www.*Microsemi*.COM

DESCRIPTION

LX1996 is an integrated white LED driver for notebook size displays. It is designed to drive up to six strings of LEDs. The LX1996 consists of a boost converter and six precision current sources. It also includes a direct analog light sensor interface and can be dimmed by a PWM signal or by application of a DC control voltage.

Precision current mirror circuitry sets all channels to the same current with a single programming input. The current value can be programmed up to 30mA per channel with a single resistor from the PRG pin to ground. Channel to channel matching is within ± 0.5 percent typical at 25°C ambient of the channels mean at the rated output current.

Unique design features include temperature compensated LED current, and audible noise reduction using Ultrasonic Pulse Skipping.

Temperature compensated LED current is accomplished by a dedicated input pin (OT) that in conjunction with an external thermistor measures the LED's ambient temperature and thereby prevents over temperature stress to the LEDs by keeping them within their safe operating area.

Additional features include low sleep mode current (6µA typ.) for extending battery time, multi-mode dimming via ambient light sensor interface, analog dimming, direct PWM dimming and combination of analog and direct PWM dimming for up to a 25000:1 dimming range.

The LX1996 is designed to work over a wide input voltage range from 6V to 28Vdc with adjustable over voltage protection (OVP), and short and open LED protection.

The LX1996 comes in a compact thermal efficient 4x4mm 24pin MLPQ package.

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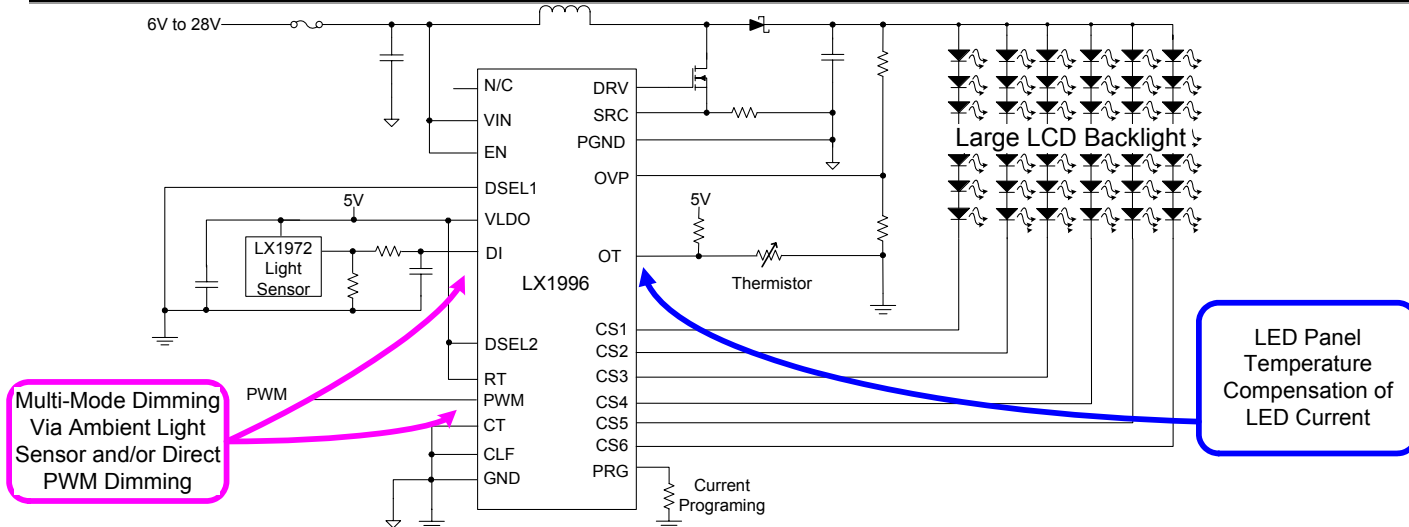**Patents Pending**

KEY FEATURES

- White LED Backlight Controller for Middle Size Display Panels
- Up to 6 LED Strings with ±0.5% Precision Current Matching
- Wide Input Voltage Range from 6V to 28V
- Temperature Compensated LED Current
- Ultrasonic Pulse Skipping for audible noise reduction
- Direct Ambient Light Sensor Interface for Brightness Control
- High Efficiency over Full Dimming Range
- Low Standby Current
- On-chip Thermal Shut-down
- Over-voltage Protection
- Packaged in a Thermally Efficient 24 pin 4x4mm MLPQ Package

APPLICATIONS

- Notebook & Monitor Displays
- Entertainment Systems
- Automotive Lighting & Panels

PRODUCT HIGHLIGHT

LX1996

PACKAGE ORDER INFO

T$_A$ (°C)	**LQ**	Plastic 4x4 mm MLPQ 24-pin
		RoHS Compliant / Pb-free
-40 to 85		**LX1996ILQ**
	Note: Available in Tape & Reel. Append the letters "TR" to the part number. (i.e. LX1996ILQ-TR)	

THERMAL DATA

θ$_{JA}$ = 30 °C/W

THERMAL RESISTANCE–JUNCTION TO AMBIENT

Junction Temperature Calculation: T$_J$ = T$_A$ + (P$_D$ x θ$_{JA}$).
The θ$_{JA}$ numbers are guidelines for the thermal performance of the device attached to a pc-board system. All of the above assume no ambient airflow.

PRODUCTION DATASHEET

ABSOLUTE MAXIMUM RATINGS

Supply Input Voltage (VIN), EN ....-0.3V to 30V
CS# pins ....-0.3V to 28V
DSEL1, DSEL2, DI and PWM pins ....-0.3V to 6.0V
OT, DRV, SRC, OVP, PRG, CLF, CT, RT Pins .... -0.3V to V_{LDO} + 0.3V
CS# Current 35mA
Operating Temperature Range.. -40 to 85°C
Maximum Operating Junction Temperature ....150°C
Storage Temperature Range...-65°C to 150°C
Package Peak Temp. for Solder Reflow (40 seconds maximum exposure) .... 260°C (+0 -5)

Notes: 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.

Solder reflow to follow: IPC/JEDEC J-STD-020B 7/02 Pb-Sn Small Body Profile
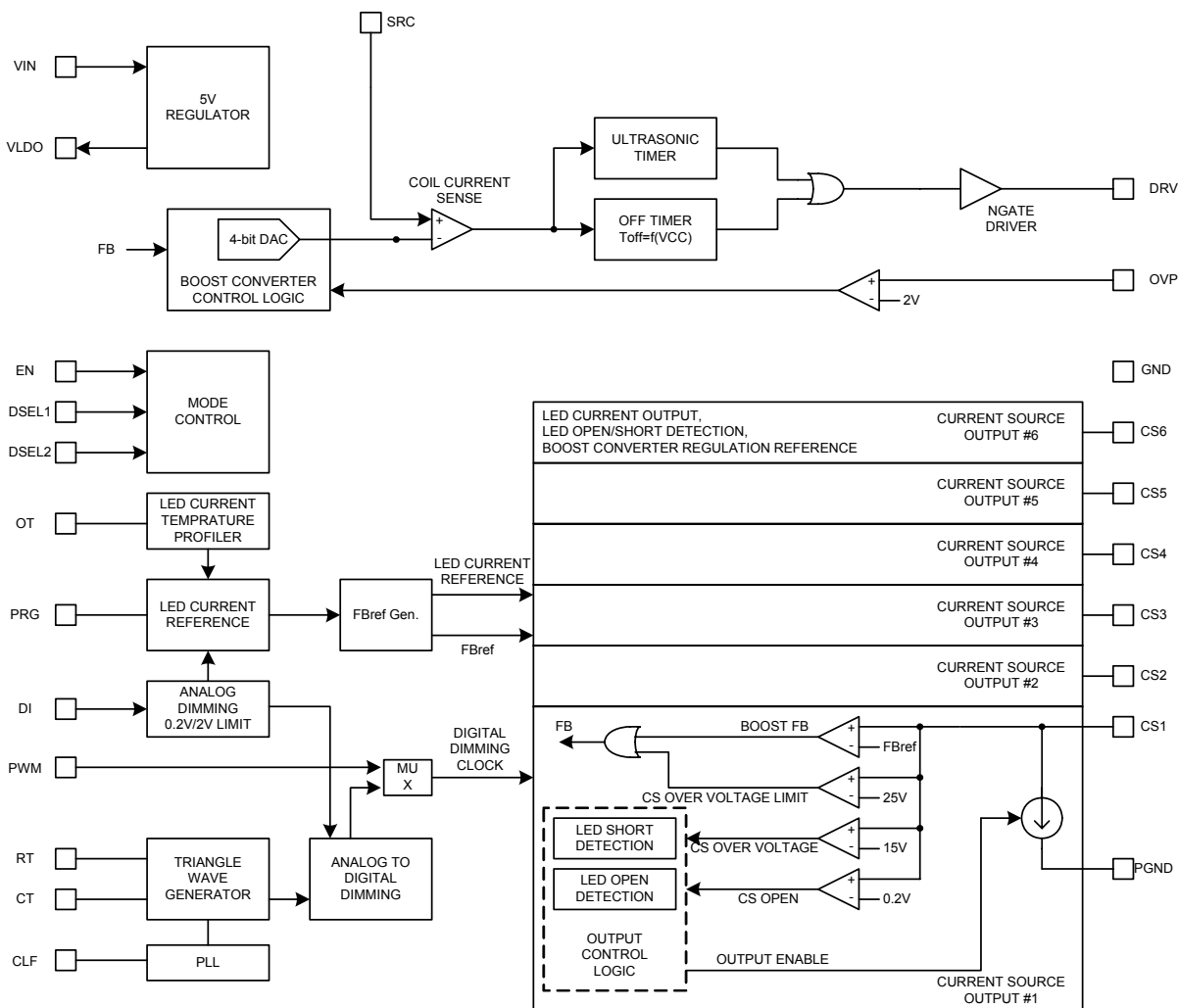
PACKAGE PIN OUT

Pins (Top View):

Top row: 24 VIN, 23 N/C, 22 DRV, 21 SRC, 20 PGND, 19 OVP

Left side: EN 1, VLDO 2, DSEL1 3, DSEL2 4, DI 5, OT 6

Right side: 18 CS6, 17 CS5, 16 CS4, 15 CS3, 14 CS2, 13 CS1

Bottom row: 7 PWM, 8 RT, 9 CT, 10 CLF, 11 PRG, 12 GND

MSC
LX1996
XXXX
Connect Bottom Pad to GND

LQ PACKAGE
(Top View)
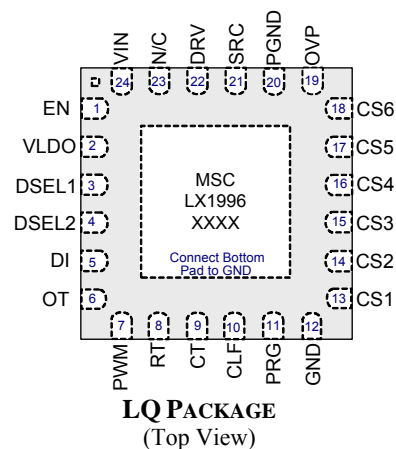
RoHS / Pb-free 100% Matte Tin pin Finish

XXXX = Date code / Lot code identifier

FUNCTIONAL PIN DESCRIPTION

Name	Pin #	Description
EN	1	Enable Input - Logic input. Pull low to put the system into sleep mode; If not used must be tied to VIN.
VLDO	2	Internal 5V Regulator Output – Power Pin. Provides a regulated 5V for internal 5V circuits. It can also power an external light sensor and/or SM Buss chip (limited to 1mA). Must be decoupled closely to the GND with a ceramic capacitor typical value of 4.7µF.
DSEL1	3	Dimming Mode Select Input 1. Three level input. Refer to Table 1 in the applications section for functionality
DSEL2	4	Dimming Mode Select Input 2. – Two Level Logic Input. Refer to Table 1 in the applications section for functionality
DI	5	Dimming Input – Signal Pin. Connect a DC dimming voltage or the light sensor output to this pin.
OT	6	LED Ambient Over Temperature Protection – Signal Pin – Connect to an external NTC thermistor to monitor the LED light bar temperature. If NTC is not used, then tie this pin to the IC's VLDO pin. The NTC needs to be 100kΩ at 25°C and B constant of 4000. Please see the applications section for more details regarding the OT option.
PWM	7	Pulse Width Modulated Dimming Signal – Signal Input. PWM input used for multi-dimming mode. With DSEL1 pin tied low, a PWM signal input in the range of 100Hz to 25kHz provides direct digital dimming for the LED outputs. With DSEL1 pin open and DSEL2 pin tied high, this pin is used as a sync input for synchronizing the LX1996's internal PWM dimming clock with an external clock signal of 400ns or greater width.
RT	8	Current source setting resistor. Must be 100KΩ between this pin and ground when Analog to Digital Dimming or Ultrasonic Pulse Skipping modes are used. If neither mode is used, this pin may be left open or tied to V_{LDO}.
CT	9	Internal Digital Dimming frequency setting capacitor. A capacitor between this pin and ground sets the internal Digital Dimming frequency. The relationship between the C_T pin capacitor and internal frequency is; F(Hz) = 5e-6/C_T(Farads) This pin should be left open or grounded when the internal oscillator is not used.
CLF	10	PLL Loop filter connection pin. A loop filter capacitor should be connected between this pin and ground when the internal dimming is used with synchronization mode engaged. Typical capacitor values are; 0.1uF for 200Hz; 1nF for 20Khz. This pin should be left open or grounded when the synchronization option is not used.
PRG	11	LED current programming. Connect a resistor between this pin and ground to set the LED current. Refer to applications section for functionality
GND	12	Signal ground. Should be tied at a single common point to Power Ground (PGND pin 20).
CS1-6	13 to18	Current Sink pins – controls individual LED string current. CS pins can be wired in parallel for higher currents. The lowest CS voltage is kept at approx. 0.8V at 20mA.

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 2

www.Microsemi.COM

FUNCTIONAL PIN DESCRIPTION		
Name	**Pin #**	**Description**
OVP	19	Over Voltage Protection – Signal input. An external voltage divider sets the maximum boost voltage limit in case of open LED strings. Refer to applications section for functionality.
PGND	20	Power Ground. Should be tied at a single common point to Signal Ground (GND pin 12).
SRC	21	Boost Converter Current Sense Pin. This connects to the junction of the external N-FET source and the current sense resistor. It is used to set the peak inductor current.
DRV	22	External N-FET Gate Drive. Connect to the Gate of the external N-channel MOSFET
N/C	23	No Connection.
VIN	24	Power Supply Input. Must be closely decoupled to PGND with a 4.7uF ceramic capacitor.

LX1996

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 3

Microsemi ™ ®

FUNCTIONAL BLOCK DIAGRAM

LX1996

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, the following specifications apply over the operating ambient temperature of -40^0C $<$ Temp $<85^0$C, and the following test conditions: VIN=12V, V_{OT} = 3V, EN = VIN , R_{PRG}= 4.99 kΩ, L=6.8µH, R_{SRC}= 0.075Ω, C_{OUTPUT} = 4.7uF

Parameter	Symbol	Test Conditions / Comment	LX1996 Min	LX1996 Typ	LX1996 Max	Units
Power Supply						
Input Voltage	V_{IN}		6	12	28	V
Quiescent current	$I_{IN\ ON}$	EN ≥2.4V, output not switching, V_{CS} = 0.8V			2.5	mA
Sleep Current	$I_{IN\ sleep}$	EN ≤ 0.4V		6	15	µA
Logic						
DSEL1 Input High Voltage	$V_{DSEL1-H}$		2.4			V
DSEL1 Input Low Voltage	$V_{DSEL1-L}$				0.8	V
DSEL1 input current High	I_{DSEL1_H}	DSEL1 = 2.4V		4	10	µA
DSEL1 input current Low	I_{DSEL1_L}	DSEL1 = 0.8V	-10	-4		µA
DSEL1 Open Voltage			1.2	1.6	2.0	V
DSEL2 Input High Voltage			2.4			V
DSEL2 Input Low Voltage					0.8	V
DSEL2 Pull-down Resistor				600		kΩ
EN Input High Voltage			2.4			V
EN Input Low Voltage					0.8	V
EN input current	I_{EN_H}	12V ≥ EN ≥ 2.4V		4.0	10	µA
EN input current	I_{EN_L}	EN < 0.4V		0.4	1	µA
PWM Input High Voltage	V_{PWM-H}		2.4			V
PWM Input Low Voltage	V_{PWM-L}				0.8	V
PWM Pull-down Resistor				600		kΩ
DIMMING						
DI Input Bias Current		V_{DI} =0.2 to 2.0V, Analog dimming			1	µA
Maximum PRG voltage	$V_{TH\_DI\_H}$	V_{DI} =2.0V, Analog dimming	1.83	2.0	2.17	V
Minimum PRG voltage	$V_{TH\_DI\_L}$	V_{DI} =0.2V, Analog dimming		0.2		V
Direct Digital Dimming Frequency	F_{PWM}		100		25000	Hz
Direct Digital Dimming Min. PWM Pulse Width (Note 2)	F_{PWM}				4	us
RT Reference Voltage		RT = 100kΩ		2		V
Internal PWM Frequency	F_{INTPWM}	CT = 200pF, RT = 100kΩ		25		kHz
		CT =.047µF, RT = 100kΩ		100		Hz
Sync. freq. Capture Range		Percent of Internal PWM Frequency	-25		+25	%
Minimum PWM Input Pulse Width		For synchronization		400		ns
Device Protection						
OVP Threshold Voltage	V_{TH_OVP}		1.9	2.0	2.1	V

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, the following specifications apply over the operating ambient temperature of $-40^0C < Temp < 85^0C$, and the following test conditions: VIN=12V, V_{OT} = 3V, EN = VIN , R_{PRG}= 4.99 kΩ, L=6.8μH, R_{SRC}= 0.075Ω, C_{OUTPUT} = 4.7uF

LED Short Protection Threshold	Vcs	Voltage at CS pin that latches off it's respective string.		15		V
CS pin Over-voltage Limit	V_{CS}	Voltage at CS pin that clamps Boost Output	23	25	27	V

LED Current Sink Outputs

LED DC Current Programming Accuracy (including string to string matching)	I_{CS}	V_{CS} = 0.8V; DI ≥ 2.0V; Direct Analog Dimming Mode	19.2	20	20.8	mA
		R_{PRG} = 6.65k (LED current set for15mA);, V_{CS} = 0.8V; DI ≥ 2.0V; Direct Analog Dimming Mode	14.4	15	15.6	mA
Analog Dimming Accuracy	I_{CS}	DI=0.5V; Direct Analog Dimming Mode		5		mA
Direct Digital Dimming Accuracy	I_{CSAVG}	Direct Digital Dimming Mode; V_{CS} = 0.8V; PWM input at 25kHz , 25% duty cycle; Average (DC) LED current.		5		mA
Current Matching between strings (Note 3).	$I_{CS-MATCH}$	VIN = 6V to 28V; -40°C to 85°C; VCS = 0.8V to 5V; DI ≥ 2.0V; Direct Analog Dimming Mode	-1.3		1.3	%
Regulated CS Pin Voltage		At the lowest CS pin, I_{CS} = 20mA	0.5	0.75		V
LED current On Rise Time	T_{CS_Rise}			200		ns
LED current Off Fall Time	T_{CS_Fall}			400		ns
Csx current to PRG current Ratio	I_{CS}/I_{PRG}			50		
PRG Reference Voltage	V_{PRG}			2.0		V

LED Current Temperature Profiler

LED Over Temperature Shut-down Voltage Threshold	V_{OT}			1.47		V
OT Recovery Voltage Threshold	V_{OT}			1.8		V
OT Input Bias Current					1	μA
V_{OT} Input vs. PRG pin Reference Voltage (Note 1, 2)	V_{PRG}	V_{OT} = 2.48V		2.0		V
	V_{PRG}	V_{OT} = 1.8V		1.2		V
	V_{PRG}	V_{OT} = 1.47V		0.8		V

VLDO Regulator

VLDO Output Voltage	V_{LDO}	V_{in} ≥6.5V; 0mA ≤ I_{VLDO} ≤ 6.0mA	4.75	5.0	5.25	V
		V_{in} < 6.5V; 0mA ≤ I_{VLDO} ≤ 6.0mA	4.5		5.25	V
VLDO Source Current	I_{VLDO}	External available current			1	mA
UVLO	V_{UVLO}	VLDO rising	4.0	4.25	4.5	V
UVLO Hysteresis				0.25		V

Boost Converter

DRV Rise Time	T_{RISE}	C_L = 1000pF; 10% to 90% of V_{LDO}		25		nsec
DRV Fall Time	T_{FALL}	C_L = 1000pF; 90% to 10% of V_{LDO}		14		ns

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570
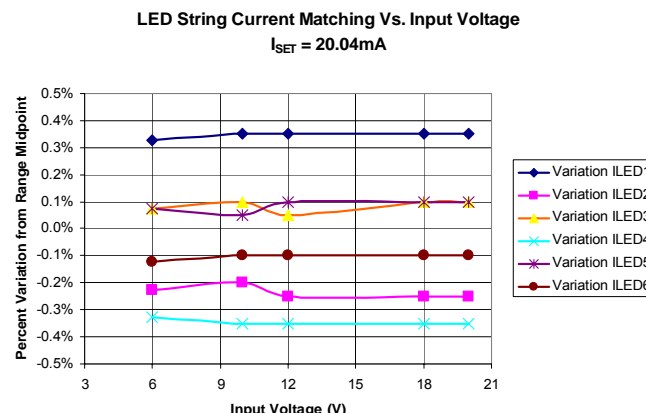
ELECTRICAL CHARACTERISTICS

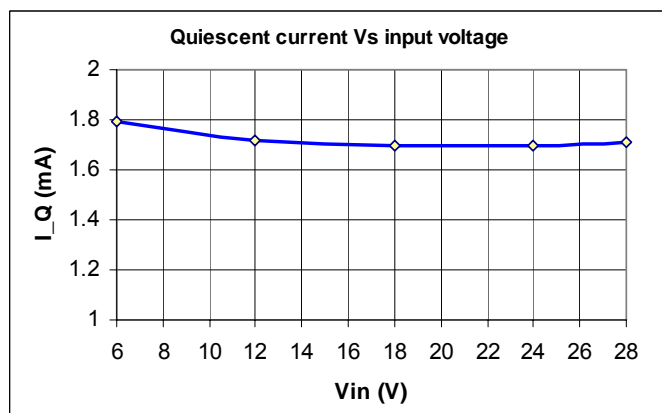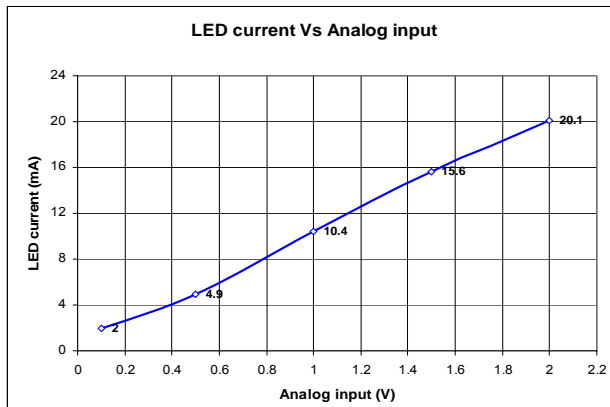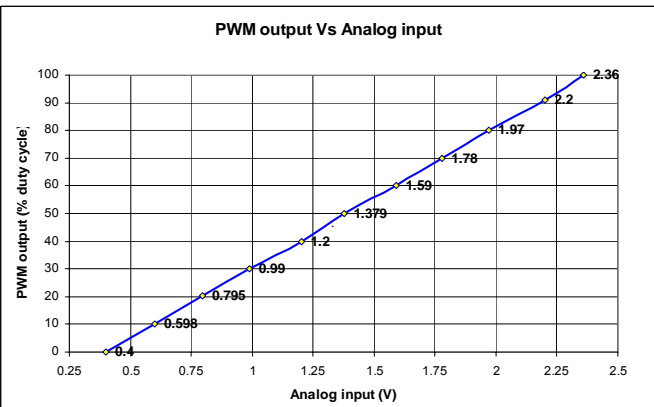Unless otherwise specified, the following specifications apply over the operating ambient temperature of -40^0C < Temp < 85^0C, and the following test conditions: VIN=12V, V_{OT} = 3V, EN = VIN , R_{PRG}= 4.99 kΩ, L=6.8µH, R_{SRC}= 0.075Ω, C_{OUTPUT} = 4.7uF

Ultrasonic Pulse Skipping (USPS)

Maximum Switching Interval		R_T=100KΩ, Ultrasonic mode	23	40	50	µs

Thermal Protection

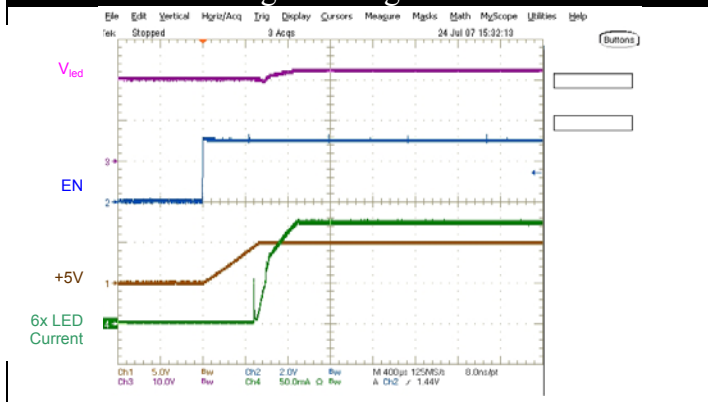|						
Over Temperature Shutdown (Note 2)				140		°C
Thermal Shutdown Recovery (Note 2)				100		°C

Notes
1. With a 100K NTC thermistor, Bconstant = 4250, and Rbias = 22.1K, V_{OT} threshold values equate to the following temperature points:
   a. OT shut off temperature = 85°C
   b. OT derating threshold = 60°C
   c. OT recovery temperature = 75°C
2. This parameter is bench characterized but not ATE tested.
3. Based on % variation from (I_{CS} Max+I_{CS} Min)/2.

Typical Characteristics @ 25°C (Refer to Figure 1)

SYSTEM EFFICIENCY vs LOAD

System Efficiency Vs Output Load
Analog Dimming Mode

Legend: 6V-Eff, 12V-Eff, 18V-Eff

Efficiency vs Total LED current (mA)

SLEEP CURRENT vs INPUT VOLTAGE

Sleep current Vs input voltage

I_sleep (uA) vs Vin (V)
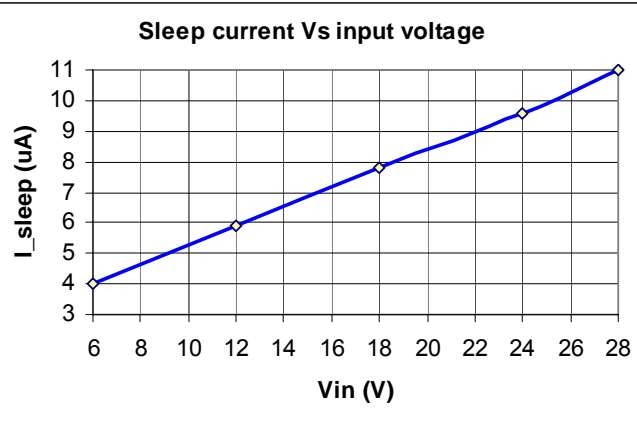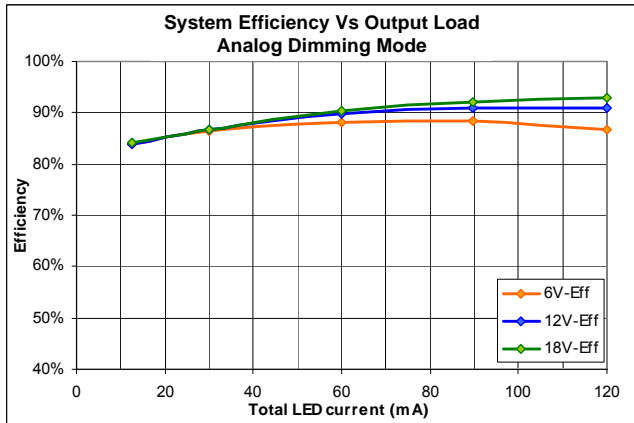
SUPPLY CURRENT vs INPUT VOLTAGE (NO LOAD)

Quiescent current Vs input voltage

I_Q (mA) vs Vin (V)

STRING CURRENT MATCHING vs Input Voltage

LED String Current Matching Vs. Input Voltage
I_{SET} = 20.04mA

Percent Variation from Range Midpoint vs Input Voltage (V)

Legend: Variation ILED1, Variation ILED2, Variation ILED3, Variation ILED4, Variation ILED5, Variation ILED6

ANALOG INPUT vs INTERNAL DIGITAL DIMMING

PWM output Vs Analog input

PWM output (% duty cycle) vs Analog input (V)

Data points: 0.4, 0.598, 0.795, 0.99, 1.2, 1.379, 1.59, 1.78, 1.97, 2.2, 2.36

ANALOG INPUT vs $I_{CS(X)}$

LED current Vs Analog input

LED current (mA) vs Analog input (V)

Data points: 2, 4.9, 10.4, 15.6, 20.1

Page 8

www.*Microsemi*.COM

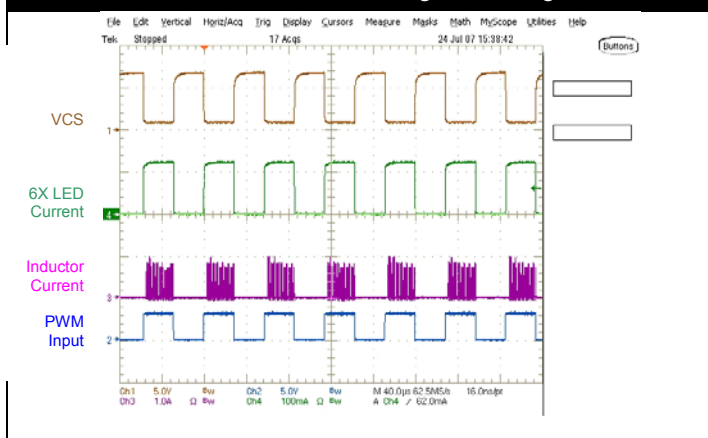**LX1996**

STARTUP WAVEFORMS
Analog dimming. Full load

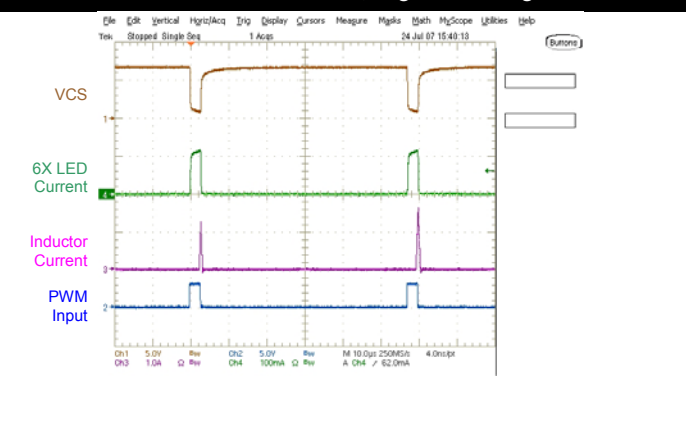

SWITCHING WAVEFORMS
Analog dimming. 50% Load
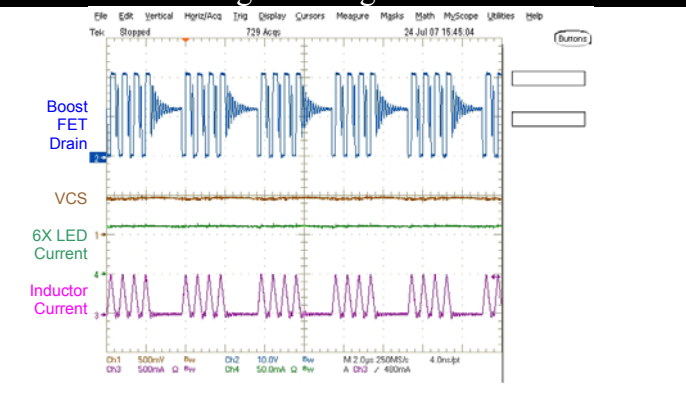
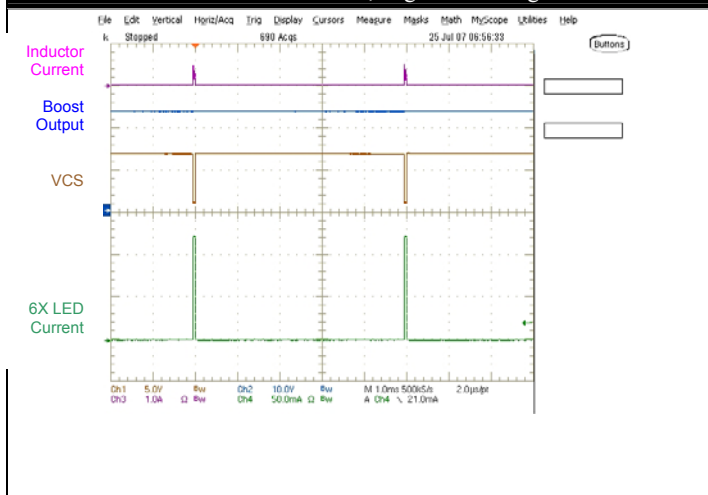## LED CURRENT WAVEFORMS
D = 50% at 17.5kHz, Digital dimming
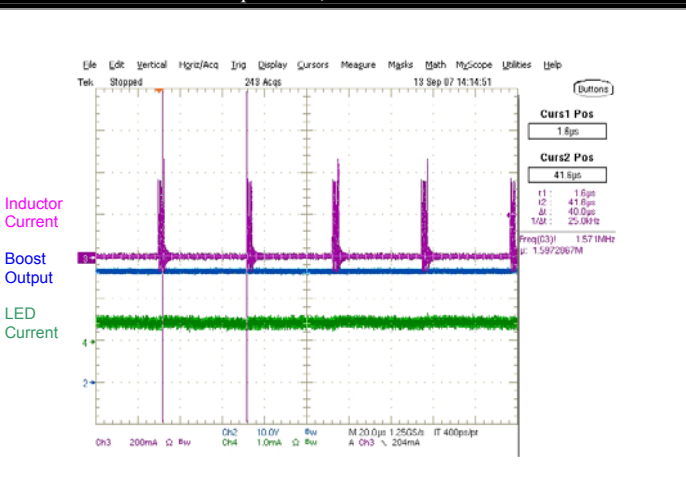

LED CURRENT WAVEFORMS
D = 5% at 17.5kHz, Digital dimming

LED CURRENT WAVEFORMS
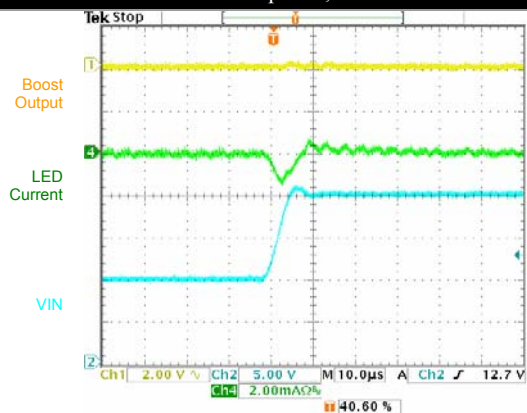### D = 1% at 200Hz, Digital dimming

LED CURRENT WAVEFORMS
USPS Operation; LED Current = 0.5mA

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570
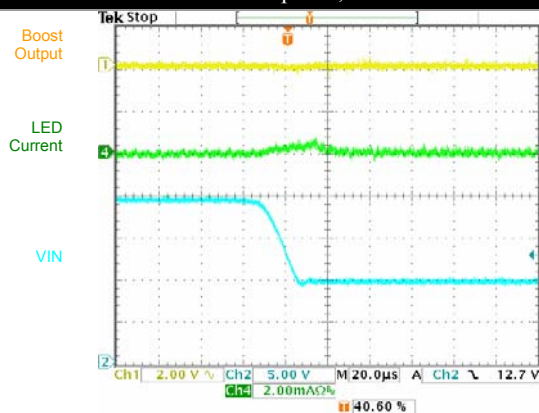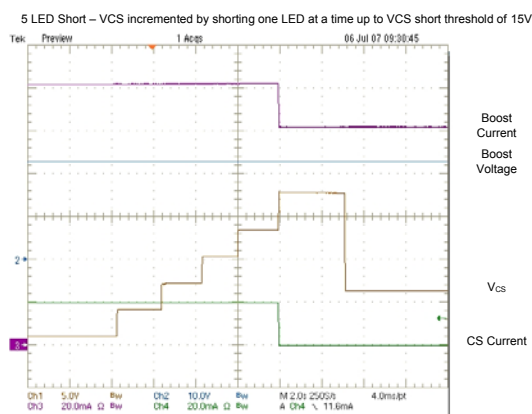
Page 9

LED CURRENT WAVEFORMS
Line Transient Response; VIN 10V to 20V Step

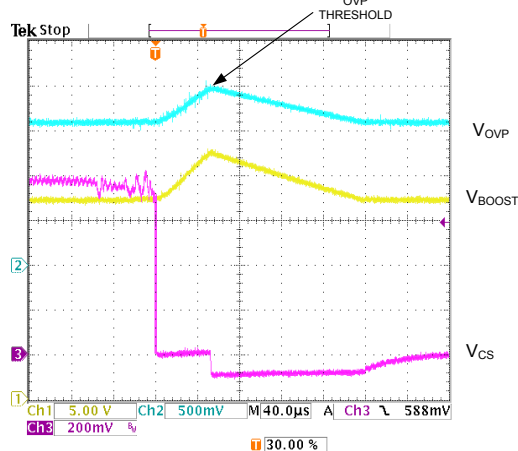## LED CURRENT WAVEFORMS
Line Transient Response; VIN 20V to 10V Step

LED PROTECTION WAVEFORMS
Shorted LED Response – 1 to 5 Shorted LEDS in a Single String

LED PROTECTION WAVEFORMS
LED Open Response

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570
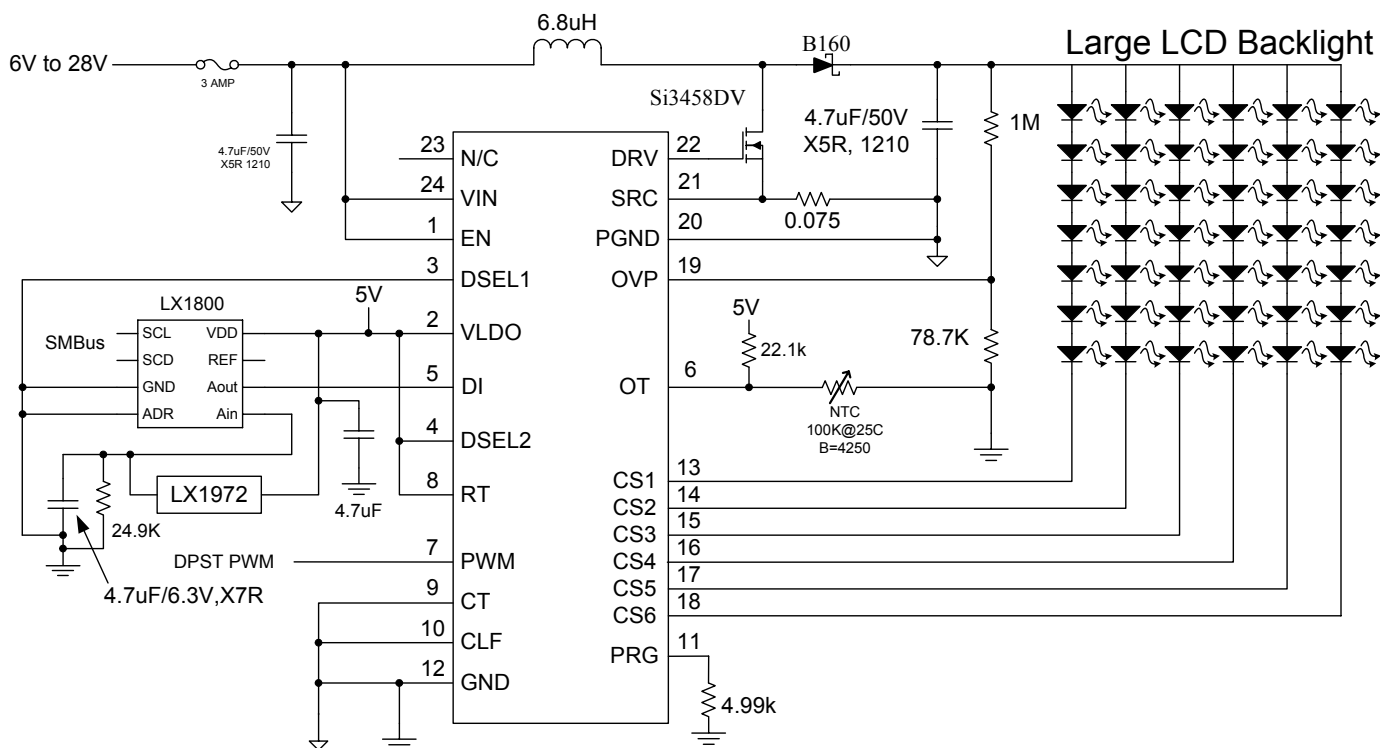
www.Microsemi.COM

TYPICAL APPLICATION

Figure 1 – Typical Application – This circuit demonstrates the LX1996 and LX1972 interfacing to the LX1800, which is an SMBus ADC/DAC. This application also uses the Display Power Saving Technology (DPST) signal.

<u>Key Components - Bill of Materials</u>

LX1996ILQ = Multi-string LED Back-light Controller, Microsemi
LX1800ILD = SMBus to Analog Interface, Microsemi
LX1972IBC = Ambient Light Detector, Microsemi
GRM188R60J475KE19 = 4.7uF/6.3V, X7R, 0603, Murata
GRM32ER71H475KA88 = 4.7uF/50V, X5R, 1210, Murata
SLF6028T-6R8M1R5-PF, 6.8µH, 1.5A, TDK
SI3458DV = N channel MOSFET, 60V/1.2A, TSOP-6,Vishay
NCP18WB104J03RA = NTC, 100K at 25C, B = 4250, Murata
B160 = Schottky Diode 1A/60V, SMA, Vishay

LX1996

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 11

OPERATION THEORY

BOOST CONVERTER

The LX1996 uses a variable peak current variable off time hysteretic PFM converter topology where inductor peak current is digitally controlled. It is a current mode step up converter in PFM burst mode. The LX1996 controls the inductor peak and the off time to minimize the switching frequency variation over a wide input power supply range. It regulates the boost output voltage based on the lowest voltage among the CS pins. This converter stays in burst PFM mode for the entire load range and has extremely fast load response. It automatically increases or decreases the inductor peak current depending on the output load to minimize the output voltage ripple while maintaining the output in regulation. Maximum coil peak current can be up to 1.55A with a 75mΩ sense resistor. For a higher power system, a user can use a smaller resistance current sense resistor. Conversely, a lower power system can use a larger resistance current sense resistor. Typical switching frequency is over 1MHz. A 6.8uH inductor is recommended for systems that require direct digital dimming. A larger inductor may be used for a higher efficiency if the system runs only in analog dimming mode.

VLDO REGULATOR

Regulated 5V is generated from VIN. It provides power to the internal 5V circuits, an external NFET, and an optional external light sensor (LX1972) or SMBus chip (LX1800). The total maximum output current is limited to 1mA from the VLDO pin. A capacitor must be closely connected across the VLDO pin and GND for noise decoupling and phase compensation. A value of 4.7μF is required. The VLDO Regulator shuts off while the chip is in sleep mode (EN=low) to minimize the sleep mode current. The VLDO output voltage is monitored by the under voltage lockout circuit.

LED CURRENT SINKS

CS1 through CS6 are the LED current sinks. Voltage information on these pins is used to regulate the boost converter output. Boost converter output regulation is based on the lowest CS pin voltage. This regulation scheme insures that the LED string with the largest total V_F has ample headroom for regulation, while maximizing the total efficiency for all other strings. CS pin voltage (at the lowest CS pin) is linearly proportional to CS current. For example, typical V_{CS} will be 800mV at $I_{CS} = 20mA$, and 80mV at $I_{CS} = 2mA$. The LX1996 uses active current sources for the best string current matching between strings. The high impedance outputs have excellent voltage compliances, therefore, V_F matching of the LEDs is less critical. The current sources can be paralleled for higher current rating.

LED current can be set with an external resistor using the following formula:

$$I_{LED} = \frac{V_{PRG}}{R_{PRG}} \times 50$$

V_{PRG} = 2V for either Direct Digital Dimming or Direct Analog Dimming. In combined Analog and Digital Dimming, V_{PRG} = 2V with DI ≥ 2V. When DI < 2V, then V_{PRG} = DI.

DIMMING CONTROL

The LX1996 offers 6 methods of dimming using only 2 pins (See Table 1).

DIRECT DIGITAL DIMMING (PWM)

The LED current source outputs are directly turned on and off by the PWM signal. A high on PWM input pin turns on the output. The current pulse magnitude is independent of PWM duty cycle and is set by the PRG resistor with a fixed 2V reference at the PRG pin.

COMBINED ANALOG AND DIGITAL DIMMING (PWM)

The LED current source outputs are directly turned on and off by the PWM signal. A high on PWM input pin turns on the output. The current pulse magnitude is dependent on the voltage input at the DI pin. Current is set by the PRG resistor, with a reference voltage at the PRG pin that varies with the voltage input at the DI pin in a 1:1 ratio. The minimum and maximum reference voltage at the PRG pin is clamped at 0.2 and 2 Volts, respectively.

ANALOG TO DIGITAL DIMMING

Analog to digital dimming mode converts a DC voltage on the DI input into a PWM output. DI input will be in the range of 0.4 to 2.4V. An internal PWM signal is generated to control the LED output, just as in direct digital dimming. Two external components are required to make this mode work; C_T and R_T. R_T is a reference current setting resistor for the internal dimming oscillator, and the ultrasonic pulse skipping timer. R_T must be a fixed 100kΩ. The internal oscillator frequency is set by the value of the C_T capacitor, and is found by the following equation:

$$F = 5e^{-6}/C_T, C_T \text{ in Farad, F in Hertz.}$$

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 12

OPERATION THEORY

ANALOG TO DIGITAL DIMMING WITH EXTERNAL SYNC

The internal dimming oscillator can be synchronized to an external clock on the PWM input. A PLL loop filter capacitor must be connected between CLF and GND pins for synchronization. Use 0.1uF for 200Hz, 0.001uF for 20KHz. The RT, CT and CLF pins can be left open if both the internal dimming and ultrasonic pulse skipping modes are not used.

DIRECT ANALOG DIMMING

In this mode, a DC voltage on the DI pin is used to vary the reference voltage at the PRG pin. The PRG pin reference voltage, in conjunction with the resistor connected between the PRG pin and ground, sets the LED current. The ratio of DI input voltage to PRG pin voltage is 1:1, up to 2V input. The DI input voltage range is 0V to 5V, however, the voltage at PRG pin is limited to 0.2V to 2V with an internal voltage clamp. Thus the dimming ratio is limited to 10:1. A higher dimming ratio is obtained in the Combined Analog and Digital Dimming mode.

The table below summarizes the dimming modes.

Table 1 - Dimming Modes		
DSEL1	**DSEL2**	**Dimming Method**
Low	Low	Direct Digital Dimming
Low	Hi	Combined Analog and Digital Dimming Modes
Hi	Low	Direct Analog Dimming
Hi	Hi	Direct Analog Dimming with Ultrasonic Pulse Skipping (USPS)
Open	Low	Analog to Digital dimming with internal clock
Open	Hi	Analog to Digital dimming with external clock synchronization.

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 13

OPERATION THEORY

DIGITAL DIMMING MODES OF OPERATION

Direct Digital Dimming

Freq. Range	Controller Performance
PWM 100Hz to 25kHz	• LED current will be turned On/Off directly by PWM. • The maximum LED current is set by a programmable resistor. • Dimming ratio is 10:1 at internal frequency = 25kHz. It will be proportionally higher at lower frequency. The minimum pulse width is 4μsec

Combined Analog and Digital Dimming

Freq. Range	Controller Performance
PWM 100Hz to 25kHz	• Signal into DI pin will be either from an Ambient Light Sensor (ALS) or a variable voltage source, V_{DI} • The LED current is linearly controlled by a programmable resistor and V_{DI} • Valid V_{DI} range is 0.2V to 2.0V • LED current will be turned On/Off directly by PWM. • Dimming ratio is 100:1 at PWM = 25kHz. It will be proportionally higher at lower frequency. The minimum pulse width is 4μsec

ANALOG DIMMING MODES OF OPERATION

Direct Analog Dimming

Freq. Range	Controller Performance
N/A	• Signal into DI pin will be either from Ambient Light Sensor (ALS) or the adjustable voltage source, V_{DI} • The LED current is linearly controlled by a programmable resistor and V_{DI} • Valid V_{DI} range is 0.2V to 2.0V • The Dimming ratio can go up to 10:1.

Direct Analog Dimming with Ultra Sonic Pulse Skipping (USPS)

Freq. Range	Controller Performance
N/A	• Enables USPS in analog dimming mode to reduce boost inductor noise by moving the switching frequency out of the audible range.

Analog to Digital dimming

Freq. Range	Controller Performance
Internal frequency 100Hz – 25kHz	• PWM duty cycle controlled by the signal into the DI pin • Signal into DI pin will be either from an Ambient Light Sensor (ALS) or a variable voltage source, V_{DI} • V_{DI} will be in the range of 0.4V to 2.4V • PWM signal is generated by an internal oscillator. Dimming frequency is set by a capacitor connected to the C_T pin • The maximum LED current is set by a programmable resistor connected to the RPRG pin. • LED current will be turned On/Off directly by the internal PWM. • Dimming ratio is 10:1 at internal frequency = 25kHz. It will be proportionally higher at lower frequency. The minimum pulse width is 4μsec

Analog to Digital dimming with external synchronization clock

Freq. Range	Controller Performance
Internal frequency 100Hz – 25kHz	• PWM duty cycle controlled by the signal into the DI pin • Signal into DI pin will be either from an Ambient Light Sensor (ALS) or a variable voltage source, V_{DI} • V_{DI} will be in the range of 0.4V to 2.4V • PWM signal is generated by an internal oscillator. Dimming frequency is set by a capacitor connected to the C_T pin • The maximum LED current is set by a programmable resistor connected to the RPRG pin. • LED current will be turned On/Off directly by the internal PWM • The internal PWM synchronizes to a clock on the PWM input pin • Dimming ratio is 10:1 at internal frequency = 25kHz. It will be proportionally higher at lower frequency. The minimum pulse width is 4μsec

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 14

OPERATION THEORY

Ultra Sonic Pulse Skipping (USPS)

At low LED current level, the boost frequency may go to audible range. With an USPS option (analog dimming mode only), the audible noise is completely eliminated.

When this mode is enabled, maximum switching interval is limited to 40μS, thus keeping the switching frequency beyond audible range. USPS is an option for analog dimming only.

PROTECTION MODES

THERMAL SHUTDOWN

The LX1996 includes a thermal protection circuit. When the IC senses temperature over +140°C (typ), the LX1996 turns off the LED output current and other circuits. The output recovers when the die temperature drops down to 100°C. The thermal protection does not latch off the IC.

OVER VOLTAGE PROTECTION

A simple resistor divider between the boost output and ground is used to program the LX1996's OVP limit. The over-voltage threshold is set to 2V at the OVP pin. When OVP limit threshold is met, the LX1996 will regulate the boost output to the OVP 2V threshold. OVP limit should be set to a voltage approximately 2 Volts above the maximum total V_F of the individual diode strings.
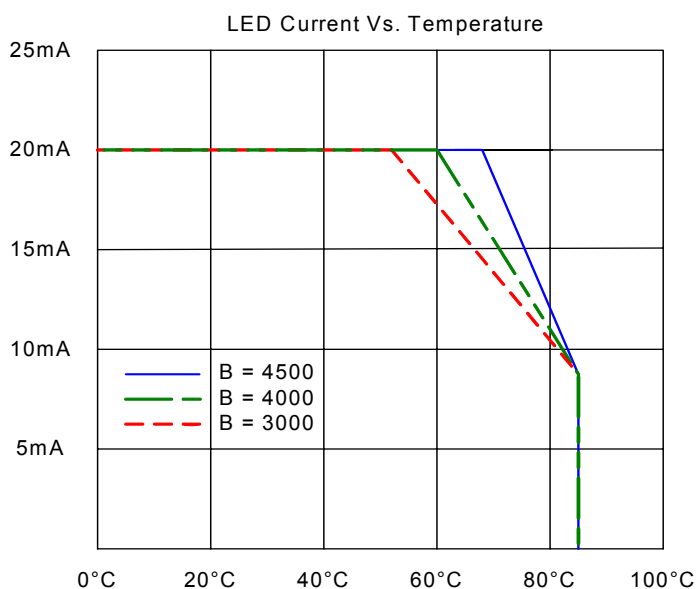
LED OPEN/SHORT PROTECTION

In case of an open string, the open string CS voltage will drop to zero and the boost voltage will rise up to its programmed OVP limit or the CS pin maximum voltage limit. When the boost output reaches the OVP limit or the voltage of any CS pin reaches 25V, the open string is latched off from the regulation loop. At the moment the open string latches off, The boost converter will stop switching until the lowest CS pin voltage gets down to 0.8V. The change in boost output voltage should have no impact to the remaining active LED string currents since they are provided by high impedance current sinks. Once the open condition is corrected, cycling power or the EN input will reset the latched off CS string.

In case of the LED short condition, LX1996 output works normally until the CS voltage rises to 15V (up to four shorted LEDs, typical). When the CS pin voltage reaches 15V, the shorted string is latched off and is disconnected from the boost converter's regulation loop. If the latched off string CS pin voltage reaches 25V, the circuit will hold the CS pin voltage at this level.

LED CURRENT TEMPERATURE PROFILER

For LED Bar temperature sensing, the LED current profiler circuit receives a voltage on the OT pin from the output of a

voltage divider network. This network consists of a thermistor and a bias resistor connected between +5V and GND. The LED current profiler circuit will reduce the LED current setting by reducing the PRG pin voltage. With our recommended external components, derating begins at 60°C (recommended by most LED manufacturers). The LED current will reduce proportional to the temperature, and shut off when the sensing temperature reaches 85°C. The LED current will recover when the sensing temperature drops to 75°C. See example chart below (recovery not shown).

LED Current Vs. Temperature

B = 4500
B = 4000
B = 3000

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 15

APPLICATION INFORMATION

INDUCTOR CURRENT SENSE RESISTOR SELECTION (R_{SRC})

Peak inductor current is determined by the resistor connected between SRC pin and GND, R_{SRC}. It's value is determined by the following equation:

$$IL_{PK} = \frac{112.5mV}{R_{SRC}} + \frac{VCC \times 20ns}{L_{BOOST}} mA$$

Typically, Peak current is determined by the size of the FET desired. Peak current will also determine the amount of energy stored in the inductor during a single switching cycle.

The V_{CS} detect signal is fed into a 4 bit up/down counter to determine the peak current level for each boost condition (V_{IN}, V_{OUT}, and I_{OUT}). There are 15 total current steps available. The DC maximum threshold, V_{SCR}, is equal to 112.5mV, and the constant voltage increment is equal to 112.5mV/15 = 7.5mV.

If we select R_{SRC} = 75mΩ, then step current:

$$I_{STEP.} = 7.5mV/75mΩ = 100mA$$

Maximum inductor peak current:

$$I_{PEAK\ (MAX)} = 100mA\ x\ 15 + 50mA = 1.55A$$
Note: 50mA term is due to propagation delay and is based on 4.7uH inductor and V_{IN} = 12V.

If higher output power is needed, the value of R_{SENSE} must be lowered accordingly. For example: If 50mΩ is used:

Each current step will be:

$$I_{STEP} = 7.5mV/50mΩ = 150mA$$

Maximum inductor peak current:

$$I_{PEAK\ (MAX)} = 150mA\ x\ 15 + 50mA = 2.3A$$

The current sense signal is very sensitive; therefore, the LX1996 SRC pin must be connected directly to the junction of the sense resistor, R_{SRC}, and the NFET Source, as close to R_{SRC} as practical. The return side of the sense resistor must tie directly to the PGND pin, and then tie the PGND pin to the ground plane.

THERMAL PROFILER COMPONENT SELECTION

The following circuit is a typical application using the OT pin for temperature profiling:
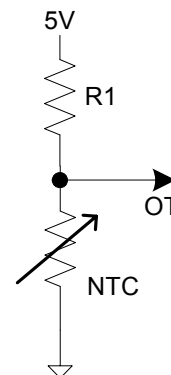
Use NTC thermistor with resistance of 100k at 25°C. B constant can be from 3000 to 4500.
1. Find out the NTC resistance at 85°C ($R85$) by manufacturing chart or formula:

$R=R_0\ expB\ (1/T-1/T_0)$ ····································
R : Resistance in ambient temperature T (K)
(K : absolute temperature)
R_0 : Resistance in ambient temperature T_0 (K)
B : B-constant of Thermistor

2. Calculate R1 value to set the shut off temperature at 85°C by: R1 = 2.4 x $R85$. This will set VOT = 1.47V when NTC is at 85°C.

Thermal profile is set by the internal circuit with the following equation:

$$V_{PRG} = (V_{OT}-0.8)*1.2,\ V_{OT} = (R_{THERM}/(R_{THERM} + R1))*5;$$
Where R_{THERM} is the thermistor resistor

At PRG pin, 2V is the 100% value and 0.8V is the shut off point (40%).

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 16

APPLICATION INFORMATION

BOOST CONVERTER INDUCTOR SELECTION (L_{BOOST})

The LX1996 boost converter operates always in PFM mode, and in conjunction with the current sink circuit to support digital dimming mode with a minimum pulse width of 4μs. Therefore, a boost inductor must be selected to satisfied digital dimming mode minimum pulse width requirements, with enough energy to supply the output during this period.

The LX1996 controls the off time and peak current for hysteretic PFM converter topology. The off time (T_{OFF}) will vary proportionally with input voltage per the following formula:

$$T_{OFF} = 150 + (22 \times V_{IN}) \text{ (nsec)} \qquad (1)$$

And PFM frequency:

$$F_{PFM} = V_{IN}/(V_{OUT} \times T_{OFF}) \text{ (Hz)} \qquad (2)$$

For any instant, the stored energy must be large enough to supply the output load and output capacitor. Therefore:

$$\tfrac{1}{2} L_{MIN} \cdot I^2 F_{PWM} \geq V_{OUT} \times I_{OUT} \qquad (3)$$

From equation 1, 2, and 3, the minimum boost inductor value can be calculated.

With a specified minimum pulse-width of 4μsec, the maximum boost inductor value must allow the inductor to reach the maximum peak current in less than 4μsec. Otherwise, the LED current can not get to the maximum.

$$L_{MAX} = V_{IN} \, dt/di \qquad (4)$$

To calculate the maximum inductor value, V_{IN} will be at minimum, di will be at maximum, and dt is set at 2us which is ½ of the minimum pulse width.

For example:

With 10 white LED in series for 6 strings with I-LED = 20mA, total I_{OUT} = 120mA.

Minimum input voltage is 6V.

Per Nichia $V_{F\,(AVG)}$ = 3.15V, and 3σ = 0.15V, then the worst case for the peak LED voltage is 31.7V. Adding 0.8V for the output diode forward drop, the boost voltage will be:

$$V_{OUT} = 31.7V + 0.8V = 32.5V$$

The maximum peak inductor current is 1.55A with 75mΩ current sense resistor.

Substitute values into equations 1, 2, and 3:

T_{OFF}	=	282nsec
F_{PWM}	=	654.7kHz
L_{MIN}	=	4.96uH

From equation 4, the maximum value of the boost inductor is:

L_{MAX}	=	7.7uH

The inductor value will be in the range of 4.96uH to 7.7uH. Lower inductance provides faster transient response; higher inductance reduces ripple current and improves efficiency. When selecting the inductor, peak current rating, series resistance, and physical size should be all considered. The right candidate for this part is 6.8uH, 1.6A (6x6mm2) from TDK or Coil craft.

OVP SETTING

The worst case for white LED forward voltage V_F = 3.5V. Therefore, the boost voltage that is set for 10 LEDs will be:

$$V_{LED} = 10 \times V_F + 2V = 37V$$

To minimize power loss through the OVP resistor network, select a top resistor R_{TOP} = 1MΩ. The bottom resistor is selected:

$$R_{BOTTOM} = V_{OVP} \times R_{TOP}/(V_{LED} - V_{OVP});$$
$$R_{BOTTOM} = (2 \times 1M\Omega)/(37-2) = 57.1k\Omega$$

Select the closest resistor value: R_{BOTTOM} = 56.2kΩ.

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 17

APPLICATION INFORMATION

OUTPUT CAPACITOR SELECTION

The output capacitor is preferred to be ceramic for low ESR, small size and relatively lower cost. The capacitor value needs to be large enough to minimize the ripple voltage, which is sensed at CS pins for the feedback current sink regulation. For up to 42 LEDs, we recommend a minimum of 4.7uF; for larger number of LEDs, use larger capacitor such as 6.8uF or 10uF.

OUTPUT DIODE SELECTION

A high switching frequency demands a high-speed rectifier. A Schottky diode is recommended with a rating of 1A/60V. 1A rating is more than adequate to meet the peak and average current required. 60V rating is to cover up to OVP limit when using 10LEDs per string.

SWITCHING MOSFET SELECTION

The switching MOSFET should be an N-channel MOSFET with a low RDS_{ON} rated at $V_{GS} = 4.5V$, and a low gate charge. Selection of a FET with the best combined low RDS_{ON} and gate charge (Q_g) will generally improve efficiency. The MOSFET breakdown rating must be higher than the OVP setting.
Good candidates are Si3458DS or AM2358N.

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 18

PCB LAYOUT GUIDE

PCB LAYOUT RECOMMENDATIONS
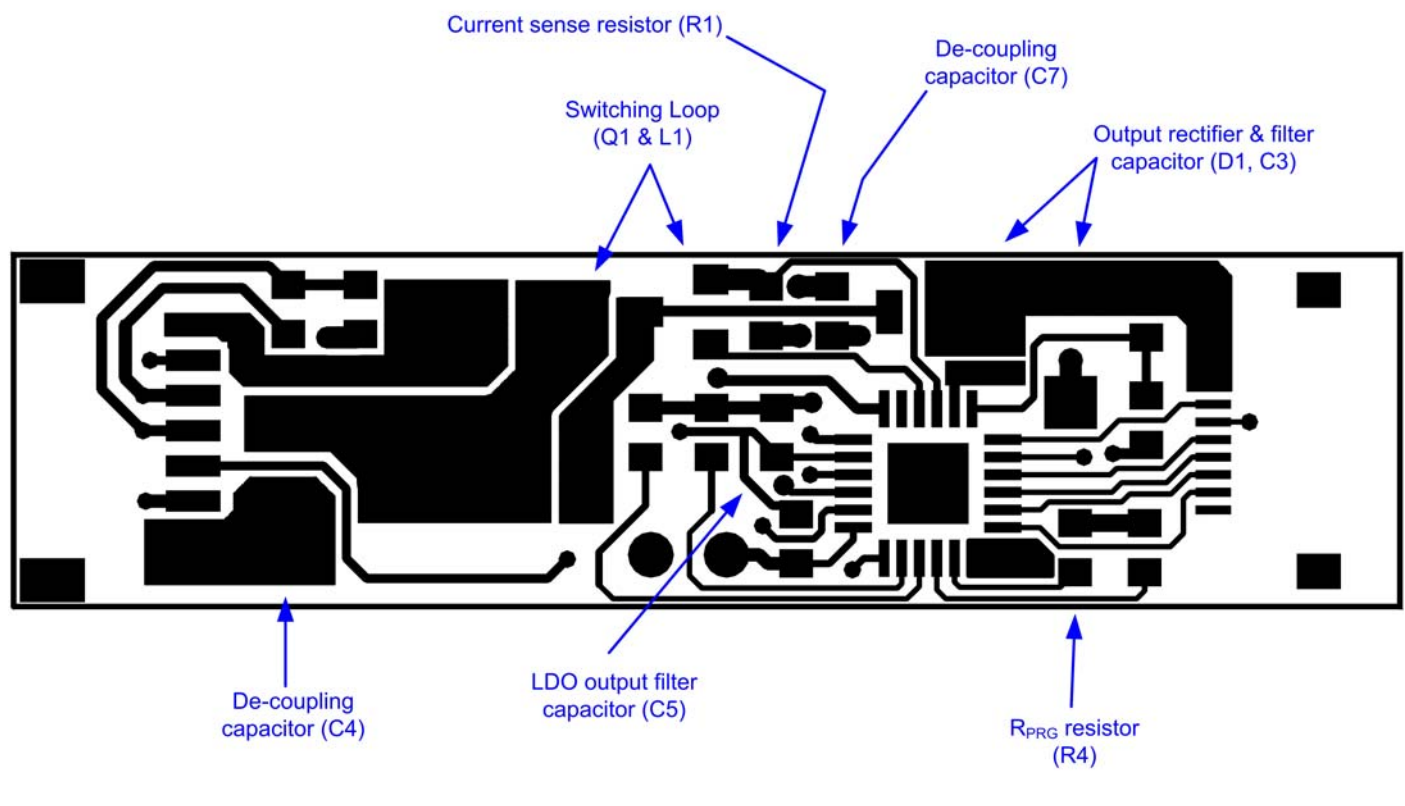**(SEE FIGURE 2 SCHEMATIC)**

It is recommended that decoupling capacitors C7 and C4 be placed as close as possible to the LX1996. The Inductor current sense resistor R1 must tie directly to PGND pin, and then tie to the power ground plane at that pin.

For a good practical layout of switching boost circuit, keep loops as short as possible for the boost switching components (Q1, L1, D1, & C3). Connect a separate signal ground plane to GND pin, a separate power ground plane to PGND pin, and then tie them together at GND pin.

It is important that the LX1996 have a good thermal path to ambient to dissipate heat. The simplest way to do this is to heat sink the LX1996 bottom pad directly to the ground plane by placing 4 or more vias in the ground pad directly under the LX1996 footprint.

Place the LDO filter capacitor (C5), R5 (R_T resistor), C2 (C_T capacitor), C1 (C_{LF} capacitor), and R4 (R_{PRG} resistor) as close to the IC as practical.
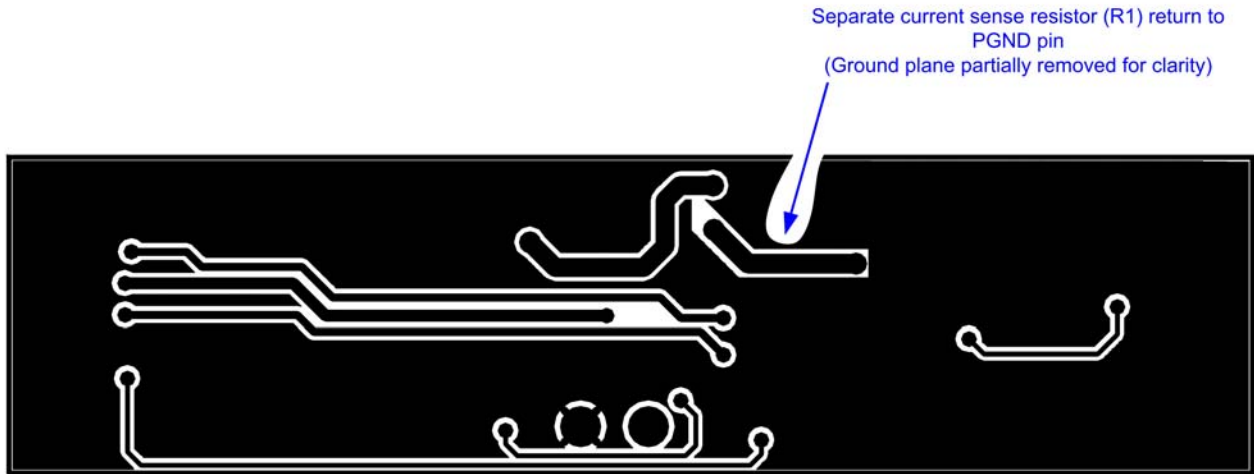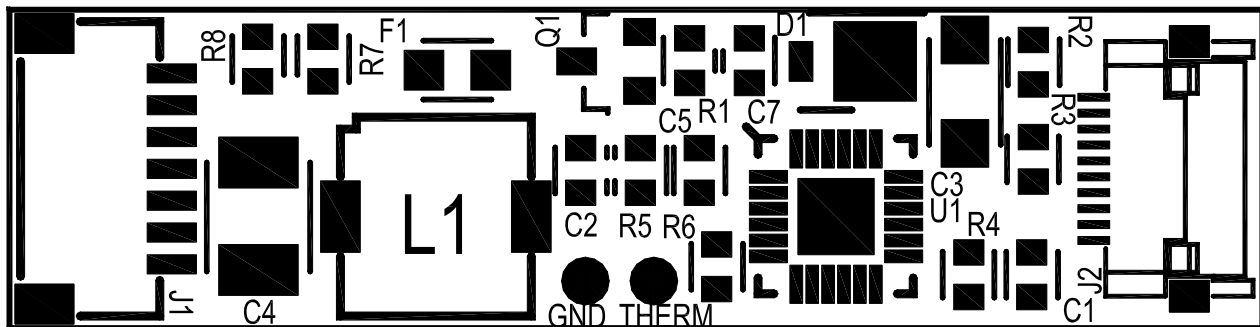
PCB LAYOUT GUIDE – TOP LAYER
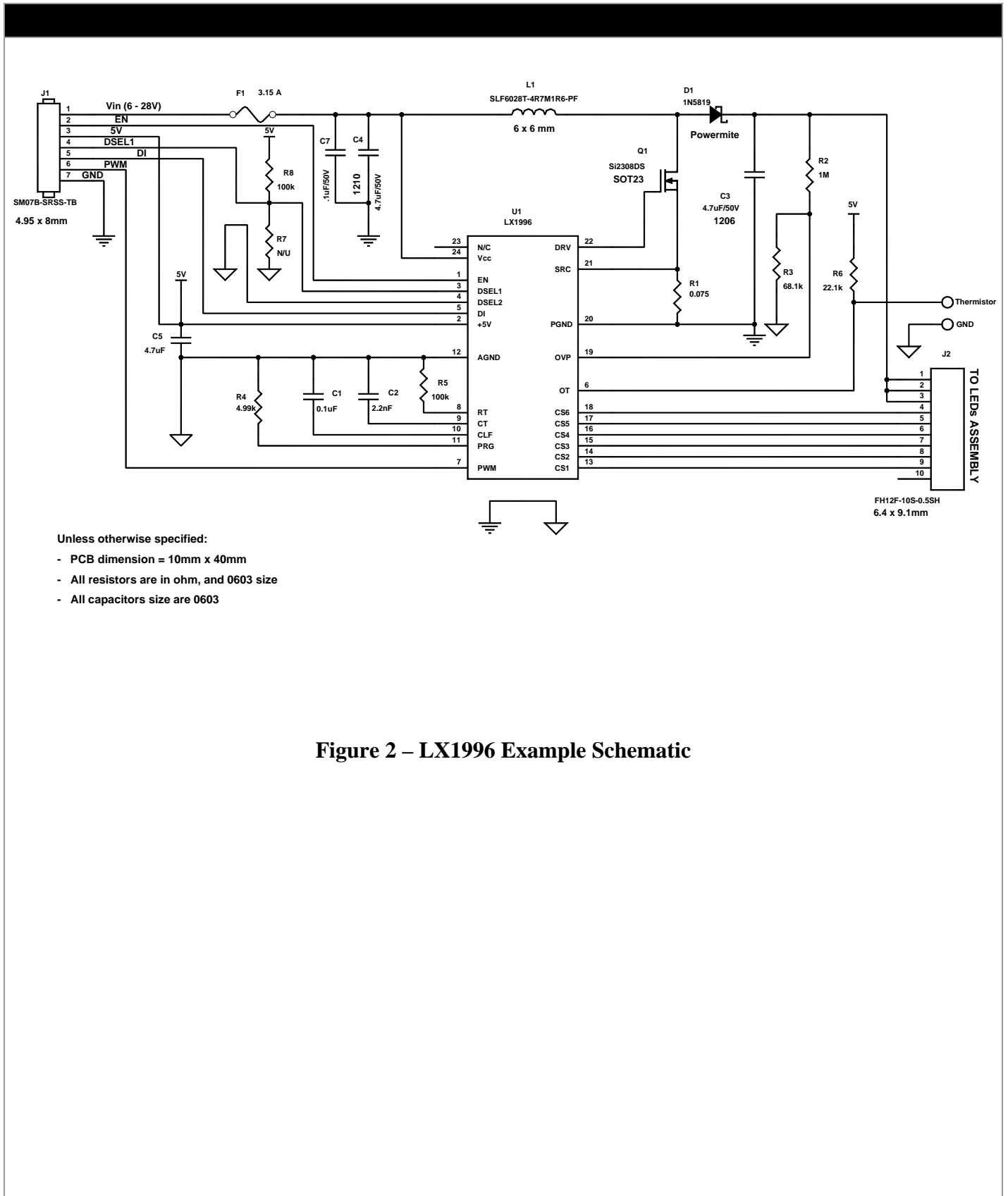

Actual PCB size (H x W): 10mm x 40mm

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 19

PCB LAYOUT GUIDE – BOTTOM LAYER

Separate current sense resistor (R1) return to
PGND pin
(Ground plane partially removed for clarity)

PCB LAYOUT GUIDE – TOP SILKSCREEN

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570
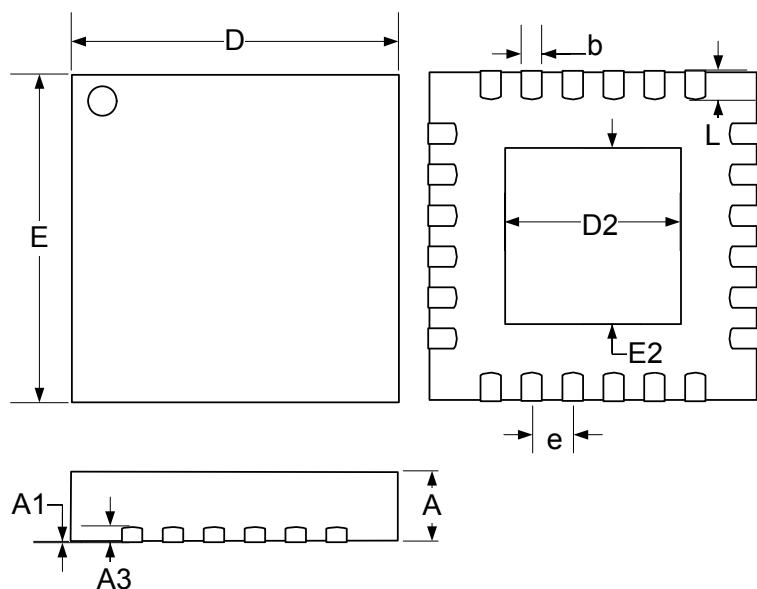
Figure 2 – LX1996 Example Schematic

Unless otherwise specified:

- PCB dimension = 10mm x 40mm
- All resistors are in ohm, and 0603 size
- All capacitors size are 0603

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 21

PACKAGE DIMENSIONS

Dim	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	0.80	1.00	0.031	0.039
A1	0	0.05	0	0.002
A3	0.20 REF		0.008 REF	
b	0.18	0.30	0.007	0.011
D	4.00 BSC		0.157 BSC	
E	4.00 BSC		0.157 BSC	
e	0.50 BSC		0.019 BSC	
D2	2.30	2.55	0.090	0.100
E2	2.30	2.55	0.090	0.100
L	0.30	0.50	0.012	0.020

Notes:
1. Controlled dimensions are in mm, inches are for reference only.
2. Dimensions do not include mold flash or protrusions; these shall not exceed 0.155mm (.006") on any side. Lead dimension shall not include solder coverage.

Copyright © 2007
Rev. 1.0, 2007-12-14

Microsemi
Analog Mixed Signal Group
11861 Western Avenue, Garden Grove, CA. 92841, 714-898-8121, Fax: 714-893-2570

Page 22

www.*Microsemi*.COM

LX1996