High Efficiency LED Driver

PRODUCTION

DESCRIPTION

The LX1993 is a high efficiency step-up boost converter that features a psuedo-hysteretic pulse frequency modulation topology for driving white or color LEDs in backlight or frontlight systems. Designed for maximum efficiency, reduced board size, and minimal cost, the LX1993 is ideal for PDA and digital camera applications. The LX1993 features an internal N-Channel MOSFET and control circuitry that is optimized for portable system design applications. The LX1993 promotes improved performance in battery-operated systems by operating with a quiescent supply current 70µA (typical) and a shutdown current of less than 1µA. The input voltage range is from 1.6V to 6.0V thus allowing for a broad selection of battery voltage applications and start-up is guaranteed at 1.6V input.

The LX1993 is capable of switching currents in excess of 300mA and the output current is readily programmed using one external current sense resistor in series with the LEDs. This configuration provides a feedback signal to the FB pin thus maintaining constant output current regardless of varying LED forward voltage (V_F). The LX1993 provides an additional feature for simple dynamic adjustment of the output current (i.e., up to 100% of the maximum programmed current). Designers can make this adjustment by generating an analog reference signal or a PWM signal applied directly to the ADJ pin and any PWM amplitude is readily accommodated via a single external resistor. The LX1993 is available in the 8-Pin MSOP and thus requires a very small PCB area.

IMPORTANT: For the most current data, consult *MICROSEMI*'s website: **http://www.microsemi.com**

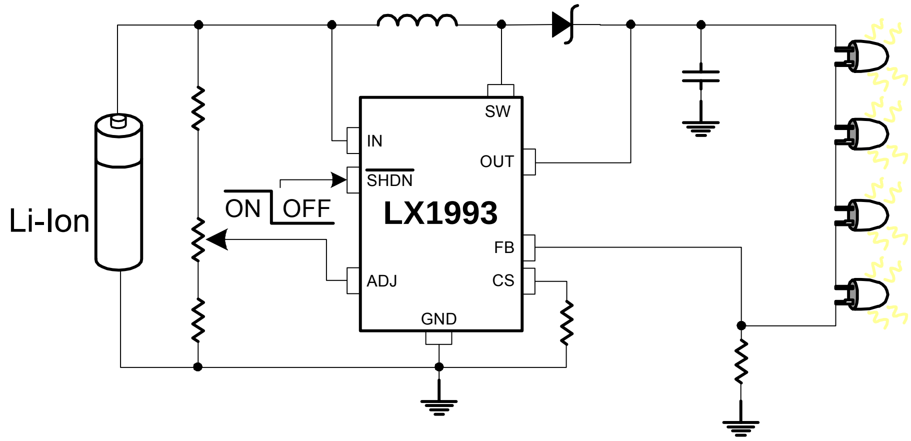
KEY FEATURES

- > 80% Maximum Efficiency
- 70µA Typical Quiescent Supply Current
- Externally Programmable Peak Inductor Current Limit For Maximum Efficiency
- Logic Controlled Shutdown
- < 1µA Shutdown Current
- Dynamic Output Current Adjustment Via Analog Reference Or Direct PWM Input
- 8-Pin MSOP Package

APPLICATIONS

- Pagers
- Wireless Phones
- PDAs
- Handheld Computers
- LED Driver
- Digital Camera Displays

PRODUCT HIGHLIGHT



PACKAGE ORDER INFO

T_A (°C)	DU Plastic MSOP 8-Pin RoHS Compliant / Pb-free Transition DC: 0432
0 to 70	LX1993CDU

Note: Available in Tape & Reel. Append the letters "TR" to the part number. (i.e. LX1993CDU-TR)

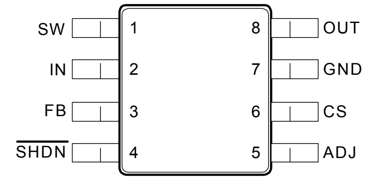
Microsemi
Integrated Products Division
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{IN}) .... -0.3V to 7.0V
Feedback Input Voltage (V_{FB}) .... -0.3V to V_{IN} + 0.3V
Shutdown Input Voltage ($V_{\overline{SHDN}}$) .... -0.3V to V_{IN} + 0.3V
Adjust Input Voltage (V_{ADJ}) .... -0.3V to V_{IN} +0.3V
Output Voltage (V_{OUT}) .... -0.3V to 25V
Switch Voltage (V_{SW}) .... -0.3V to (V_{OUT} + 1.0V)
Switch Current (I_{SW}) 500mArms
Operating Junction Temperature .... 150°C
Storage Temperature Range .... -65°C to 150°C
Peak Package Solder Reflow Temp. (40 second max. exposure) ... 260°C (+0, -5)

Note: Exceeding these ratings could cause damage to the device. All voltages are with respect to Ground. Currents are positive into, negative out of specified terminal.

PACKAGE PIN OUT



DU PACKAGE
(Top View)

RoHS / Pb-free 100% Matte Tin Lead Finish

FRONT MARKING

1993
C
• MSC

• pin 1 indicator

THERMAL DATA

DU **Plastic MSOP 8-Pin**

THERMAL RESISTANCE-JUNCTION TO AMBIENT, θ_{JA}	206°C/W
THERMAL RESISTANCE-JUNCTION TO CASE, θ_{JC}	39°C/W

Junction Temperature Calculation: $T_J = T_A + (P_D \times \theta_{JC})$.
The θ_{JA} numbers are guidelines for the thermal performance of the device/pc-board system. All of the above assume no ambient airflow.

FUNCTIONAL PIN DESCRIPTION

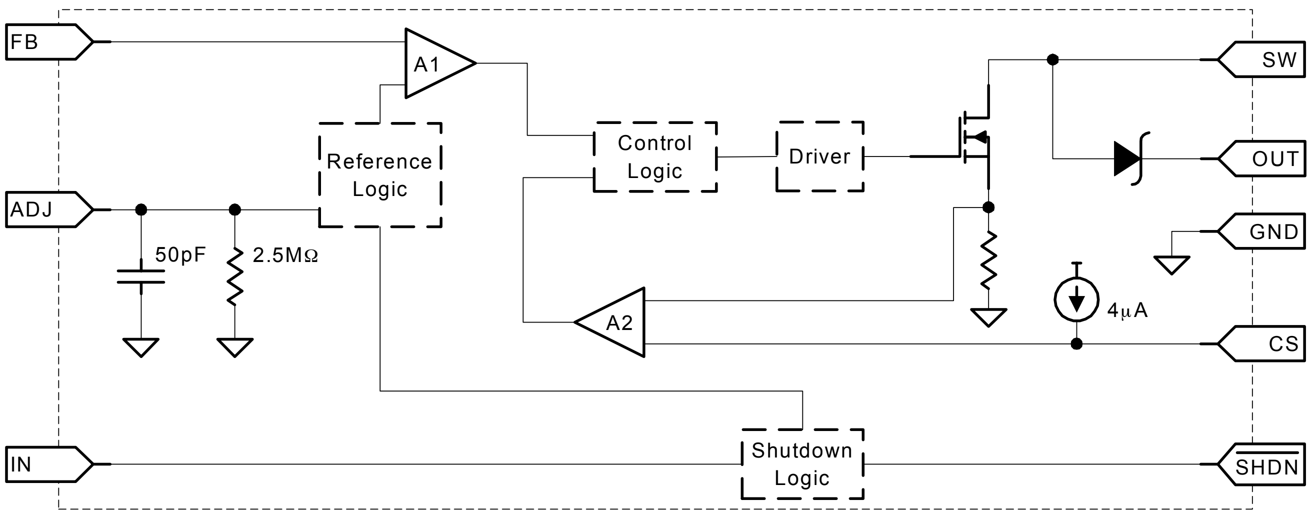
NAME	DESCRIPTION
IN	Unregulated IC Supply Voltage Input – Input range from +1.6V to +6.0V. Bypass with a 1μF or greater capacitor for low voltage operation.
FB	Feedback Input – Connect to a current sense resistor between the load and GND to set the maximum output current.
$\overline{SHDN}$	Active-Low Shutdown Input – A logic low shuts down the device and reduces the supply current to <1μA. Connect $\overline{SHDN}$ to V_{CC} for normal operation.
SW	Inductor Switching Connection – Internally connected to the drain of a 28V N-channel MOSFET. SW is high impedance in shutdown.
CS	Current-Sense Amplifier Input – Connecting a resistor between CS and GND sets the peak inductor current limit.
GND	Common terminal for ground reference.
ADJ	Output Current Adjustment Input – Provides the internal reference for the output current feedback. The signal input can be either a PWM signal or analog voltage allowing a dynamic output current adjustment. The signal should typically range from 500mV to GND, but is capable of an input up to V_{IN}. Caution should be used not to exceed the device output current rating.
OUT	Output Current - Adjustable up to 25mA. Load voltage should not exceed 25V.

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, the following specifications apply over the operating ambient temperature $0°C \le T_A \le 70°C$ except where otherwise noted and the following test conditions: V_{IN} = 3V, V_{FB} = 0.3V, V_{ADJ} = 0.2V and SW pin has +5V through 39.2Ω, $\overline{SHDN}$ = V_{IN} and CS = GND.

Parameter	Symbol	Test Conditions	LX1993			Units
			Min	Typ	Max	
Operating Voltage	V_{IN}		1.6		6.0	V
Minimum Start-up Voltage	V_{SU}	T_A = +25°C			1.6	V
Start-up Voltage Temperature Coefficient	k_{VST}	Guaranteed; not tested		-2		mV/°C
Quiescent Current	I_Q	Not switching		70	100	µA
		$V_{\overline{SHDN}}$ < 0.4V		0.2	0.5	µA
FB Threshold Voltage	V_{FB}		275	300	325	mV
FB Input Bias Current	I_{FB}	Switching V_{ADJ} = 0.4V	-100		100	nA
ADJ Input Voltage Range	V_{ADJ}		0.0		V_{IN}	V
ADJ Input Bias Current	I_{ADJ}	V_{ADJ} < 0.3V	-150		50	nA
Shutdown Input Bias Current	$I_{\overline{SHDN}}$	$V_{\overline{SHDN}}$ = 0V	-100		100	nA
Shutdown High Input Voltage	$V_{\overline{SHDN}}$		1.6			V
Shutdown Low Input Voltage	$V_{\overline{SHDN}}$				0.4	V
Current Sense Bias Current	I_{CS}		2		6	µA
Minimum Peak Current	I_{MIN}	R_{CS} = 0Ω	85		155	mA
Internal NFET On-resistance	$R_{DS(ON)}$	T_A = +25°C; I_{SW} = 10mA; V_{FB} = 1V		1.1		Ω
Switch Pin Leakage Current	I_{LEAK}	V_{SW} = 25V		0.23		µA
Maximum Switch Off-Time	t_{OFF}	V_{FB} = 1V	100	300	500	ns
Diode Forward Voltage	V_F	T_A = +25°C; I_F = 150mA		1.0		V
Diode Reverse Current	I_R	T_A = +25°C; V_R = 25V		1.5		µA

SIMPLIFIED BLOCK DIAGRAM



ELECTRICALS

APPLICATION CIRCUITS

Typical LED Driver Applications

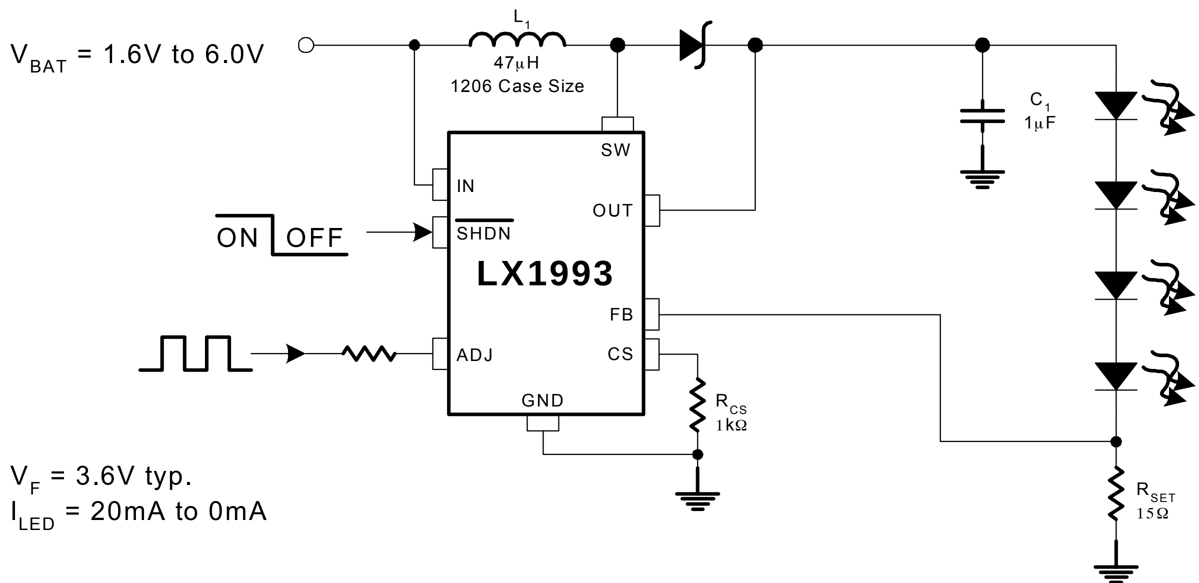


Figure 1 – LED Driver with Full-Range Dimming Via PWM Input

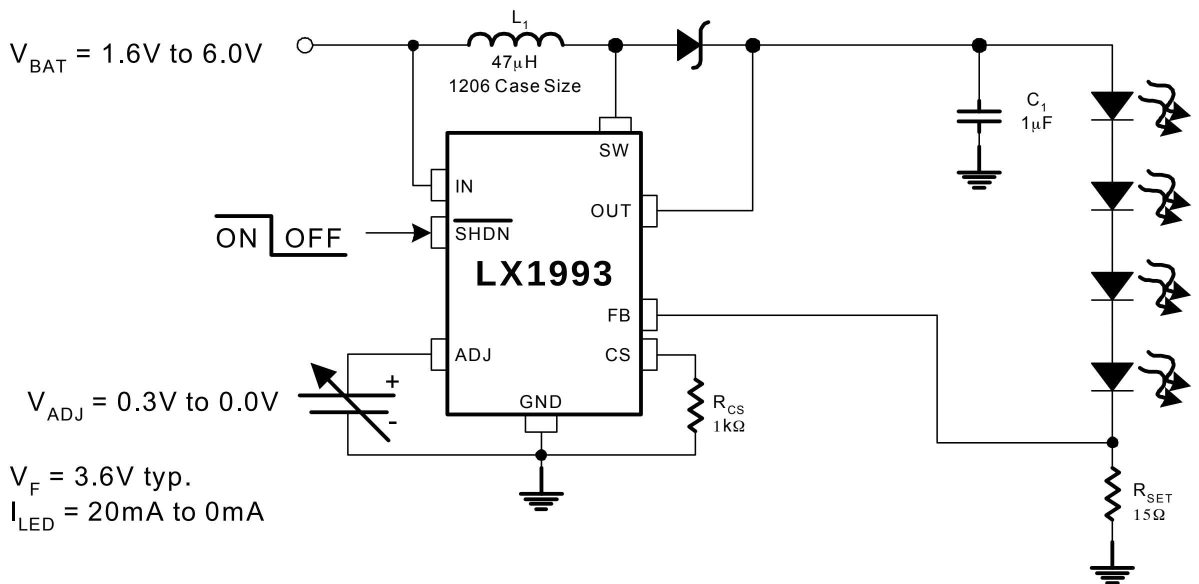


Figure 2 – LED Driver with Full-Range Dimming Via Analog Voltage Input

Note: The component values shown are only examples for a working system. Actual values will vary greatly depending on desired parameters, efficiency, and layout constraints.

APPLICATION INFORMATION

OPERATING THEORY

The LX1993 is a PFM boost converter that is optimized for driving a string of series connected LEDs. It operates in a pseudo-hysteretic mode with a fixed switch "off time" of 300ns. Converter switching is enabled as LED current decreases causing the voltage across R_{SET} to decrease to a value less than the voltage at the VADJ pin. When the voltage across R_{SET} (i.e., V_{FB}) is less than VADJ, comparator A1 activates the control logic. The control logic activates the DRV output circuit that connects to the gate of the internal FET. The output (i.e., SW) is switched "on" (and remains "on") until the inductor current ramps up to the peak current level. This current level is set via the external R_{CS} resistor and monitored through the CS input by comparator A2.

The LED load is powered from energy stored in the output capacitor during the inductor charging cycle. Once the peak inductor current value is achieved, the output is turned off (off-time is typically 300ns) allowing a portion of the energy stored in the inductor to be delivered to the load (e.g., see Figure 6, channel 2). This causes the output voltage to continue to rise across R_{SET} at the input to the feedback circuit. The LX1993 continues to switch until the voltage at the FB pin exceeds the control voltage at the ADJ pin. The value of R_{SET} is established by dividing the maximum adjust voltage by the maximum series LED current. A minimum value of 15Ω is recommended for R_{SET}. The voltage at the FB pin is the product of I_{OUT} (i.e., the current through the LED chain) and R_{SET}.

$$R_{SET} = \left[V_{ADJmax} / I_{LEDmax} \right]$$

The application of an external voltage source at the ADJ pin provides for output current adjustment over the entire dimming range and the designer can select one of two possible methods. The first option is to connect a PWM logic signal to the ADJ pin (e.g., see Figure 1). The LX1993 includes an internal 50pF capacitor to ground that works with an external resistor to create a low-pass filter (i.e., filter out the AC component of a pulse width modulated input of $f_{PWM} \geq 100KHz$). The second option is to adjust the reference voltage directly at the ADJ pin by applying a DC voltage from 0.0 to 0.3V (e.g., see Figure 2). The adjustment voltage level is selectable (with limited accuracy) by implementing the voltage divider created between the external series resistor and the internal 2.5MΩ resistor. Disabling the LX1993 is achieved by driving the SHDN pin with a low-level logic signal thus reducing the device power consumption to approximately 0.5µA (typ).

INDUCTOR SELECTION AND OUTPUT CURRENT LIMIT PROGRAMMING

Setting the level of peak inductor current to approximately **2X** the expected maximum DC input current will minimize the inductor size, the input ripple current, and the output ripple voltage. The designer is encouraged to use inductors that will not saturate at the peak inductor current level. An inductor value of 47µH is recommended. Choosing a lower value emphasizes peak current overshoot while choosing a higher value emphasizes output ripple voltage. The peak switch current is defined using a resistor placed between the CS terminal and ground and the I_{PEAK} equation is:

$$I_{PEAK} = I_{MIN} + \left(V_{IN} / L \right) t_D + \left(I_{SCALE} \right) R_{CS}$$

The maximum I_{PEAK} value is limited by the I_{SW} value (max. = 500mA rms). The minimum I_{PEAK} value is defined when R_{CS} is zero. The minimum I_{PEAK} value is defined when R_{CS} is zero. A typical value for the minimum peak current (I_{MIN}) at 25°C is 197mA. The parameter t_D is related to internal operation of comparator A. A typical value at 25°C is 850ns. A typical value of I_{SCALE} at 25°C is 44mA per KΩ. All of these parameters have an effect on the final I_{PEAK} value.

DESIGN EXAMPLE:

Determine I_{PEAK} where V_{IN} equals 3.0V and R_{CS} equals 4.02KΩ using nominal values for all other parameters.

$$I_{PEAK} = 197mA + \left(3.0V / 47\mu 7 \right) \times 850ns + \left(44mA / k\Omega \right) \times 4.02K\Omega$$

The result of this example yields a nominal I_{PEAK} of approximately 428mA.

OUTPUT RIPPLE AND CAPACITOR SELECTION

Output voltage ripple is a function of the inductor value (L), the output capacitor value (C_{OUT}), the peak switch current setting (I_{PEAK}), the load current (I_{OUT}), the input voltage (V_{IN}) and the output voltage (V_{OUT}) for a this boost converter regulation scheme. When the switch is first turned on, the peak-to-peak voltage ripple is a function of the output droop (as the inductor current charges to I_{PEAK}), the feedback transition error (i.e., typically 10mV), and the output overshoot (when the stored energy in the inductor is delivered to the load at the end of the charging cycle). Therefore the total ripple voltage is

$$V_{RIPPLE} = \Delta V_{DROOP} + \Delta V_{OVERSHOOT} + 10mV$$

The initial droop can be estimated as follows where the 0.5V value in the denominator is an estimate of the voltage drop across the inductor and the FET RDS_ON:

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$$\Delta V_{DROOP} = \frac{\left(\frac{L}{C_{OUT}}\right) \times \left(I_{PK} \times I_{OUT}\right)}{\left(V_{IN} - 0.5\right)}$$

The output overshoot can be estimated as follows where the 0.5 value in the denominator is an estimate of the voltage drop across the diode:

$$\Delta V_{OVERSHOOT} = \frac{\frac{1}{2} \times \left(\frac{L}{C_{OUT}}\right) \times \left(I_{PK} - I_{OUT}\right)^2}{\left(V_{OUT} + 0.5 - V_{IN}\right)}$$

DESIGN EXAMPLE:

Determine the V_{RIPPLE} where I_{PK} equals 200mA, I_{OUT} equals 13.0mA, L equals 47µH, C_{OUT} equals 4.7µF, V_{IN} equals 3.0V, and V_{OUT} equals 13.0V:

$$\Delta V_{DROOP} = \frac{\left(\frac{47\mu H}{4.7\mu F}\right) \times \left(200mA \times 12.8mA\right)}{\left(13.0 - 0.5\right)} \cong 2.0mV$$

$$\Delta V_{OVERSHOOT} = \frac{\frac{1}{2} \times \left(\frac{47\mu H}{4.7\mu F}\right) \times \left(200mA - 12.8mA\right)^2}{\left(13.0 + 0.5 - 3.0\right)} \cong 18.4mV$$

Therefore, V_{RIPPLE} = 2.0mV + 18.4mV + 10mV = 30.4mV

DIODE SELECTION

A Schottky diode is recommended for most applications (e.g., Microsemi UPS5817). The low forward voltage drop and fast recovery time associated with this device supports the switching demands associated with this circuit topology. The designer is encouraged to consider the diode's average and peak current ratings with respect to the application's output and peak inductor current requirements. Further, the diode's reverse breakdown voltage characteristic must be capable of withstanding a negative voltage transition that is greater than V_{OUT}.

PCB LAYOUT

The LX1993 produces high slew-rate voltage and current waveforms hence; the designer should take this into consideration when laying out the circuit. Minimizing trace lengths from the IC to the inductor, diode, input and output capacitors, and feedback connection (i.e., pin 3) are typical considerations. Moreover, the designer should maximize the DC input and output trace widths to accommodate peak current levels associated with this topology.

EVALUATION BOARD

The LXE1993 evaluation board is available from *Microsemi* for assessing overall circuit performance. The evaluation board, shown in Figure 3, is 3 by 3 inches (i.e., 7.6 by 7.6cm) square and programmed to drive 2 to 4 LEDs (provided). Designers can easily modify circuit parameters to suit their particular application by replacing R_{CS} (as described in this section) R_{SET} (i.e., R4) and LED load. Moreover, the inductor, FET, and switching diode are easily swapped out to promote design verification of a circuit that maximizes efficiency and minimizes cost for a specific application. The evaluation board input and output connections are described in Table 1.

The DC input voltage is applied to VBAT (not VCC) however the LX1993 IC may be driven from a separate DC source via the VCC input. The output current (i.e., LED brightness) is controlled by adjusting the on-board potentiometer. The designer may elect to drive the brightness adjustment circuit from VBAT or via a separate voltage source by selecting the appropriate jumper position (see Table 2). Optional external adjustment of the output LED current is achieved by disengaging the potentiometer and applying either a DC voltage or a PWM-type signal to the VADJ input. The PWM signal frequency should be higher than 150KHz and contain a DC component less than 350mV.

The LX1993 exhibits a low quiescent current (I_Q < 0.5µA: typ) during shutdown mode. The SHDN pin is used to exercise the shutdown function on the evaluation board. This pin is pulled-up to VCC via a 10KΩ resistor. Grounding the SHDN pin shuts down the IC (not the circuit output). The output voltage (i.e., voltage across the LED string) is readily measured at the VOUT terminal and LED current is derived from measuring the voltage at the VFDBK pin and dividing this value by 15Ω (i.e., R4). The factory installed component list for this must-have design tool is provided in Table 3 and the schematic is shown in Figure 4.

Efficiency Measurement Hint: When doing an efficiency evaluation using the LX1993 Evaluation Board, VPOT should be driven by a separate voltage supply to account for losses associated with the onboard reference (i.e., the 1.25V shunt regulator and 1KΩ resistor). This circuit will have VBAT - 1.25V across it and at the higher input voltages the 1KΩ resistor could have as much as 4mA through it. This shunt regulator circuitry will adversely effect the overall efficiency measurement. It is not normally used in an application; hence, it should not be considered when measuring efficiency.

APPLICATION INFORMATION (CONTINUED)

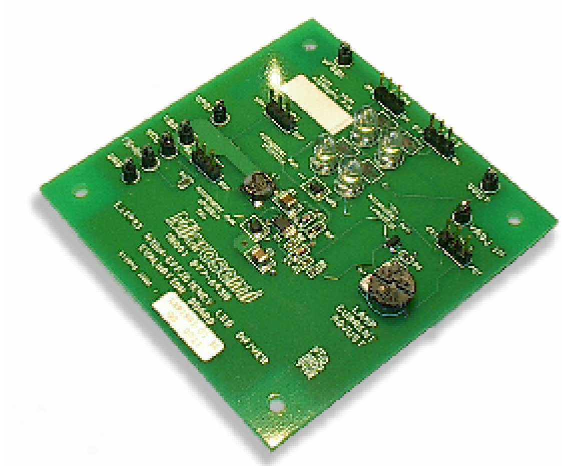

Figure 3: LXE1993 Engineering Evaluation Board

Table 1: Input and Ouput Pin Assignments

Pin Name	Allowable Range	Description
VBAT	0 to 6V	Main power supply for output. (Set external current limit to 0.5A)
VCC	1.6V to 6V	LX1993 power. May be strapped to VBAT or use a separate supply if VCC jumper is in the SEP position. Do not power output from VCC pin on board..
VPOT	1.6V to 6V	Potentiometer power. May be strapped to VBAT or use a separate supply if VPOT jumper is in the SEP position. Do not power output from VPOT pin on board.
VADJ IN	0 to 350mV	Apply a DC voltage or a PWM voltage to this pin to adjust the LED current. PWM inputs should be greater than 120Hz and DC portion less than 350mV.
/SHDN	0 to VCC	Pulled up to VCC on board (10KΩ), Ground to inhibit the LX1992.
VOUT	0 to 18V	Power supply output voltage that is applied to LED string.
VFDBK	0 to 400mV	Sense resistor voltage. Divide this voltage by 15 to determine LED current.

Table 2: Jumper Pin Position Assignments

Jumper Position	Functional Description
VCC/ BAT	Use this position when powering VBAT and VCC from the same supply. Do not connect power to the VCC input when using this jumper position.
VCC/ SEP	Use this position when using a separate VCC supply (different from VBAT).
VPOT/ VBAT	Use this position when powering the potentiometer reference circuit from the VBAT supply. Do not connect power to the VCC input when using this jumper position.
VPOT/ SEP	Use this position when using a separate power supply (different from VBAT) to power the potentiometer reference circuit. This will lower the VBAT current and provide a more accurate efficiency reading for the LX1993 circuit.
ADJ/ POT	Use this position when using the potentiometer to adjust LED current.
ADJ/ EXT	Use this position when adjusting the LED current with an external PWM that has a repetition rate >120Hz. Or when using a DC adjustment voltage.
LED# OFF	Use this position to short out LED # 3 and / or LED # 4.

Note: Always put jumpers in one of the two possible positions

APPLICATION INFORMATION (CONTINUED)

Table 3: Factory Installed Component List for the LX1993 Evaluation Board

Quantity	Part Reference	Description	Manufacturer	Part Number
1	CR1	Rectifier, Schottky, 1A, 20V, Powermite Type SMT	Microsemi	UPS5817
1	L1	Inductor, 47uH, 540mA, SMT	Toko	A920CY-470
2	C1, C2	Capacitor, Ceramic X5R, 4.7uF, 25V, 1210 Type SMT	Taiyo Yuden	CETMK325BJ475MN
2	C3, C4	Capacitor, Ceramic X7R, 0.1uF, 50V, 0805 Type SMT	Murata	GRM40X7R104M050
1	R4	Resistor, 15 Ohm, 1/10W, 0805 Type SMT	Panasonic	ERJ6ENF15R0
1	R3	Resistor, 590K, 1/16W, 0603 Type SMT	Panasonic	ERJ3EKF5903
1	R2	Resistor, 100, 1/16W, 0603 Type SMT	Panasonic	ERJ3EKF1000
2	R6, R8	Resistor, 100K, 1/16W, 0603 Type SMT	Panasonic	ERJ3EKF1003
1	R1, R5	Resistor, 10K, 1/16W, 0603 Type SMT	Panasonic	ERJ3EKF1002
1	R7	Trimpot, 50K, 1/2W, Through Hole Type	Bourns	3352E-1-503
1	VR1	IC, Voltage Reference, 1.25 Volts, SOT23 Type SMT	Microsemi	LX432CSC
1	VR2	Diode, Zener, 20V, 1W Powermite Type SMT	Microsemi	1PMT4114
4	LED1 - 4	White LED	Chicago Miniature	CMD333UWC
5	JB1 - JB3	Header, 3 Pos Vertical Type	3M	929647-09-36
5		Jumper	3M	929955-06

Note: The minimum set of parts needed to build a working power supply are: CR1, L1, C1, C2, R2, R4, U1. Evaluation board P/L subject to change without notice.

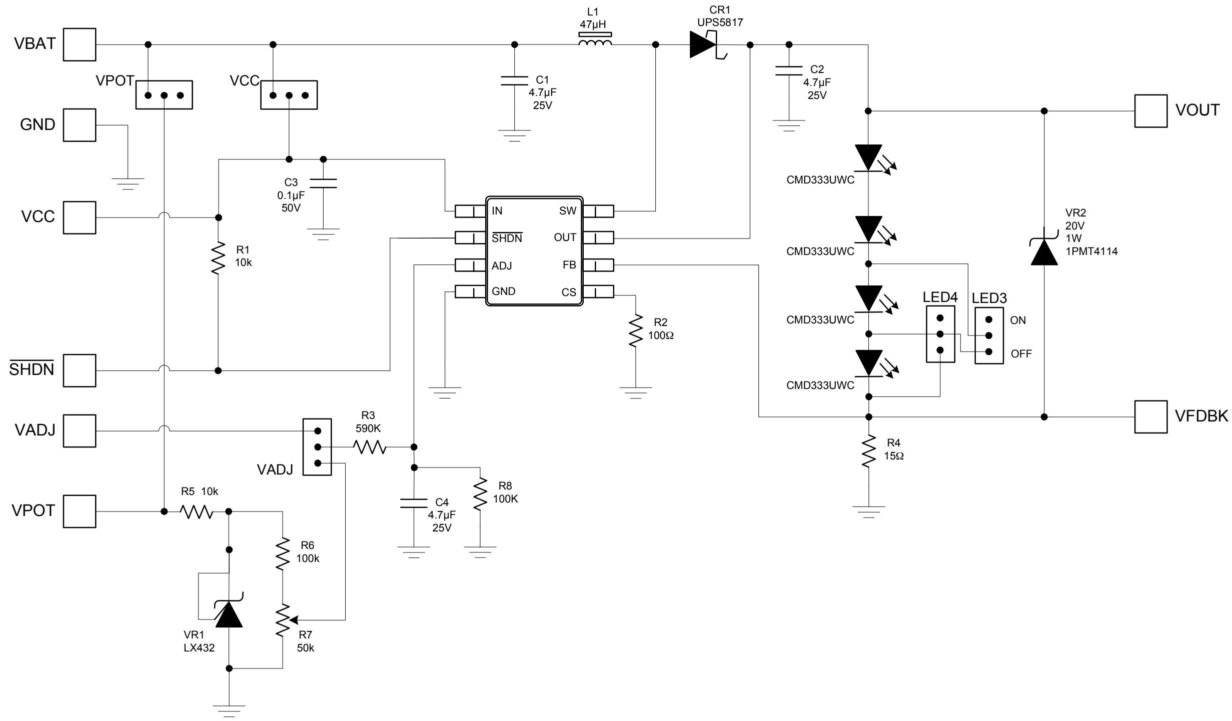

Figure 4 – LXE1993 Boost Evaluation Board Schematic

CHARACTERISTIC CURVES

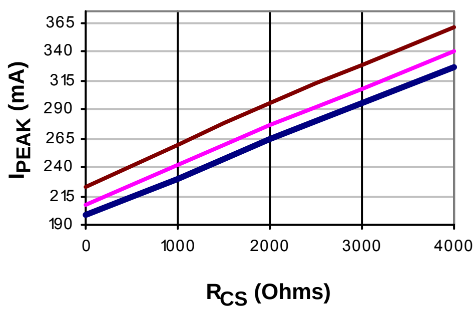

Figure 5: Example of Peak Current versus R_{CS} value
Conditions:
V_{IN} = 2.5V (bottom), 3.3V (middle) & 4.5V (top)
@ $T_A = 25^oC$

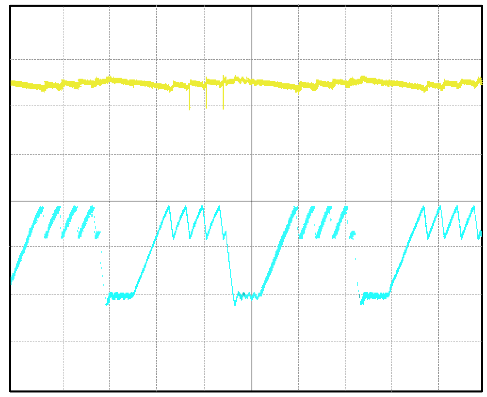

Figure 6: V_{OUT} and Inductor Current Waveforms.
Channel 1: V_{OUT} (AC coupled; 100mV/div)
Channel 2: Inductor Current (100mA/div.)
4 LED Configuration: V_{IN} = 3.0V

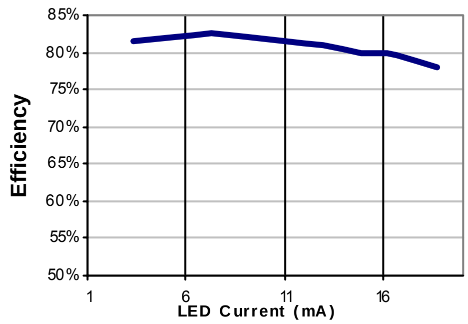

Figure 7: Efficiency vs. LED Output Current.
2 LED Configuration: V_{IN} = 3.5V, L = 47µH, R_{CS} = 100Ω
Note: Data taken from LXE1993 Evaluation Board

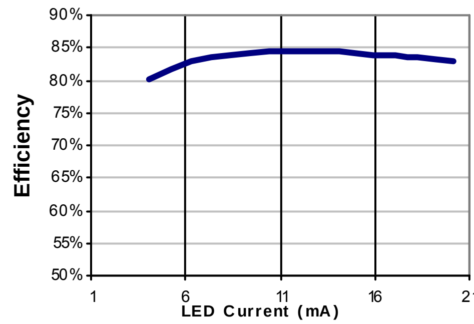

Figure 8: Efficiency vs. LED Output Current.
2 LED Configuration: V_{IN} = 5.0V, L = 47µH, R_{CS} = 100Ω
Note: Data taken from LXE1993 Evaluation Board

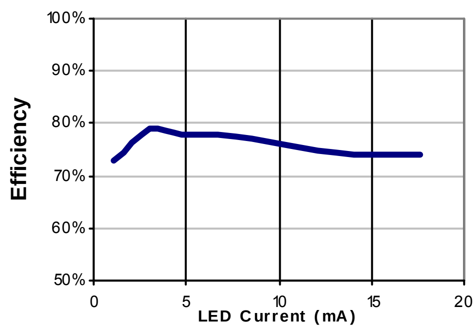

Figure 9: Efficiency vs. LED Output Current.
4 LED Configuration: V_{IN} = 3.5V, L = 47µH, R_{CS} = 100Ω
Note: Data taken from LXE1993 Evaluation Board

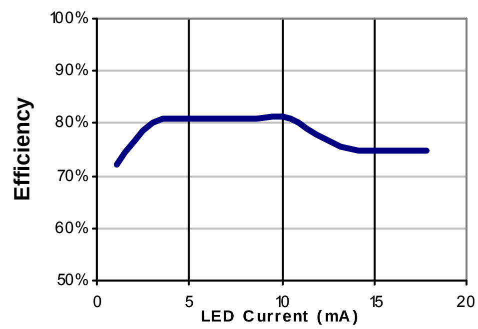

Figure 10: Efficiency vs. LED Output Current.
4 LED Configuration: V_{IN} = 5.0V, L = 47µH, R_{CS} = 100Ω
Note: Data taken from LXE1993 Evaluation Board

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CHARACTERISTIC CURVES

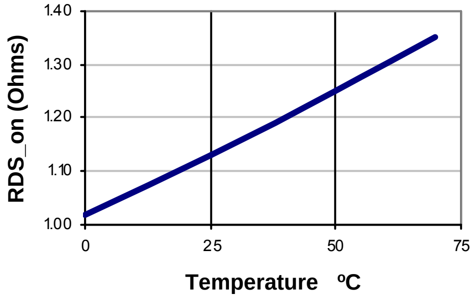


Figure 11: $R_{DS(on)}$ vs. Temperature
Condition: V_{IN} = 3.0V; I_{SW} = 10mA

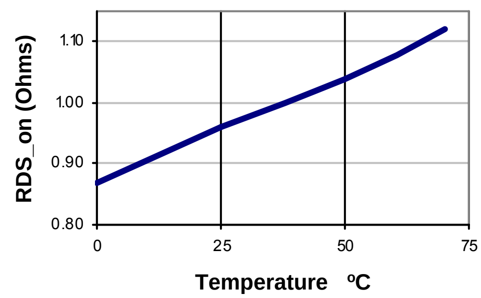


Figure 12: $R_{DS(on)}$ vs. Temperature
Condition: V_{IN} = 5.0V; I_{SW} = 10mA

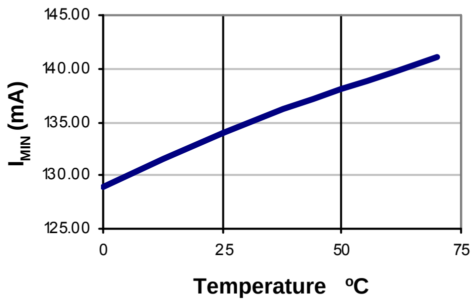


Figure 13: I_{MIN} versus Temperature.
Condition: V_{IN} = 3.0V

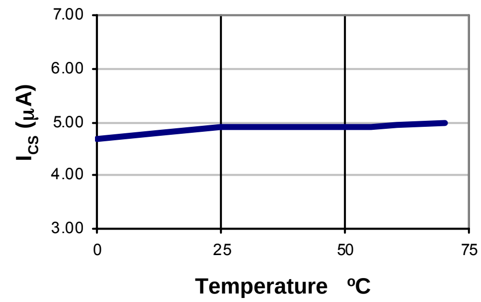


Figure 14: I_{CS} versus Temperature.
Condition: V_{IN} = 3.0V

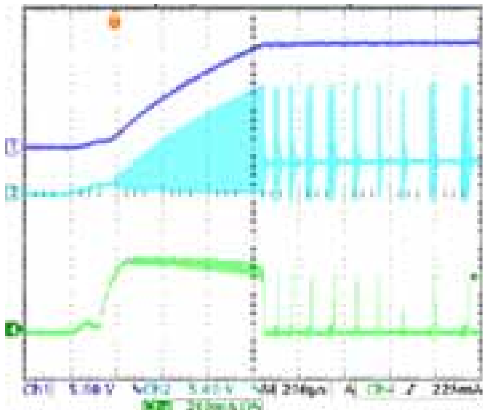
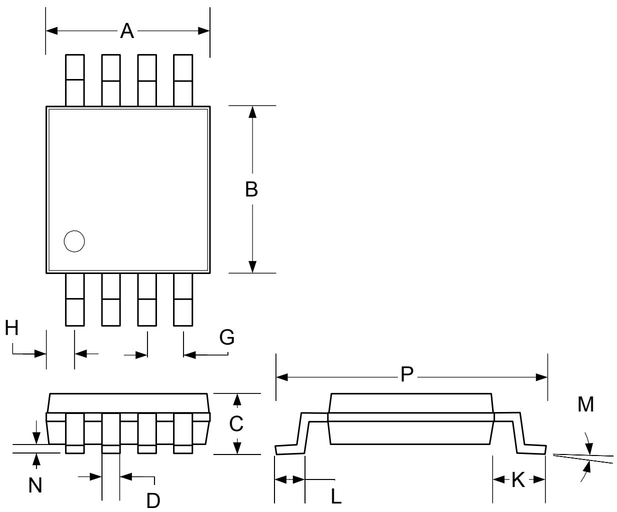


Figure 15: Start-Up Waveforms.
Condition: V_{IN} = 3.6V, CH1 = V_{OUT}, CH2 = V_{SW}, CH4 = I_L

PACKAGE DIMENSIONS

DU 8-Pin Miniature Shrink Outline Package (MSOP)



Dim	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	2.85	3.05	.112	.120
B	2.90	3.10	.114	.122
C	–	1.10	–	0.043
D	0.25	0.40	0.009	0.160
G	0.65 BSC		0.025 BSC	
H	0.38	0.64	0.015	0.025
J	0.13	0.18	0.005	0.007
K	0.95 BSC		0.037 BSC	
L	0.40	0.70	0.016	0.027
M	3°		3°	
N	0.05	0.15	0.002	0.006
P	4.75	5.05	0.187	0.198

Note: Dimensions do not include mold flash or protrusions; these shall not exceed 0.155mm(0.006”) on any side. Lead dimension shall not include solder coverage.

NOTES