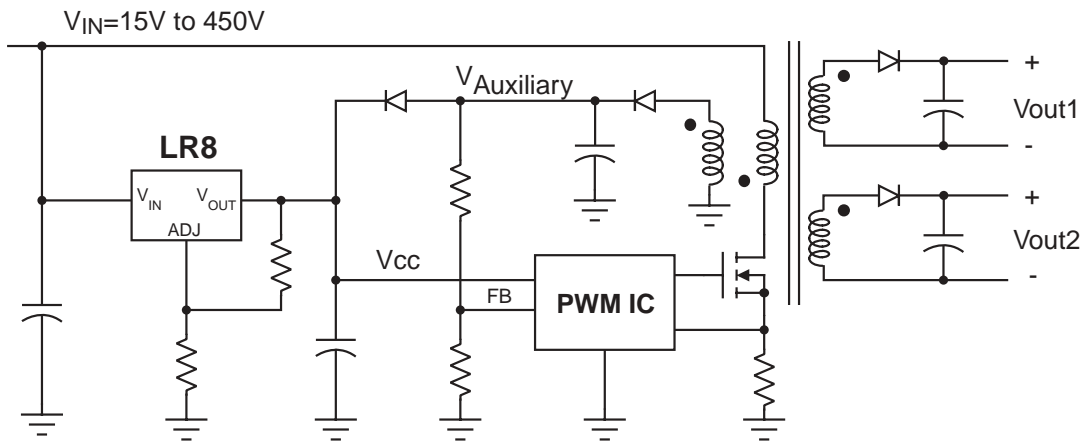
* Required for conditions where V_{IN} is less than V_{OUT}.

Figure 2: SMPS Start-Up Circuit

$$I_{OUT} = \frac{1.20V}{R}$$
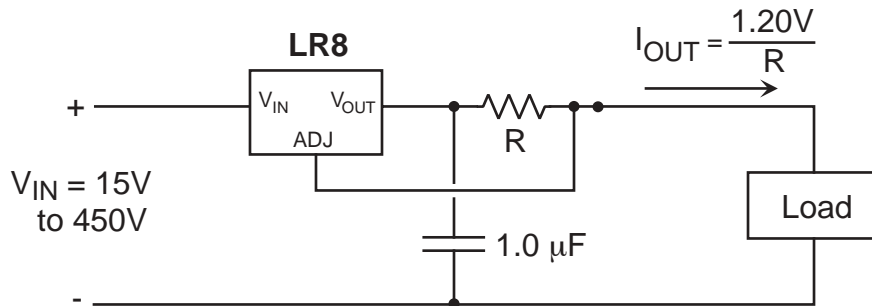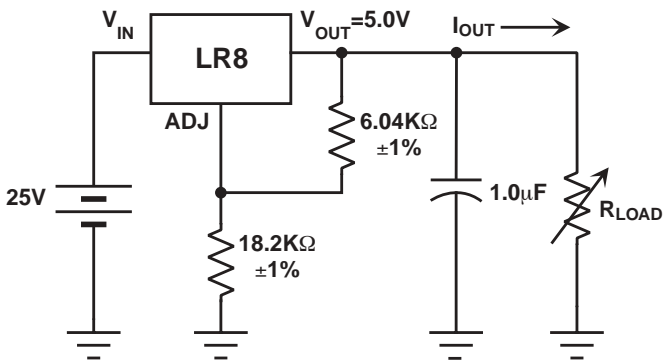
Figure 3: High Voltage Adjustable Constant Current Source

Typical Performance Curves

Temperature Variation

Adjustment Current

Load Regulation

Typical Performance Curves

V_{OUT} vs. V_{IN}

Circuit diagram:
- V_IN → LR8 → V_OUT=5.0V
- ADJ
- 6.04KΩ ±1%
- 18.2KΩ ±1%
- 1.0μF
- 1KΩ
- 0V to 50V

Graph: V_{OUT} (V) vs V_{IN} (V)

Current Limit

Circuit diagram:
- V_IN → LR8 → V_OUT=5.0V → I_OUT →
- ADJ
- 6.04KΩ ±1%
- 18.2KΩ ±1%
- 1.0μF
- R_LOAD
- 20V_P-P @ 60Hz
- 65V

Graph: Ripple Rejection — Ripple Rejection Ratio (dB) vs I_{OUT} (mA)

Graph: Icl (mA) vs Temperature (°C)
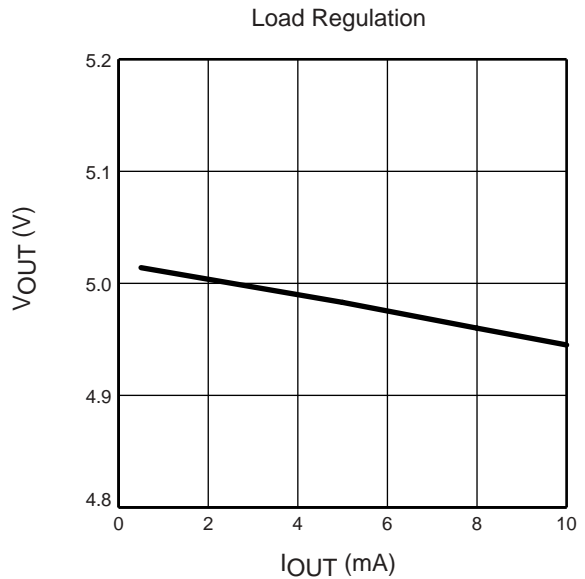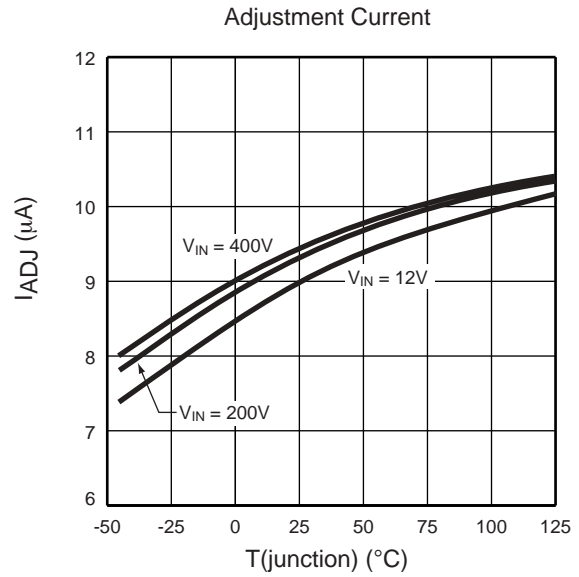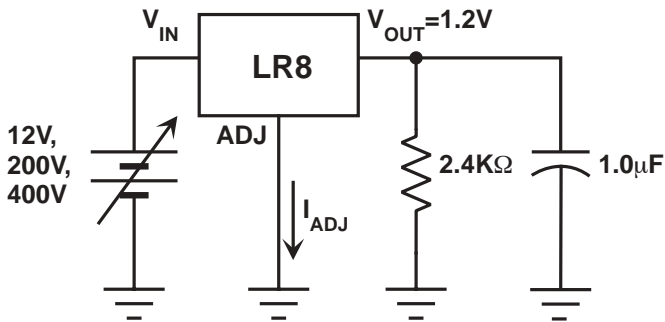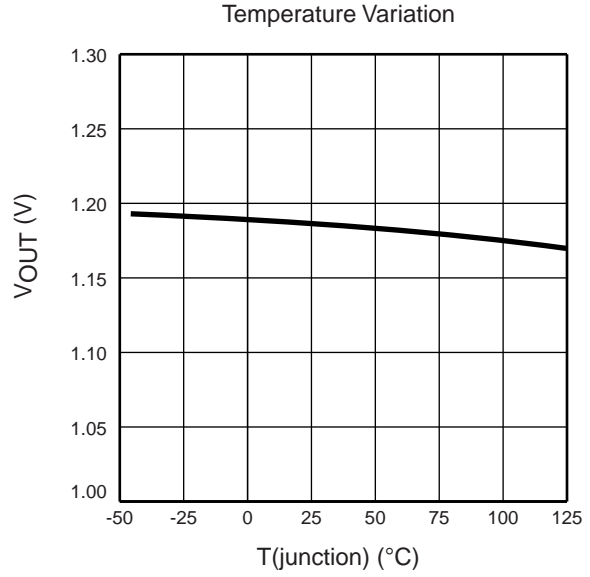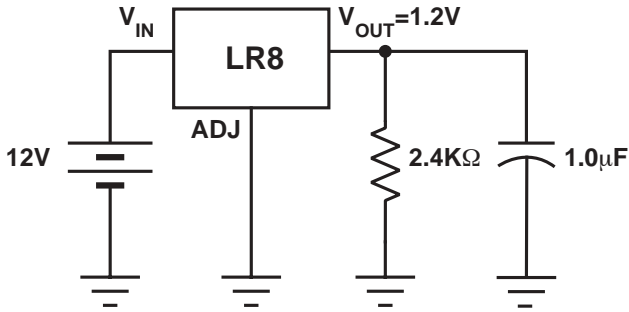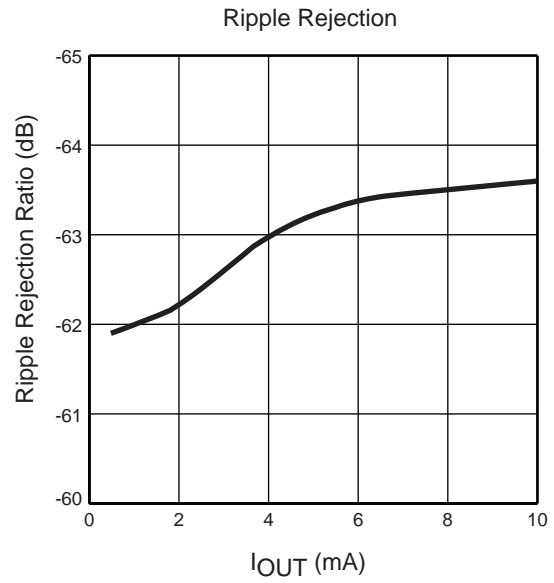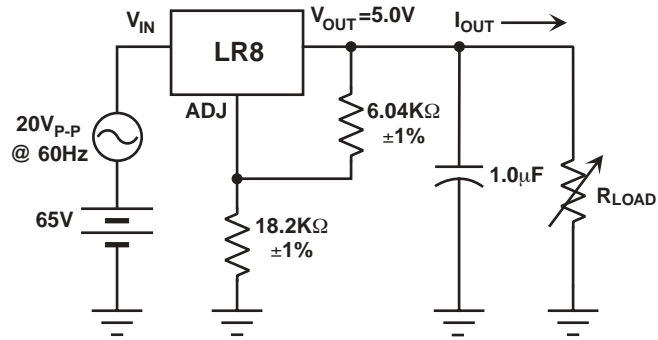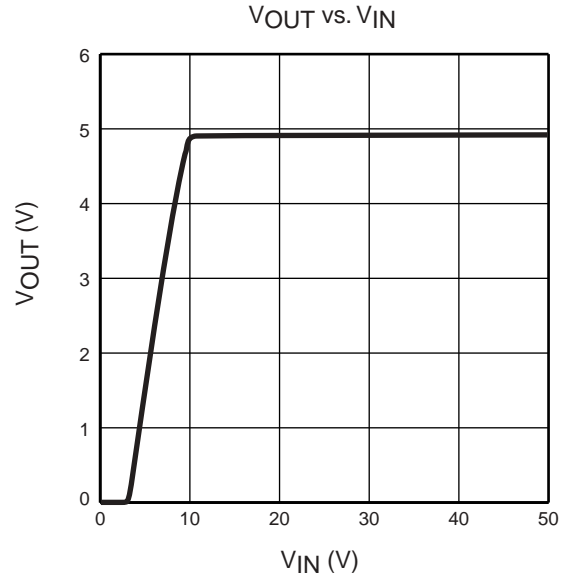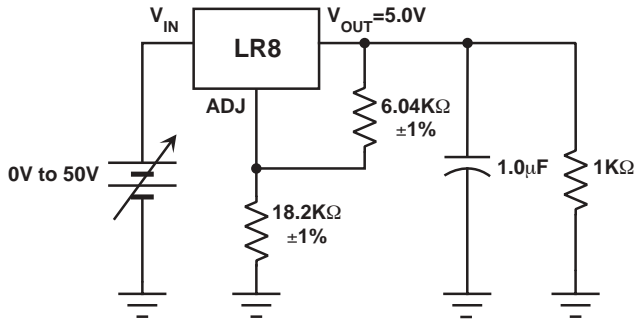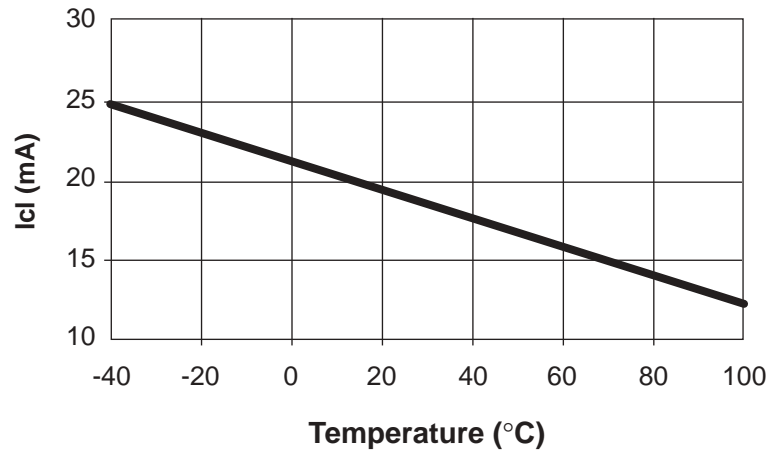
Typical Performance Curves

Load Transient Response

Load Transient Response

Line Transient Response

Line Transient Response

Line Power Up Transient

Line Power Down Transient

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High Voltage Linear Regulators and Constant Current Sources Using LR8

by Scott Lynch, Senior Applications Engineer

Introduction

The LR8 is a high voltage 3-terminal adjustable linear regulator. Intended for operation directly off rectified AC mains, the LR8 operates at input voltages up to 450 volts, making it compatible with line voltages up to 240 VAC. It's output voltage adjustability assures that it 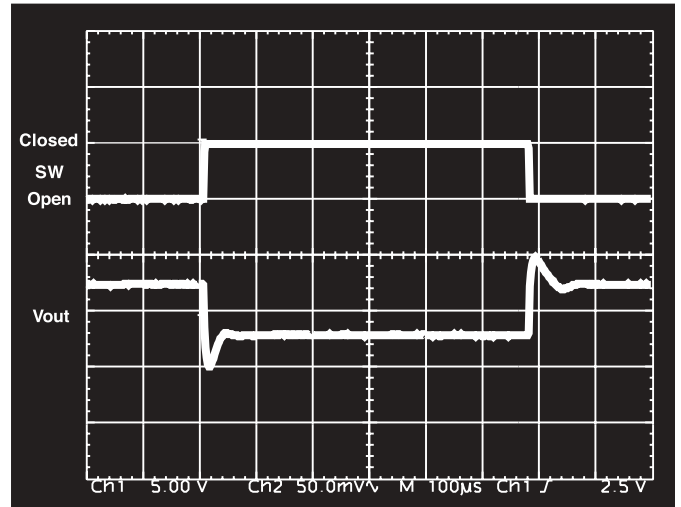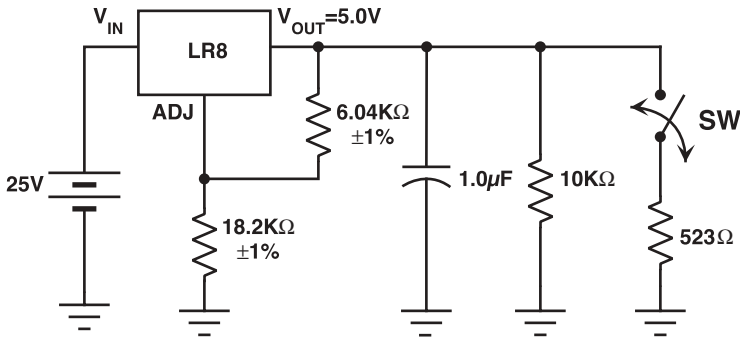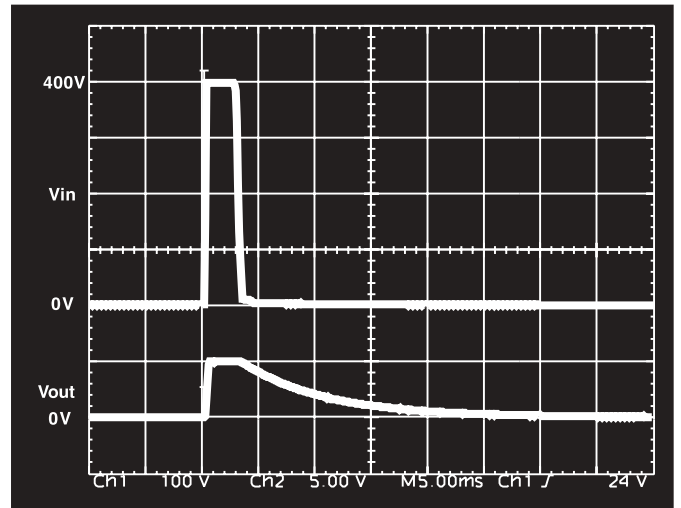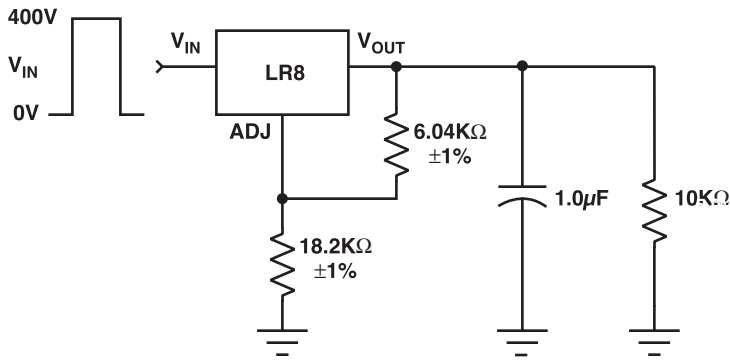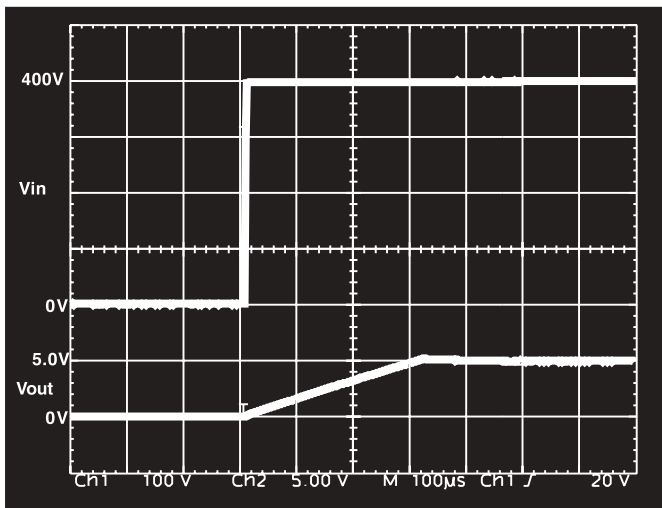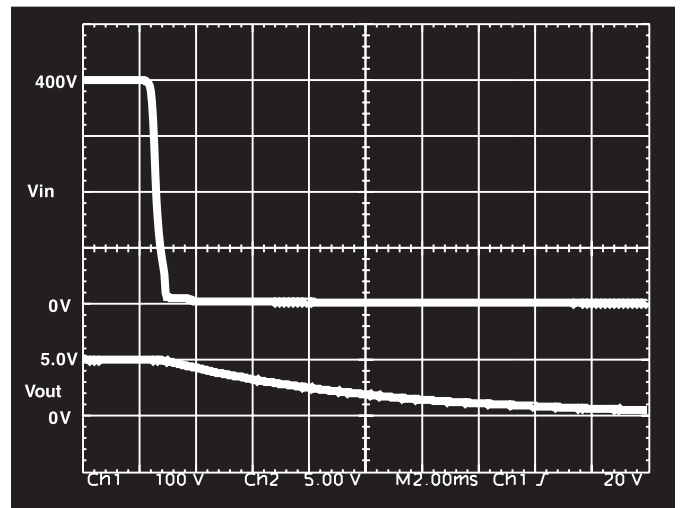can be used in most any application. The LR8 is ideally suited for low power off-line DC power supplies and SMPS start-up circuits.

Available in a leaded TO-92 package and surface mount SOT-89 and D-PAK packages, it is ideal for applications where space is at a premium.

Relevant specifications are shown in the table below.

LR8 Specifications

Input Voltage Range	(V_{OUT} +10V) to 450V
Output Voltage Range	1.2V to (V_{IN} - 10V)
Output Voltage Accuracy	±5%
Power Dissipation	TO-92: 0.74W TO-243AA (SOT-89): 1.6W TO-252 (D-PAK): 2.5W
Output Current	0.5 to 10mA
Load Regulation	3%
Line Regulation	0.01%/V
Supply Rejection	60dB typ @120Hz

Operation

Except for its' higher voltage rating, the LR8 operates like any other 3-terminal adjustable linear regulator.

A simple resistive divider sets the output voltage while a capacitor at the output improves transient response and ensures regulator stability. When applicable, an input capacitor is required to provide energy storage for rectified AC.

Keeping in mind that the LR8 requires at least a 12V difference between input and output for proper operation, the minimum value for C_{IN} is:

$$C_{IN} > I_{LOAD} \frac{t}{V_{IN(pk)} - V_{OUT} - 12\text{V}}$$

where
$$\begin{aligned}
I_{LOAD} &= Load\ current \\
t &= Time\ between\ peaks\ of\ input \\
&\quad waveform \\
V_{IN(pk)} &= Peak\ input\ voltage \\
V_{OUT} &= Output\ voltage
\end{aligned}$$

Note that the LR8 requires a minimum of 0.5mA load current for proper operation. The current through the resistive divider may be included as part of the minimum load.

LR8 Block Diagram and Typical Application

Needed for protection should V_{OUT} exceed V_{IN}

$$V_{OUT} = 1.2\text{v}\left(1 + \frac{R_2}{R_1}\right) + 10\mu\text{A} \bullet R_2$$
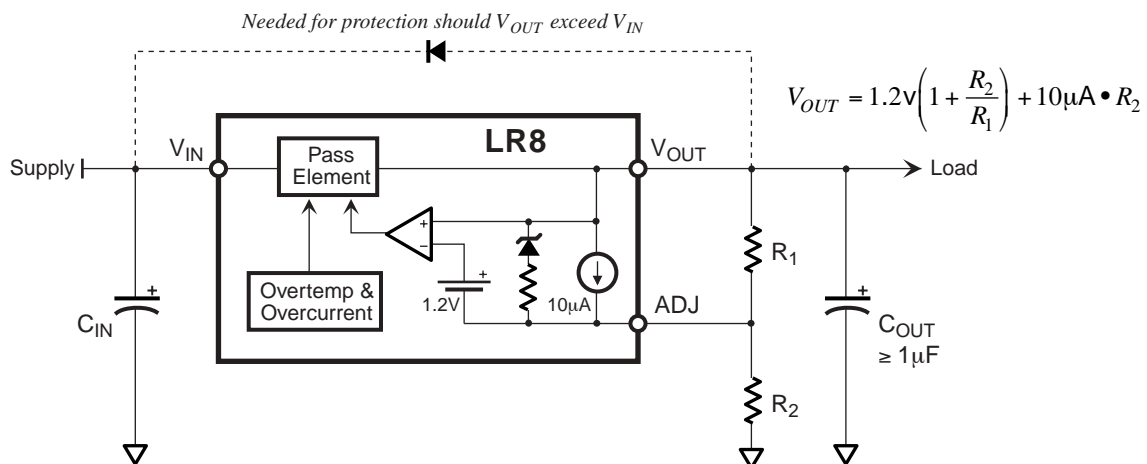
Constant Current Operation

The LR8 may be configured to provide a constant current output. The current is independent of both supply voltage and load impedance. Constant current operation finds application in driving LEDs and trickle-charging NiCad batteries, as shown below. The trickle charger is for applications that require battery backup (i.e. no cycling), such as emergency lights.

Constant Current LED Driver

$$I = \frac{1.2V}{R}$$

NiCad Battery Trickle Charger

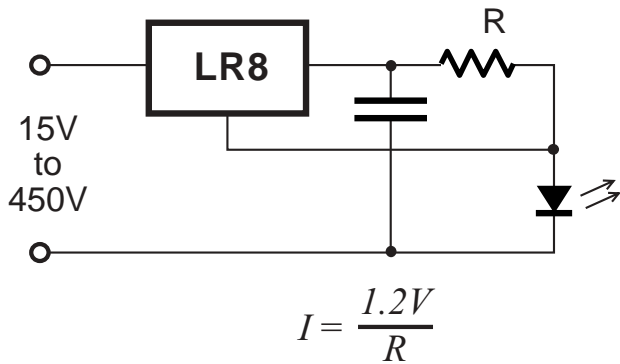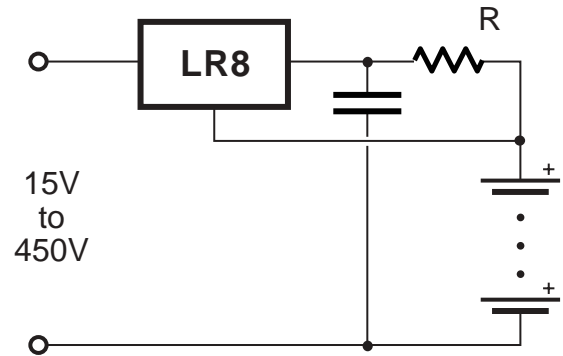# Start-up Circuit

The schematic below depicts a simplified off-line switching power supply using the LR8 for start-up. When V_{BOOT} rises above the LR8's output voltage, the LR8 goes into standby mode, consuming very little current. All current is then supplied from the bootstrap circuit rather than from the high voltage source, increasing overall efficiency.

The output voltage of the LR8 should be set high enough above the minimum operating voltage of the PWM controller, yet low enough to ensure the bootstrap circuit takes over after start-up.

With 240VAC input, instantaneous power dissipation can reach 3.4W (340VDC * 10mA). This level exceeds the LR8's rating, but exists for only as long as it takes for the supply to bootstrap. Thermal mass will prevent die temperature from rising quickly. If boot time is short, die temperatures will not reach the overtemperature protection trip point. It is advisable to mount the LR8 on 2 oz. copper with an area of at least 2.5 square centimeters.

Startup Current for Off-line Switching Power Supply
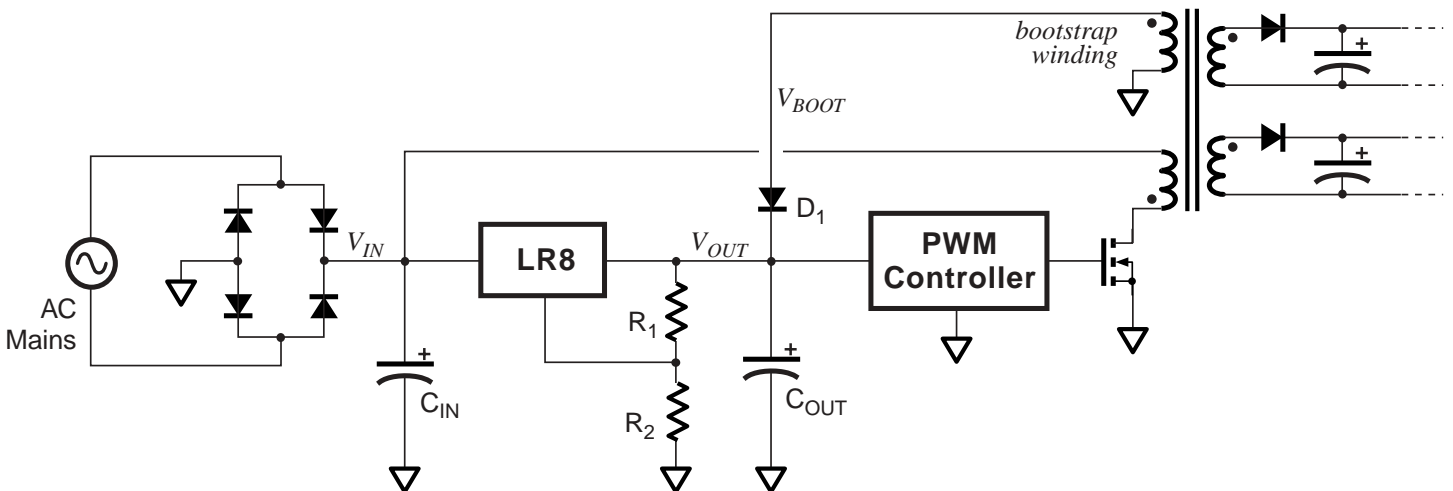
Comparison with Discrete Startup Implementations

The LR8 provides several advantages when compared with discretely implemented start-up circuits.

Zener Implementation

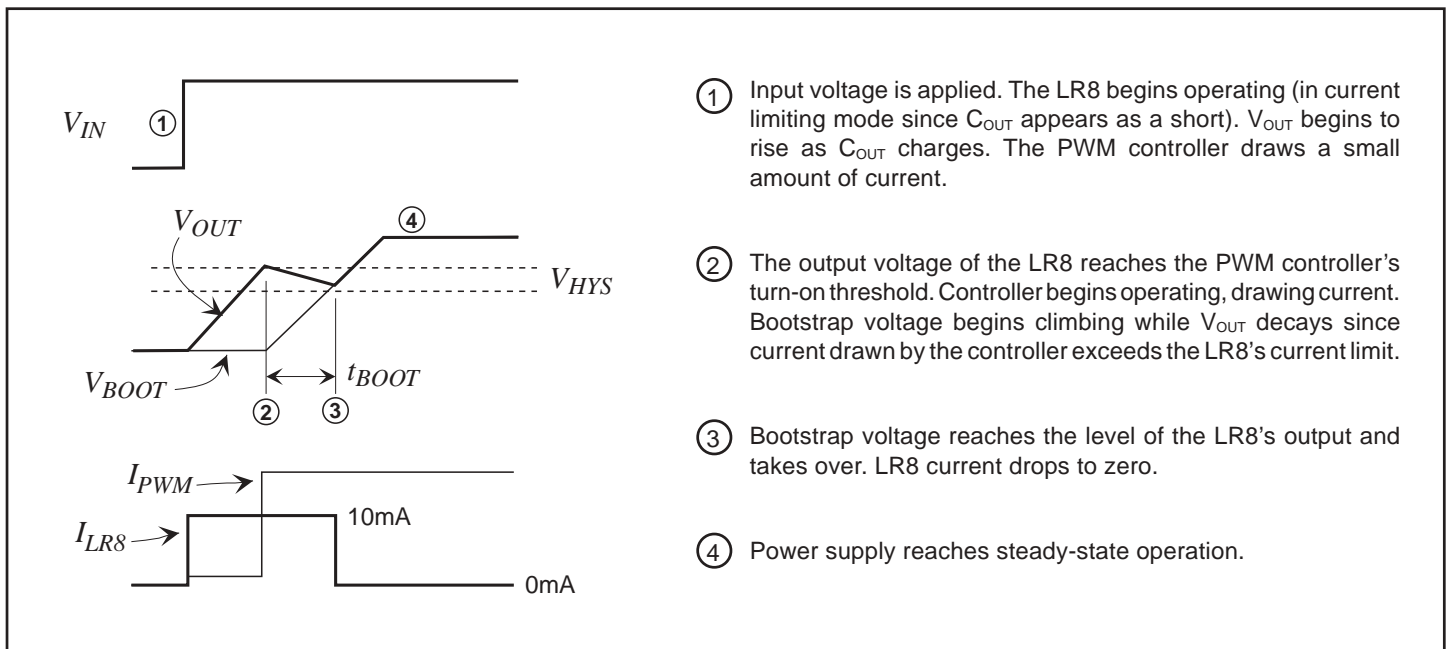V_{IN} → V_{OUT}

Transistor Implementation

V_{IN} → V_{OUT}

LR8 Implementation

V_{IN} → **LR8** → V_{OUT}

Disadvantages

- Continues to draw current from high voltage source after supply has bootstrapped, resulting in inefficiencies
- Bias must be set for minimum input voltage, resulting in high current drain at high input voltages
- Poor regulation
- No current limit
- No overtemperature protection
- In the Zener implementation, requires large power resistor and Zener

Advantages

- LR8 goes into standby mode after supply has bootstrapped, drawing no current from high voltage input
- Good regulation
- Built-in current limiting
- Overtemperature protection

Exceeding LR8's Current Limit for Startup Applications

The LR8 has a built-in current limit of 10mA minimum. If the current drawn by the PWM controller exceeds this limit, the LR8 may still be used. To do this, the LR8's output capacitor supplies a portion of the current until the power supply can bootstrap itself and the LR8 is no longer needed. The following figure graphically illustrates how this is accomplished.

Most PWM controllers have an undervoltage lockout (UVL) circuit or programmable start/stop voltages. When the voltage supplied to the PWM controller reaches the turn-on threshold, the controller begins operating and consuming current. If current exceeds the current limit for the LR8, the voltage at V_{OUT} begins to decay. With a large enough capacitor, the supply will bootstrap before voltage decays to the turn-off threshold.

V_{IN} ①

V_{OUT} ④

V_{HYS}

V_{BOOT} ② ③ t_{BOOT}

I_{PWM} →
I_{LR8} → 10mA

0mA

① Input voltage is applied. The LR8 begins operating (in current limiting mode since C_{OUT} appears as a short). V_{OUT} begins to rise as C_{OUT} charges. The PWM controller draws a small amount of current.

② The output voltage of the LR8 reaches the PWM controller's turn-on threshold. Controller begins operating, drawing current. Bootstrap voltage begins climbing while V_{OUT} decays since current drawn by the controller exceeds the LR8's current limit.

③ Bootstrap voltage reaches the level of the LR8's output and takes over. LR8 current drops to zero.

④ Power supply reaches steady-state operation.

The minimum capacitance required for given boot-up time is given by the following equation:

$$C_{OUT} > t_{BOOT}\, \frac{I_{PWM} - I_{LIM}}{V_{HYS}}$$

where C_{OUT} = *Capacitor at LR8 output*
t_{BOOT} = *Time required for supply to bootstrap*
I_{PWM} = *Current used by PWM controller*
I_{LIM} = *LR8 current limit (10mA min)*
V_{HYS} = *PWM controller UVL hysteresis*

Remember that this equation is valid only when PWM current exceeds the LR8's current limit.

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