19-1621; Rev 0; 1/00

EVALUATION KIT AVAILABLE

MAXIM

High-Efficiency Step-Up Current Regulator for LEDs

MAX1698

General Description

The MAX1698 is the most efficient driver for white or color LEDs. The device is ideal for LED backlit displays in PDAs and digital cameras, and can also be used for larger displays like those in laptop computers. Its numerous benefits include greater simplicity, lower cost, higher efficiency, longer bulb life, and greater reliability when compared to fluorescent (CCFL) and electroluminescent (EL) lamps.

The MAX1698 is a switch-mode boost controller in which LED current, rather than output voltage, provides the feedback signal. It can operate with battery inputs as low as 0.8V. The device drives series-connected LEDs with a controlled current that is measured at a sense resistor connected at the feedback pin. The required sense resistor is typically 15Ω, not an expensive fractional-ohm value. LED current control and dimming are accomplished with an adjust input (ADJ), not with lossy current-limiting resistors. For larger light output, multiple LED banks can be connected in parallel with up to 5W total output power.

The MAX1698 is supplied in a space-saving 10-pin µMAX package that occupies half the space of an 8-pin SO. An evaluation kit (MAX1698EVKIT) is available to speed designs.

Applications

Battery-Powered Backlight Applications

Backlight for LCD Panels

Cell Phones

Handy Terminals

PDAs

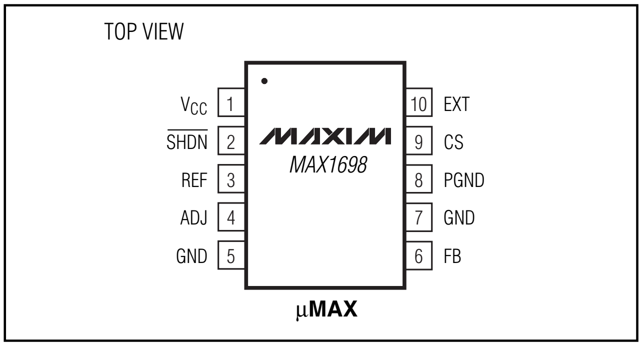
Features

- ♦ Over 90% Efficiency
- ♦ Lossless, Adjustable LED Brightness
- ♦ Space-Saving 10-Pin µMAX Package
- ♦ Simpler, Lower Cost, More Reliable Compared to CCFL or EL Backlights
- ♦ Up to 5W Output Power

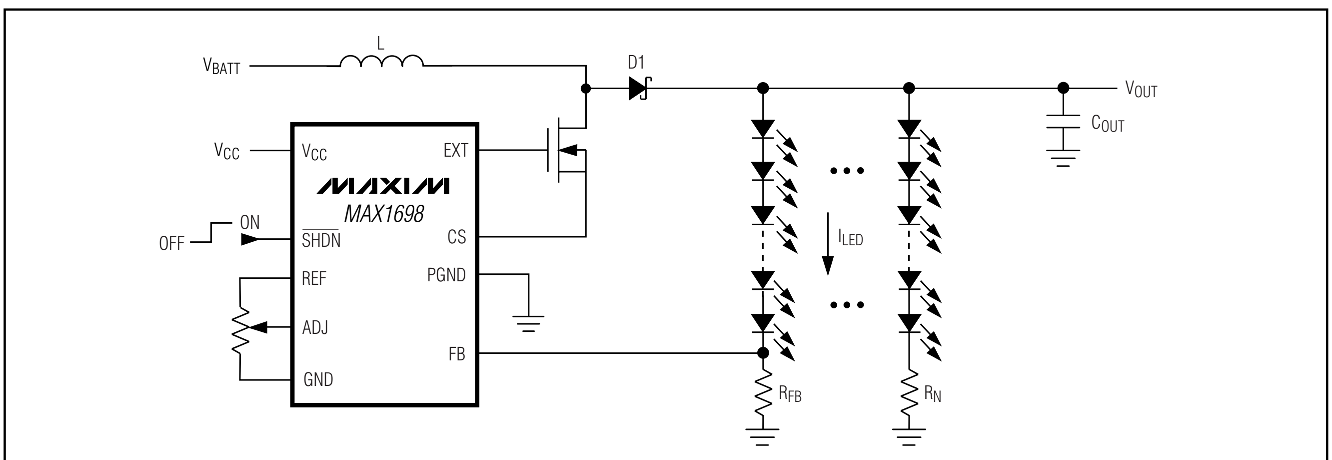
Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1698EUB	-40°C to +85°C	10 µMAX

Pin Configuration



Typical Operating Circuit



High-Efficiency Step-Up Current Regulator for LEDs

ABSOLUTE MAXIMUM RATINGS

V_{CC}, $\overline{SHDN}$ to GND ....-0.3V to +6V
EXT, FB, CS, ADJ, REF to GND..................-0.3V to (V_{CC} + 0.3V)
GND to PGND ....±0.3V
Continuous Power Dissipation (T_A = +70°C)
10-Pin µMAX (derate 5.6mW/°C above +70°C) 444mW

Operating Temperature Range ....-40°C to +85°C
Junction Temperature..+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature Range (soldering, 10s).....................+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.3V, **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage	V_{CC}		2.7		5.5	V
Quiescent Supply Current	I_{CC}	V_{FB} = 0.3V		260	500	µA
Undervoltage Lockout		Rising edge	2.25	2.4	2.55	V
Undervoltage Hysteresis				80		mV
FB Regulation Voltage	V_{FB}	ADJ = REF	285	300	315	mV
		V_{ADJ} = 100mV	18	24	30	
CS Trip Current		FB = GND	0.8	1.5	2.5	A
CS Input Current	I_{CS}				0.8	A_{RMS}
Minimum Off Time	$t_{OFF(MIN)}$	FB = GND, ADJ = REF	0.8	1.0	1.2	µs
Maximum On Time	$t_{ON(MAX)}$	FB = GND, ADJ = REF, CS = GND	10	15	20	µs
ADJ Start Threshold			30	50	70	mV
ADJ Input Range	V_{ADJ}		0.03		REF	V
FB Input Bias Current	I_{FB}	V_{FB} = 300mV	-15		15	nA
ADJ Input Bias Current	I_{ADJ}	ADJ = REF	-50		50	nA
Shutdown Supply Current		$\overline{SHDN}$ = GND		0.01	1	µA
REF Output Voltage	V_{REF}	I_{REF} = 0	1.20	1.25	1.30	V
REF Load Regulation	ΔV_{REF}	I_{REF} = 0 to 150µA		-2	-25	mV
REF Short-Circuit Current		REF = GND		0.45	1	mA
REF Power-Supply Rejection Ratio	PSRR	V_{CC} = 2.7V to 5.5V		+0.3	+2	mV/V
EXT Driver Sink/Source Current		V_{CC} = 5V, EXT = 2V		0.2		A
EXT Driver On-Resistance		V_{CC} = 5V			8	Ω
$\overline{SHDN}$ Input High Voltage	V_{IH}	V_{CC} = 2.7V to 5.5V	2			V
$\overline{SHDN}$ Input Low Voltage	V_{IL}	V_{CC} = 2.7V to 5.5V			0.8	V
$\overline{SHDN}$ Input Bias Current	$I_{\overline{SHDN}}$	V_{CC} = 2.7V to 5.5V	-1		1	µA

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.3V, **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	MAX	UNITS
Supply Voltage	V_{CC}		2.7	5.5	V
Quiescent Supply Current	I_{CC}	V_{FB} = 0.3V		500	µA
Undervoltage Lockout		Rising edge	2.20	2.65	V
FB Regulation Voltage	V_{FB}	ADJ = REF	280	320	mV
		V_{ADJ} = 100mV	13	35	
CS Trip Current		FB = GND	0.8	3.0	A
Minimum Off Time	$t_{OFF(MIN)}$	FB = GND, ADJ = REF	0.6	1.4	µs
Maximum On Time	$t_{ON(MAX)}$	FB = GND, ADJ = REF, CS = GND	9	21	µs
ADJ Start Threshold			25	75	mV
FB Input Bias Current	I_{FB}	V_{FB} = 300mV	-20	20	nA
ADJ Input Bias Current	I_{ADJ}	ADJ = REF	-50	50	nA
Shutdown Supply Current		$\overline{SHDN}$ = GND		1	µA
REF Output Voltage	V_{REF}	I_{REF} = 0	1.17	1.33	V
REF Load Regulation	ΔV_{REF}	I_{REF} = 0 to 150µA		-30	mV
REF Short-Circuit Current		REF = GND		1	mA
REF Power-Supply Rejection Ratio	PSRR	V_{CC} = 2.7V to 5.5V		+2	mV/V
EXT On-Resistance		V_{CC} = 5V		8	Ω
$\overline{SHDN}$ Input High Voltage	V_{IH}	V_{CC} = 2.7V to 5.5V	2		V
$\overline{SHDN}$ Input Low Voltage	V_{IL}	V_{CC} = 2.7V to 5.5V		0.8	V
$\overline{SHDN}$ Input Bias Current	$I_{\overline{SHDN}}$	V_{CC} = 2.7V to 5.5V	-1	1	µA

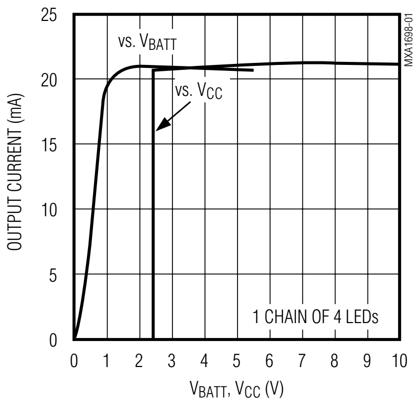
Note 1: Specifications to -40°C are guaranteed by design, not production tested.

High-Efficiency Step-Up Current Regulator for LEDs

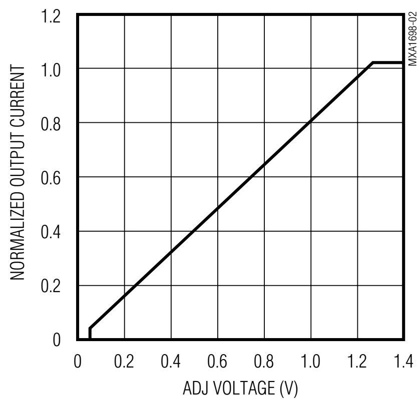
Typical Operating Characteristics

(Circuit of Figure 2, $V_{CC} = V_{BATT} = 3.3V$, $V_{ADJ} = V_{REF}$, $T_A = +25°C$, unless otherwise noted.)

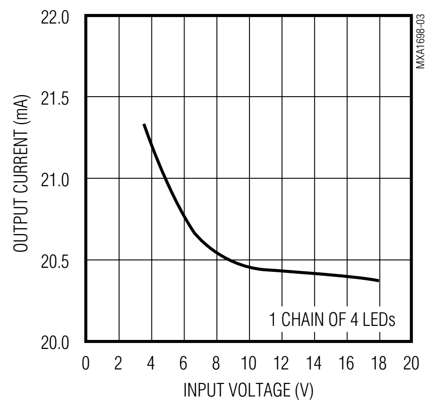
OUTPUT CURRENT vs. V_{BATT} AND V_{CC}



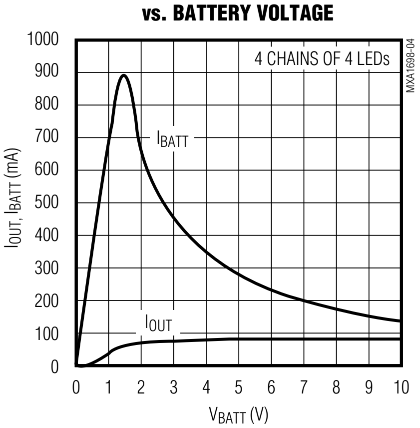
NORMALIZED OUTPUT CURRENT vs. ADJ VOLTAGE



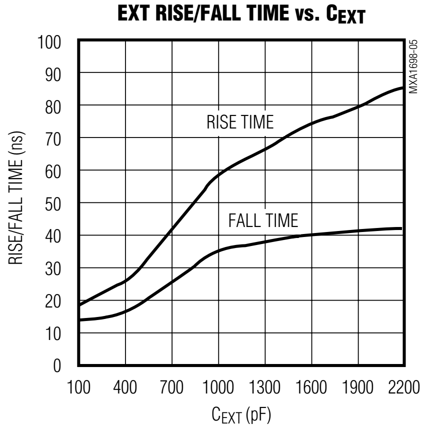
OUTPUT CURRENT vs. INPUT VOLTAGE



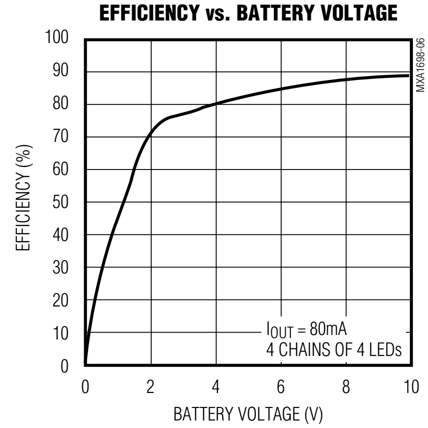
BATTERY CURRENT vs. BATTERY VOLTAGE



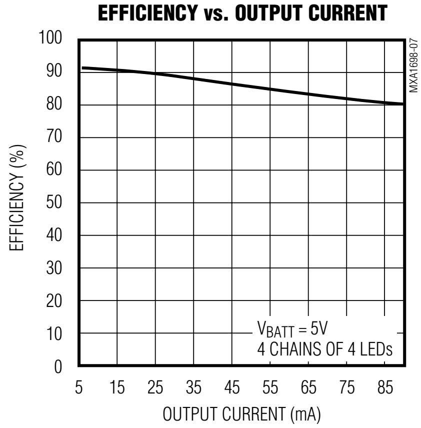
EXT RISE/FALL TIME vs. C_{EXT}



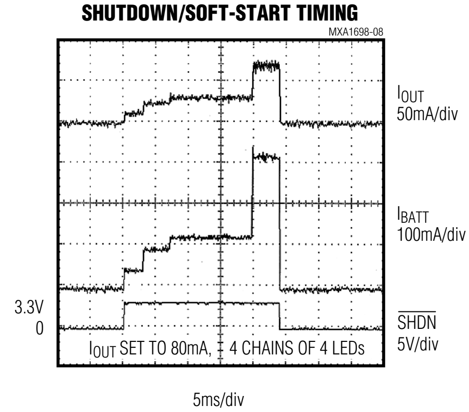
EFFICIENCY vs. BATTERY VOLTAGE



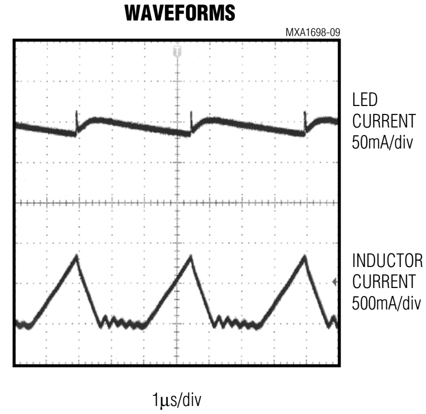
EFFICIENCY vs. OUTPUT CURRENT



SHUTDOWN/SOFT-START TIMING



LED AND INDUCTOR CURRENT WAVEFORMS



Pin Description

PIN	NAME	FUNCTION
1	V_{CC}	IC Supply Voltage Input. Power for internal circuitry. Input range is 2.7V to 5.5V.
2	$\overline{SHDN}$	Active-Low Shutdown Input. In shutdown, the MOSFET turns off, but a current path still exists between the input and output. The minimum forward voltage of the LED array must exceed the maximum V_{BATT} to ensure that the LEDs are off in shutdown.
3	REF	1.25V Reference Output. Capable of sourcing 150μA for external loads. This pin is internally compensated. Do not connect any bypass capacitors at REF.
4	ADJ	Adjust Input. Allows dynamic adjustment of the output current. FB regulates to 300mV when ADJ = REF.
5, 7	GND	Ground
6	FB	Feedback Input. Connect to the external LED current-sense feedback resistor.
8	PGND	Power Ground
9	CS	FET Current-Sense Input
10	EXT	Gate Driver Output

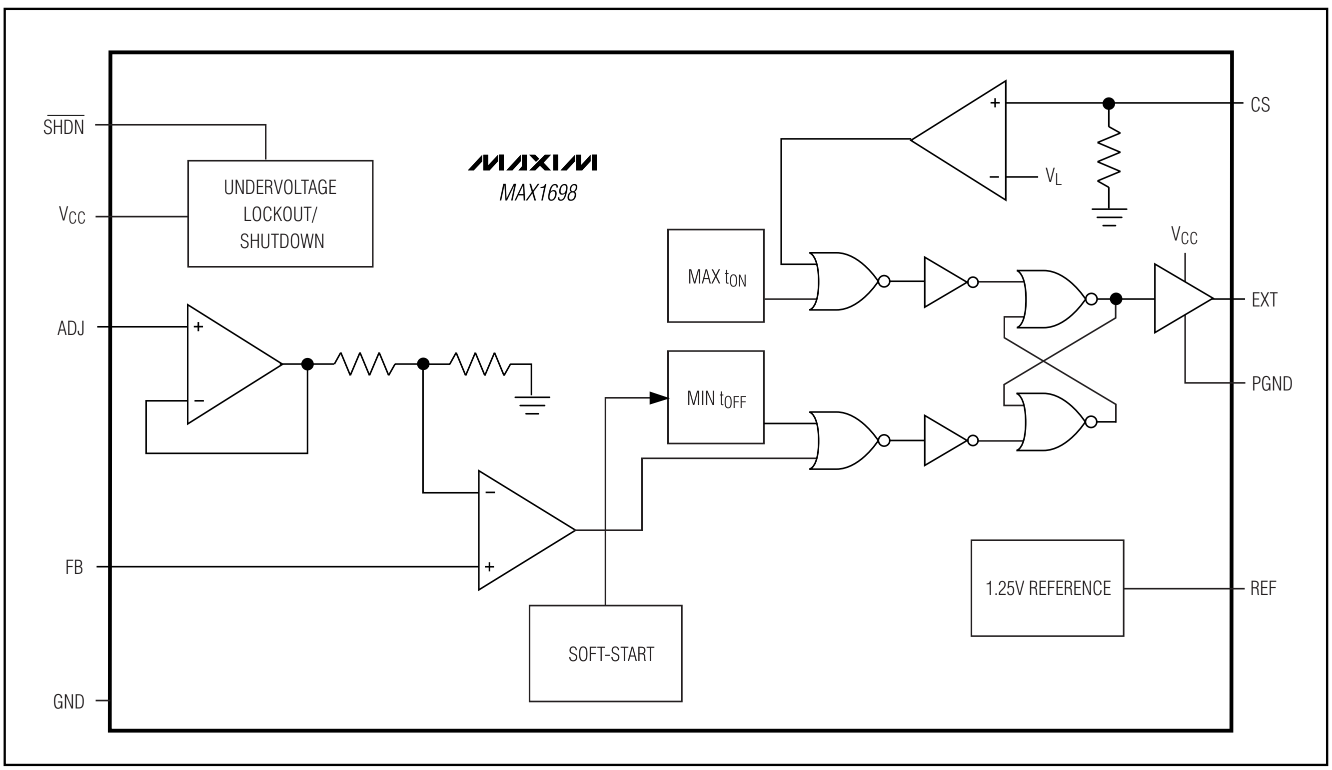


Figure 1. Functional Diagram

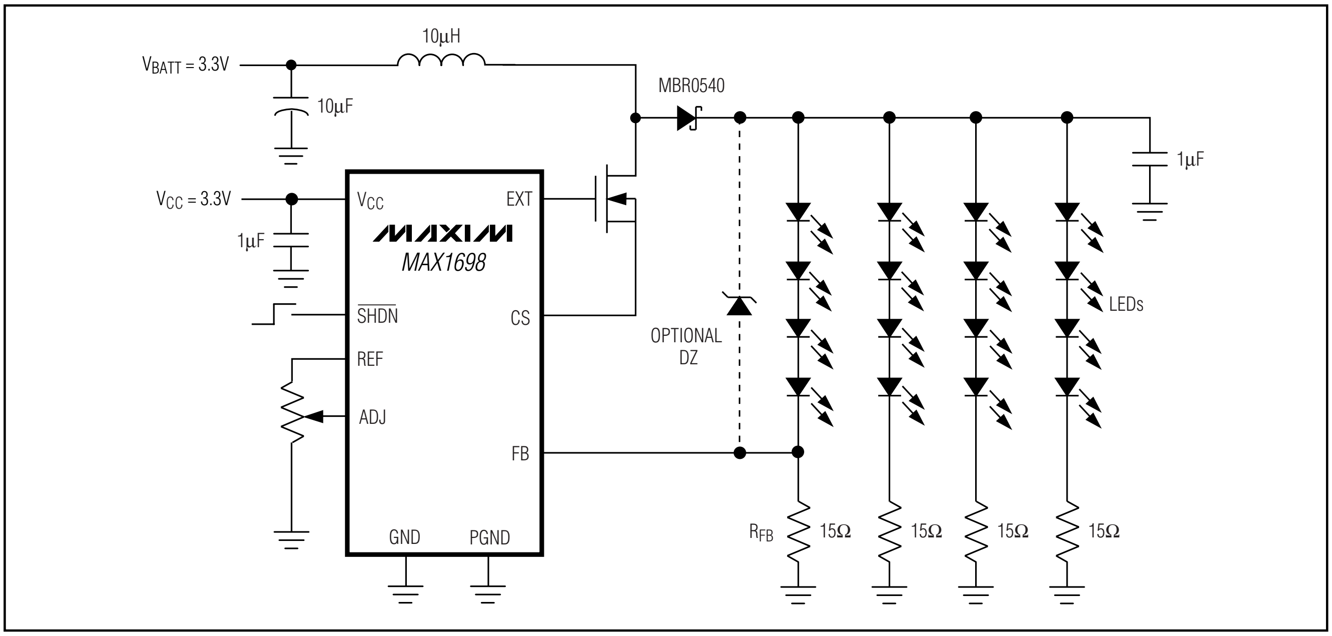


Figure 2. Typical Operating Circuit

Detailed Description

The MAX1698's high efficiency and small size make it ideally suited to drive LEDs. It operates as a boost DC-DC converter that controls output current rather than voltage. Losses are minimized by a low, 300mV current-sense threshold. In the standard configuration, a feedback resistor, R_{FB}, sets the current through the primary chain of LEDs. Additional chains of matching LEDs can be added with an equivalent resistor. In matched LED arrays, the secondary chain currents closely track the primary chain. An optional zener diode, D2, prevents overvoltage in the event that one of the LEDs in the primary chain becomes an open circuit. The LED brightness can be adjusted dynamically by a voltage input at ADJ.

Shutdown

In shutdown, the MAX1698's supply current is reduced below 1µA. EXT goes low in shutdown, shutting off the external N-channel FET. This leaves a current path between the input and the LEDs through the boost inductor and catch diode. The minimum forward voltage of the LED array must exceed the maximum V_{BATT} to ensure that the LEDs remain off in shutdown. Typical shutdown timing characteristics are shown in the *Typical Operating Characteristics.*

Soft-Start

The MAX1698 includes a soft-start function that eliminates input current surges at turn-on. It does this by extending the external FET driver (EXT) minimum off-time during start-up. During the first 512 switching cycles, the minimum off-time is 5µs. It is then allowed to drop to 2µs for the next 1500 switching cycles. After that time, the minimum off-time falls to the 1µs value used during normal operation. (See Shutdown/Soft-Start Timing in the *Typical Operating Characteristics* section.)

Design Procedure

Setting the Maximum LED Current

Resistor R_{FB} sets the maximum current in the primary chain of LEDs:

$$R_{FB} = \frac{300mV}{I_{LEDMAX}}$$

where I_{LEDMAX} is the maximum LED current.

Adjusting LED Current

R_{FB} sets the maximum LED current. This current can be reduced proportional to the voltage at the ADJ pin (see Normalized Output Current vs. ADJ Voltage in the *Typical Operating Characteristics* section). Figure 3

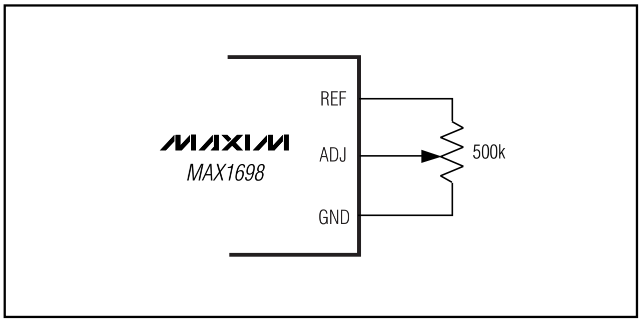


Figure 3. Adjusting LED Current

shows the standard method of setting the ADJ voltage. Use the following equation to determine I_{LED}:

$$I_{LED} = \frac{V_{ADJ}}{4.16 \cdot R_{FB}}$$

where V_{ADJ} is the voltage at ADJ. Note that ADJ voltages below 50mV turns the LEDs off.

Inductor Selection

Choose an inductor with low DC resistance (in the neighborhood of 100mΩ) to minimize losses. A typical inductance value for L is 10µH; however, values from 3.3µH to 100µH can also be used. Higher inductor values will reduce the MAX1698's switching frequency. The typical operating frequency is given by:

$$f = \frac{0.67 \cdot V_{BATT}}{L}$$

The MAX1698 limits peak inductor current to 1.5A, but also contains a control loop that reduces inductor current as a function of output power. For a given output power, the required inductor peak current rating is approximately set by:

$$I_{L(PEAK)} = 1.0 \cdot P_{OUT}$$

where P_{OUT} is the output power to all LED banks in watts and $I_{L(PEAK)}$ is in amperes.

Capacitor Selection

The exact value of output capacitance is not critical. Typical values for the output capacitor are 0.1µF to 10µF. Larger values help reduce output ripple at the expense of size and higher cost.

The requirements of the input capacitor depend on the type of the input voltage source. However, in many applications, the same capacitor type and value are used for both the input and output capacitors.

Transistor Selection

The MAX1698 drives an external N-channel MOSFET. Since the gate drive voltage is derived from V_{CC}, best performance is achieved with low-threshold NFETs that specify on-resistance with gate-source voltages (V_{GS}) at the voltage supplied at V_{CC} or less. For best results, minimize the FET's $R_{DS(ON)}$. The external NFET's maximum drain-to-source voltage ($V_{DS(MAX)}$) must exceed the output voltage.

Catch Diode (D1) Selection

The MAX1698's high switching frequency demands a high-speed rectifier. Schottky diodes are recommended for most applications, due to their fast recovery time and low forward-voltage drop. Ensure that the diode's average and peak current ratings exceed the average output current and peak inductor current, respectively. In addition, the diode's reverse breakdown voltage must exceed V_{OUT}. For output voltages exceeding 40V, high-speed silicon rectifiers may be required for their higher breakdown voltages.

Zener Diode

For applications requiring open-circuit protection if one of the LEDs in the primary chain opens, add a zener diode as shown in Figure 2. The zener diode protects the MOSFET and output capacitor if the current feedback signal is lost. The zener voltage should exceed the maximum forward voltage of the LED network by at least 2V.

Applications Information

PC Board Layout

Due to fast switching waveforms and high-current paths, careful PC board layout is required. Protoboards and wire-wrap boards should not be used for evaluation. An EV kit (MAX1698EVKIT) is available to aid most designs.

When laying out a board, minimize trace lengths to CS, the inductor, diode, input capacitor, and output capacitor. Keep traces short, direct, and wide. Keep noisy traces such as the inductor's traces away from FB. V_{CC}'s bypass capacitor should be placed as close to the IC as possible.

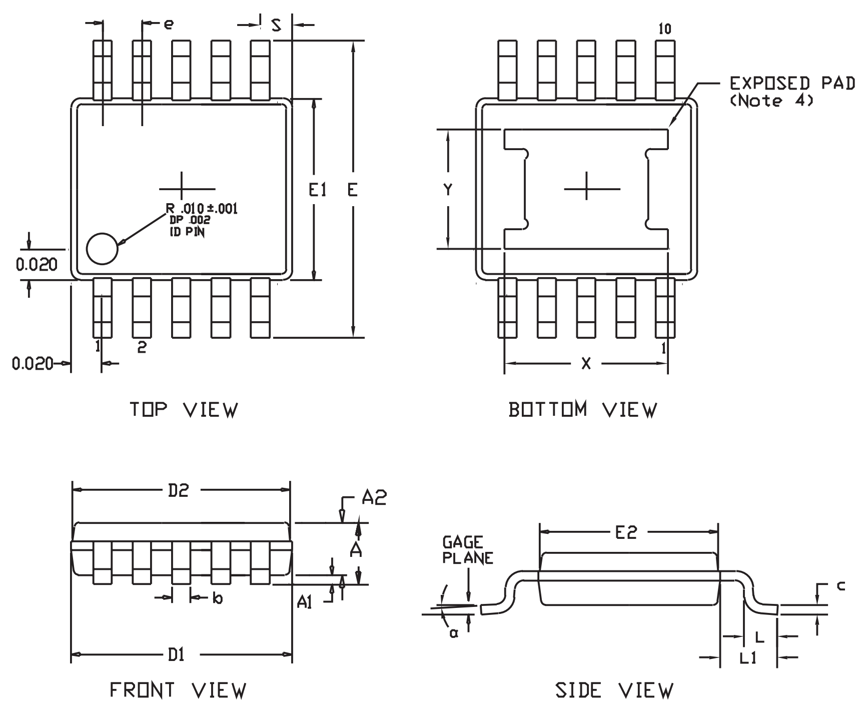
Refer to the MAX1698 EV kit for an example of proper layout.

Chip Information

TRANSISTOR COUNT: 2180

High-Efficiency Step-Up Current Regulator for LEDs

Package Information



10LUMAX.EPS

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.037	0.043	0.94	1.10
A1	0.002	0.006	0.05	0.15
A2	0.030	0.037	0.75	0.95
D1	0.116	0.120	2.95	3.05
D2	0.114	0.118	2.89	3.00
E1	0.116	0.120	2.95	3.05
E2	0.114	0.118	2.89	3.00
E	0.187	0.199	4.75	5.05
L	0.0157	0.0275	0.40	0.70
L1	0.037 REF		0.940 REF	
b	0.007	0.0106	0.177	0.270
e	0.0197 BSC		.500 BSC	
c	0.0035	0.0078	0.090	0.200
S	0.0196 REF		.498 REF	
α	0°	6°	0°	6°
*X	0.087	0.099	2.210	2.515
*Y	0.062	0.074	1.575	1.880

* EXPOSED PAD (Note 4

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15 MM (.006").
3. CONTROLLING DIMENSION: MILLIMETERS.
4. DIMENSIONS X & Y APPLY TO EXPOSED PAD (EP) VERSIONS ONLY. SEE INDIVIDUAL PRODUCT DATASHEET TO DETERMINE IF A PRODUCT USES EXPOSED PAD PACKAGE.
5. EXPOSED PAD FLUSH WITH BOTTOM OF PACKAGE WITHIN .002".

MAXIM
PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, 10L uMAX WITH EP OPTION
APPROVAL | DOCUMENT CONTROL NO. 21-0061 | REV F | 1/1

Note: *The MAX1698 does not have an exposed pad.*