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maxim integrated™

MAX8930

WLED Charge Pump, RGB, OLED Boost, LDOs with ALC and CAI

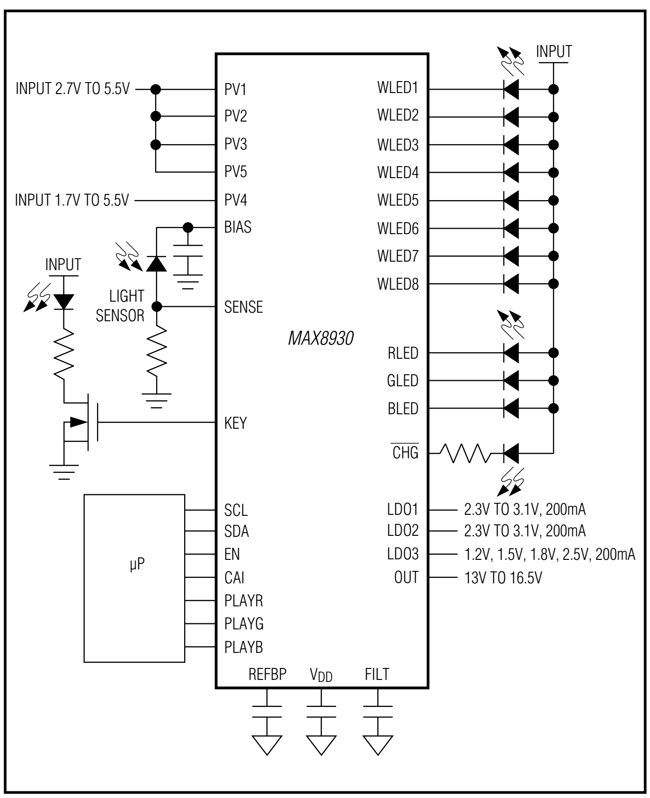
General Description

The MAX8930 integrates a charge pump for white LED display backlighting with ambient light control (ALC) feature. The high-efficiency, adaptive-mode 1x/-0.5x charge pump drives up to 11 LEDs (8 WLEDs + RGB LED) with constant current for uniform brightness. The LED current is adjustable from 0.1mA to 25.6mA in 256 linear steps through I^2C. High accuracy and LED-to-LED current matching are maintained throughout the adjustment range. The MAX8930 includes soft-start, thermal shutdown, open-circuit, and short-circuit protection.

Three 200mA LDOs are provided with programmable output voltages to provide power to external circuitry. These three LDOs can also be configured for a GPO function through the I^2C. A step-up converter is also available on the MAX8930 for biasing a PMOLED subpanel.

The MAX8930 is available in the 49-bump, 3.17mm x 3.17mm WLP package.

Simplified Application Circuit



Features

- ♦ **White LED Charge Pump**
- ♦ **Adaptive 1x or -0.5x Negative Modes**
- ♦ **11 Low-Dropout LED Current Sinks with 25.6mA to 0.1mA in 256 Dimming Steps**
- ♦ **Ramp-Up/Down Control for Main White LED**
- ♦ **Ramp-Up/Down Control for RGB LED**
- ♦ **Individual Brightness Control for Each White, RGB LED**
- ♦ **Low 240µA (typ) Quiescent Current**
- ♦ **Ambient Light Control (ALC) for Any Type of Light Sensor**
- ♦ **Content Adaptive Interface**
- ♦ **I^2C-Compatible Control Interface**
- ♦ **Three Programmable LDOs Up to 200mA**
- ♦ **Step-Up DC-DC Converter with Programmable Output for PMOLED Application**
- ♦ **Low 0.1µA Shutdown Current**
- ♦ **2.7V to 5.5V Supply Voltage Range**
- ♦ **Thermal Shutdown**
- ♦ **Open and Short-Circuit Protection**

Applications

Cell Phones and Smartphones

PDAs, Digital Cameras, Camcorders, and Other Portable Equipment

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX8930EWJ+	-40°C to +85°C	49 WLP 0.4mm pitch

+Denotes a lead(Pb)-free/RoHS-compliant package.

Typical Operating Circuit appears at end of data sheet.

ABSOLUTE MAXIMUM RATINGS

PV_, V_{DD}, EN, CAI, PLAY_, BIAS,
SENSE, REFBP, ECAGND to AGND.................-0.3V to +6.0V
PV_, V_{DD}, PGND_, AGND to NEG ....-0.3V to +6.0V
ECAGND, PGND_ to AGND................................-0.3V to +0.3V
WLED_, RGB_, C1N, C2N,
C1P, C2P to NEG.........-0.3V to (V_{PV1} + V_{PV2} + V_{PV3} + 0.3V)
FILT to AGND .... -0.3V to (V_{PV3} + 0.3V)
SCL, SDA to AGND .... -0.3V to (V_{DD} + 0.3V)
LDO_ to AGND........................... -0.3V to (V_{PV3} + V_{PV4} + 0.3V)
SW to PGND3.. -0.3V to (V_{PV5} + 0.3V)
LX, OUT to PGND3 ....-0.3V to +22V
KEY to AGND ....-0.3V to (V_{PV3} + 0.3V)
Continuous Power Dissipation (T_A = +70°C)
49-Pin WLP 3.17mm x 3.17mm
(derate 20mW/°C above +70°C)...............................1600mW
Operating Temperature Range.......................... -40°C to +85°C
Junction Temperature ....+150°C
Storage Temperature Range........................... -65°C to +150°C
Soldering Temperature (reflow) ....+260°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

($V_{PV\_}$ = V_{EN} = V_{DD} = 3.7V, $V_{PGND\_}$ and V_{AGND} = 0V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
PV1, PV2, PV3, PV5 Operating Voltage			2.7		5.5	V
Undervoltage Lockout Threshold	V_{PV1}, V_{PV2}, V_{PV3}, V_{PV5} rising		2.25	2.45	2.65	V
UVLO Hysteresis				100		mV
PV4 Operating Voltage			1.7		5.5	V
V_{DD} Operating Range	V_{DD} is supply voltage for I²C input block only; all other logic is supplied from PV_		1.7		5.5	V
PV_ Shutdown Supply Current 1 (All Outputs Off, I²C Disabled)	EN = AGND, V_{DD} = 0V	T_A = +25°C		0.1	1	µA
		T_A = +85°C		0.1		
PV_ Shutdown Supply Current 2 (All Outputs Off, I²C Enabled)	V_{DD} = V_{PV3}, EN = AGND	T_A = +25°C		2	10	µA
		T_A = +85°C		2		
V_{DD} Shutdown Threshold	V_{DD} falling, hysteresis = 50mV		1.15	1.4	1.65	V
Supply Current	1x mode, no load, ALC off, step-up off, $I_{LDO\_}$ = 0mA			240	400	µA
	-0.5x mode, 4MHz switching, each $I_{LED\_}$ = 0.1mA, ALC off, I_{LDO} = 0mA, step-up I_o = 0mA at V_{PV3} = 2.7V (Note 2)			6.8		mA
Reference Bypass (REFBP) Output Voltage	0µA ≤ I_{REFBP} ≤ 1µA		1.164	1.200	1.236	V
REFBP Supply Rejection	2.5V ≤ V_{PV3} ≤ 5.5V			0.2	5	mV
Thermal Shutdown				+160		°C
Thermal Shutdown Hysteresis				20		°C

I2C INTERFACE CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
SDA, SCL Input High Voltage	V_{DD} = 1.7V to 5.5V		0.7 x V_{DD}			V
SDA, SCL Input Low Voltage	V_{DD} = 1.7V to 5.5V				0.3 x V_{DD}	V
SDA, SCL Input Current	V_{IL} = 0V or V_{IH} = 5.5V, V_{DD} = 5.5V	T_A = +25°C		0.01	1	µA
		T_A = +85°C		0.1		
SDA Output Low Voltage	I_{SDA} = 3mA, for acknowledge (Note 3)			0.03	0.4	V
Clock Frequency	(Note 3)		100		400	kHz
Bus-Free Time Between START and STOP	t_{BUF} (Note 3)		1.3			µs
Hold Time Repeated START Condition	$t_{HD,STA}$ (Note 3)		0.6	0.1		µs
SCL Low Period	t_{LOW} (Note 3)		1.3	0.2		µs
SCL High Period	t_{HIGH} (Note 3)		0.6	0.2		µs
Setup Time Repeated START Condition	$t_{SU,STA}$ (Note 3)		0.6	0.1		µs
SDA Hold Time	$t_{HD,DAT}$ (Note 3)		0	0.01		µs
SDA Setup Time	$t_{SU,DAT}$ (Note 3)		100	50		ns
Setup Time for STOP Condition	$t_{SU,STO}$ (Note 3)		0.6	0.1		µs

CHARGE PUMP CHARACTERISTICS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Switching Frequency			4		MHz
Pump Soft-Start Time			0.5		ms
Charge-Pump Regulation Voltage (and OVP)	V_{PV1}, V_{PV2} - V_{NEG}	4.3	5		V
Open-Loop NEG Output Resistance	(0.5 x (V_{PV1} or V_{PV2}) - V_{NEG})/I_{NEG}		1.3	2.49	Ω
Guaranteed Output Current	LED V_{FMAX} = 3.9V, V_{PV1} = V_{PV2} = 3.2V	281			mA
NEG Discharge Resistance in Shutdown	All LEDs off		10		kΩ

CURRENT SINK DRIVER CHARACTERISTICS

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
Current Setting Range	WLED1–WLED8, RGB programmable by I^2C			0.1		25.6	mA
WLED_, RGB Ramp-Up/Ramp-Down Time	Main WLED_ and RGB ramp-up/ramp-down in 0.1mA increments; 8 steps are programmable through I^2C; ramp-up and ramp-down times are set separately				0 (default)		ms/ 0.1mA
					0.016		
					0.064		
					0.128		
					0.256		
					0.512		
					1.024		
					2.048		
WLED_, RGB Current Accuracy	25.6mA setting, T_A = +25°C			-2.5		+2.5	%
	0.1mA setting, T_A = +25°C			-50	±10	+50	
WLED_, RGB Current Matching	WLED1–WLED8, RGB (Note 4)				5	10	%
WLED_, RGB R_{DSON}	1x mode				2.68		Ω
	-0.5x mode				4.12		
WLED_, RGB Current Regulator Dropout Voltage	25.6mA setting (Note 5)	1x mode	T_A = 0°C to +85°C		62	120	mV
			T_A = -40°C		62	150	
		-0.5x mode			95	200	
WLED_, RGB Current Regulator Switchover Threshold (1x to -0.5x)	V_{LED} falling			125	150	175	mV
WLED_, RGB Current Regulator Switchover Hysteresis					100		mV
WLED_, RGB Leakage in Shutdown	All LEDs off	T_A = +25°C			0.01	5	µA
		T_A = +85°C			0.1		

LDO1 CHARACTERISTICS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage V_{LDO1} (Default)	200mA at V_{PV3} = 3.6V	2.522	2.6	2.678	V
Programmable Output Voltage	I_{LDO1} = 50mA	2.231	2.3	2.369	V
		2.425	2.5	2.575	
		2.522	2.6	2.678	
		2.619	2.7	2.781	
		2.716	2.8	2.884	
		2.813	2.9	2.987	
		2.910	3.0	3.090	
		3.007	3.1	3.193	
Output Current		200			mA
Current Limit	V_{LDO1} = 90% of nominal regulation voltage (Note 3)	250	475	750	mA
Dropout Voltage	I_{LDO1} = 200mA, T_A = +25°C		120	300	mV
Line Regulation	3.4V ≤ $V_{PV3\_}$ ≤ 5.5V, I_{LDO1} = 150mA		2.4		mV
Load Regulation	1mA < I_{LDO1} < 200mA		25		mV

LDO1 CHARACTERISTICS (continued)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Power-Supply Rejection $\Delta V_{LDO1}/\Delta V_{PV3}$	f = 10Hz to 10kHz, I_{LDO1} = 10mA, C_{LDO1} = 1µF		60		dB
Output Noise Voltage (RMS)	f = 100Hz to 100kHz, I_{LDO1} = 10mA, C_{LDO1} = 1µF		45		$µV_{RMS}$
Minimum Output Capacitor	I_{LDO1} < 200mA		1		µF
Startup Time from Shutdown	I_{LDO1} = 150mA (Note 3)		40	100	µs
Startup Transient Overshoot	I_{LDO1} = 150mA (Note 3)		3	50	mV
Shutdown Output Impedance	LDO1 disabled through I^2C (default on)		1		kΩ

LDO2 CHARACTERISTICS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage V_{LDO2} (Default)	200mA at V_{PV3} = 3.6V	2.813	2.9	2.987	V
Programmable Output Voltage	I_{LDO2} = 50mA	2.231	2.3	2.369	V
		2.425	2.5	2.575	
		2.522	2.6	2.678	
		2.619	2.7	2.781	
		2.716	2.8	2.884	
		2.813	2.9	2.987	
		2.910	3.0	3.090	
		3.007	3.1	3.193	
Output Current		200			mA
Current Limit	V_{LDO2} = 90% of nominal regulation voltage (Note 4)	250	475	750	mA
Dropout Voltage	I_{LDO2} = 200mA, T_A = +25°C		120	300	mV
Line Regulation	3.4V ≤ $V_{PV3\_}$ ≤ 5.5V, I_{LDO2} = 150mA		2.4		mV
Load Regulation	1mA < I_{LDO2} < 200mA		25		mV
Power-Supply Rejection $\Delta V_{LDO2}/\Delta V_{PV3}$	f = 10Hz to 10kHz, I_{LDO2} = 10mA, C_{LDO2} = 1µF		60		dB
Output Noise Voltage (RMS)	f = 100Hz to 100kHz, I_{LDO2} = 10mA, C_{LDO2} = 1µF		45		$µV_{RMS}$
Minimum Output Capacitor	I_{LDO2} < 200mA		1		µF
Startup Time from Shutdown	I_{LDO2} = 150mA (Note 3)		40	100	µs
Startup Transient Overshoot	I_{LDO2} = 150mA (Note 3)		3	50	mV
Shutdown Output Impedance	LDO2 disabled through I^2C (default on)		1		kΩ

LDO3 CHARACTERISTICS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Operating Range	V_{PV4}	1.7		5.5	V
Output Voltage V_{LDO3}	200mA at V_{PV4} = 2.4V	1.764	1.80	1.854	V
Programmable Output Voltage	V_{PV4} = 1.8V, I_{LDO3} = 50mA	1.164	1.2	1.236	V
		1.455	1.5	1.545	
	V_{PV4} = 3.7V, I_{LDO3} = 50mA	1.764	1.80	1.854	
		2.425	2.5	2.575	
Output Current				200	mA
Current Limit	V_{LDO3} = 90% of nominal regulation voltage (Note 4)	250	475	750	mA
Dropout Voltage	I_{LDO3} = 200mA, T_A = +25°C		120	300	mV
Line Regulation	2.4V ≤ V_{PV4} ≤ 5.5V, I_{LDO3} = 150mA		2.4		mV
Load Regulation	1mA < I_{LDO3} < 200mA		25		mV
Power-Supply Rejection $\Delta V_{LDO3}/\Delta V_{PV4}$	f = 10Hz to 10kHz, I_{LDO3} = 10mA, C_{LDO3} = 2.2µF		60		dB
Output Noise Voltage (RMS)	f = 100Hz to 100kHz, I_{LDO3} = 10mA, C_{LDO3} = 2.2µF		75		$µV_{RMS}$
Minimum Output Capacitor	0µA < I_{LDO3} < 200mA (Note 3)	2.2			µF
Startup Time from Shutdown	I_{LDO3} = 150mA (Note 3)		100	250	µs
Startup Transient Overshoot	I_{LDO3} = 150mA (Note 3)		3	50	mV
Shutdown Output Impedance	LDO3 disabled through I^2C (default on)		1		kΩ

STEP-UP CONVERTER CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Input Operating Range	V_{PV5}		2.7		5.5	V
Line Regulation	V_{OUT} = 14V, I_{OUT} = 5mA, V_{PV5} = 2.7V to 5.5V			0.1		%/V
Load Regulation	V_{OUT} = 14V, I_{OUT} = 0mA to 5mA, V_{PV5} = 3.7V			0.1		%/mA
LX Voltage Range					20	V
LX Switch Current Limit			192	241	289	mA
LX Leakage Current	V_{LX} = 20V, step-up converter disabled	T_A = +25°C		0.01	2	µA
		T_A = +85°C		0.1		
Isolation pMOS $R_{DS(ON)}$	V_{PV5} = 2.7V, I_{SW} = 100mA			1.5	2.4	Ω
pMOS Rectifier $R_{DS(ON)}$	LX to OUT, V_{PV5} = 3.7V, I_{LX} = 100mA			4.0		Ω
Isolation pMOS Current Limit	V_{PV5} = 3.7V, V_{SW} = 0V		0.15	0.3	0.6	A
Isolation pMOS Leakage Current	SW = PGND3, V_{PV5} = 5.5V	T_A = +25°C		0.01	1	µA
		T_A = +85°C		0.1		
SW Soft-Start Time	V_{PV5} = 2.7V			0.2		ms
nMOS $R_{DS(ON)}$	V_{PV5} = 3.7V, I_{LX} = 100mA			0.9	1.5	Ω
Maximum LX On-Time			8	11	14	µs
Minimum LX Off-Time	V_{OUT} > 12V		1.6	2	2.4	µs
OVP Threshold	No feedback, V_{OUT} rising		17.6	18.5	19.4	V
OVP Threshold Hysteresis				1		V

STEP-UP CONVERTER CHARACTERISTICS (continued)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Current Limit Propagation Delay (LX)				55		ns
Output Voltage Accuracy	V_{PV5} = 3.7V, I_{OUT} = 0mA	T_A = 0°C to +85°C	-2		+2	%
		T_A = -40°C	-2.5		+2.5	
Programmable Output Voltage	V_{PV5} = 3.7V, I_{OUT} = 0mA			13.0		V
				13.5		
				14.0		
				14.5		
				15.0		
				15.5		
				16.0		
				16.5		

AMBIENT LIGHT SENSOR INTERFACE

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
BIAS Output Voltage	I_{BAIS} = 200µA, V_{PV3} = 3.2V to 5.5V		2.85	3.0	3.15	V
BIAS Output Current	V_{BIAS} = 3.0V ±5%				30	mA
BIAS Dropout Voltage	I_{BIAS} = 10mA (Note 3)			125	250	mV
SENSE Input Voltage Range			0		V_{BIAS} x 255/256	V
BIAS Discharge Resistance in Shutdown				1.0	1.5	kΩ
ADC Resolution				8		Bit
ADC Integral Nonlinearity Error			-3		+3	LSB
ADC Differential Nonlinearity Error			-1		+1	LSB
SENSE Input Impedance	T_A = +25°C (Note 3)		1			MΩ
Waiting Time for ADC Movement After ALCEN = 1	V_{BIAS} = 3V	Bit 0 = 0 in 02h register		32		ms
		Bit = 1 in 02h register		64 (default)		ms

KEY CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Low-Level Output Voltage	I_{SINK} = 1mA				0.4	V
High-Level Output Voltage	I_{SOURCE} = 1mA		1.8			V
nMOS Output Leakage Current	At complementary output, V_{PV3} = 3.7V (Note 6)	T_A = +25°C		0.01	1	µA
		T_A = +85°C		0.1		
pMOS Output Leakage Current	At complementary output, V_{PV3} = 3.7V (Note 6)	T_A = +25°C		0.01	1	µA
		T_A = +85°C		0.1		

CAI CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
PWM Low-Level Input Voltage					0.4	V
PWM High-Level Input Voltage			1.4			V
PWM Dimming Frequency	C_{FILT} = 0.1µF (Note 3)		0.1	0.2	15	kHz
Current Dimming Range	Duty cycle = 0% to 100% (Note 3)		0		25.6	mA
PWM Dimming Resolution	1% ≤ duty cycle ≤ 100% (Note 3)			0.256		mA/%
CAI Enable Blanking Time (t_B)	Time from CAI enable until dimming control switches to CAI input (Note 4)			10		ms
Input Leakage Current	CAI = GND or V_{CAI} = 3.7V	T_A = +25°C		0.1	1	µA
		T_A = +85°C		1		

GPO (OPEN-DRAIN OUTPUT) CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Low-Level Output Voltage	I_{SINK} = 1mA				0.2	V
Output Leakage Current	$V_{LDO\_\_}$ = 2.6V	T_A = +25°C		0.1		µA
		T_A = +85°C		1		

EN CHARACTERISTICS

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Low-Level Input Voltage					0.4	V
High-Level Input Voltage			1.4			V
Input Leakage Current	V_{EN} = 0V or 3.7V	T_A = +25°C		0.1	1	µA
		T_A = +85°C		1		

PLAYR/PLAYG/PLAYB CHARACTERISTICS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Low-Level Input Voltage				0.4	V
High-Level Input Voltage		1.4			V
ON/OFF PWM Frequency	(Note 3)	2		200	Hz
PLAY_ Minimum High Time	PLAY_ active high (Bit 1 = low in Register 20h) (Note 3)	80			µs
PLAY_ Minimum Low Time	PLAY_ active low (Bit 1= high in Register 20h) (Note 3)	80			µs
Pulldown Resistor to AGND			800		kΩ

$\overline{CHG}$ PIN CHARACTERISTICS

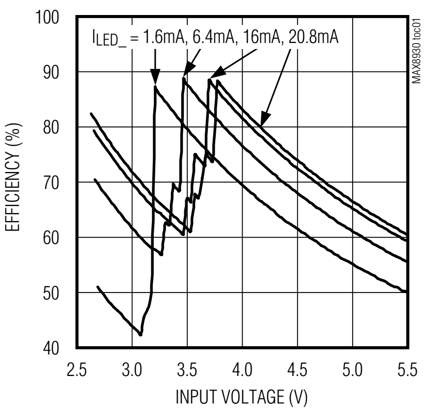
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Low-Level Voltage	$I_{\overline{CHG}}$ = 5mA			0.05	0.2	V
Leakage Current	$V_{\overline{CHG}}$ = 3.7V	T_A = +25°C		0.1	1	µA
		T_A = +85°C		1		

Note 1: Limits are 100% production tested at T_A = +25°C. Limits over the operating temperature range are guaranteed by design.
Note 2: 0.1mA LED load current is not included.
Note 3: Guaranteed by design. Not production tested.
Note 4: LED current matching is defined as: (I_{MAX} - I_{MAX})/25.6mA. Matching is for LEDs within the RGB group (RLED, GLED, BLED) or the white LED group (WLED1–WLED8).
Note 5: Dropout voltage is defined as the LED_ to AGND voltage at which current into LED_ drops 10% from the value at $V_{LED\_}$ = 0.5V at 1x mode.
Note 6: V_{KEY} = 0V when pulling low, leakage current from PV3. V_{KEY} = 3.7V when pulling high, leakage current is to GND.

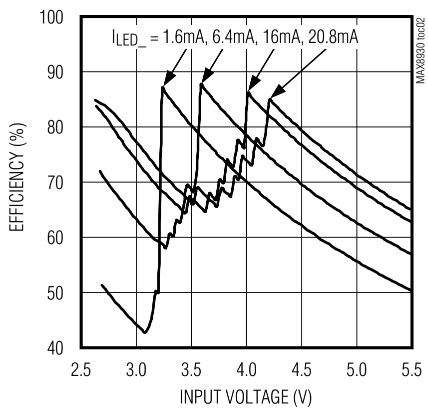
Typical Operating Characteristics

($V_{PV\_}$ = V_{EN} = 3.7V, circuit of Figure 1, T_A = +25°C, unless otherwise noted.)

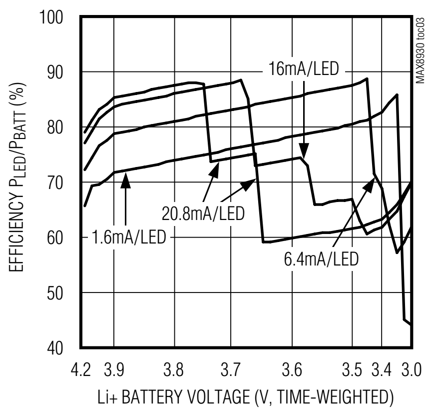
WLED EFFICIENCY vs. INPUT VOLTAGE, 6 MATCHED WLEDS



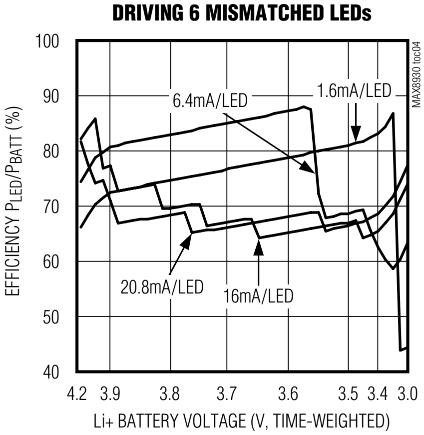
WLED EFFICIENCY vs. INPUT VOLTAGE, 6 MISMATCHED WLEDS



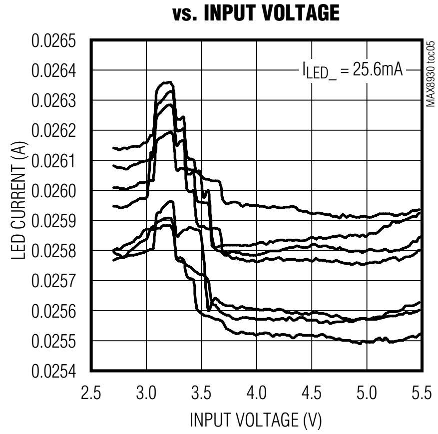
EFFICIENCY vs. Li+ BATTERY VOLTAGE DRIVING 6 MATCHED LEDs



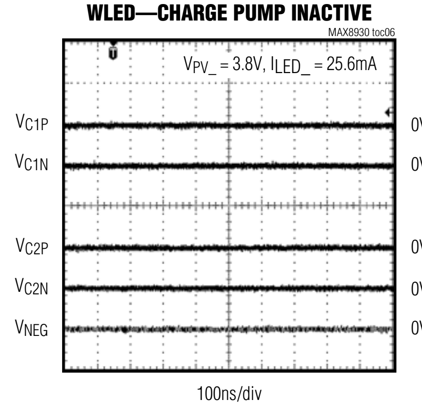
EFFICIENCY vs. Li+ BATTERY VOLTAGE DRIVING 6 MISMATCHED LEDs



WLED CURRENT MATCHING vs. INPUT VOLTAGE



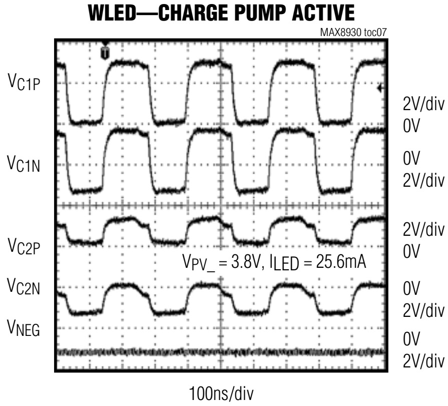
WLED—CHARGE PUMP INACTIVE



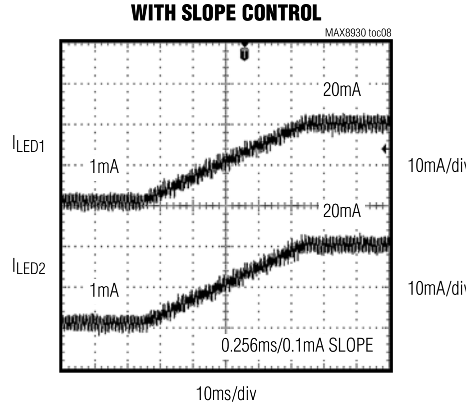
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

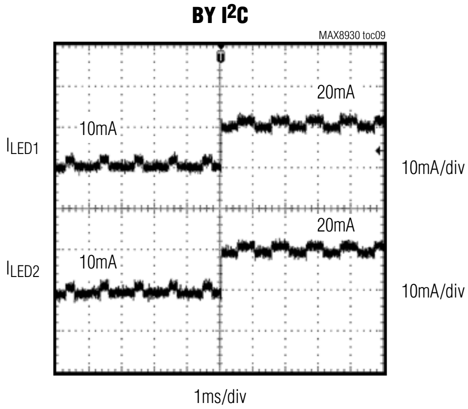
WLED—CHARGE PUMP ACTIVE



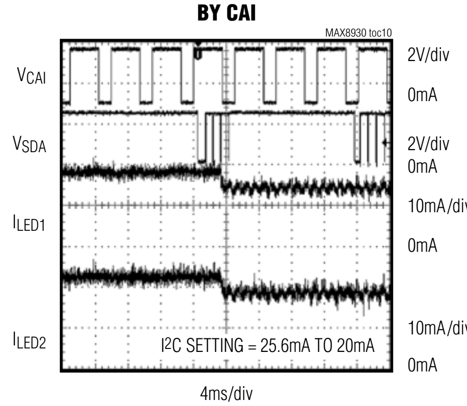
WLED—DIMMING CURRENT TRANSIENT WITH SLOPE CONTROL



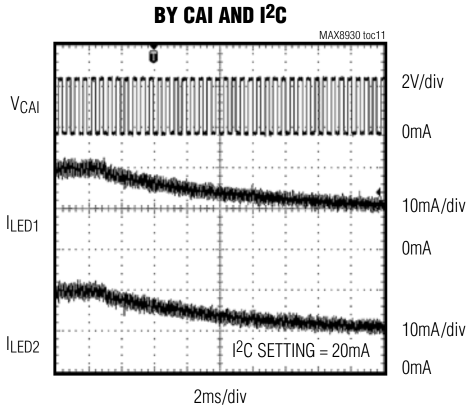
WLED—DIMMING CURRENT TRANSIENT BY I2C



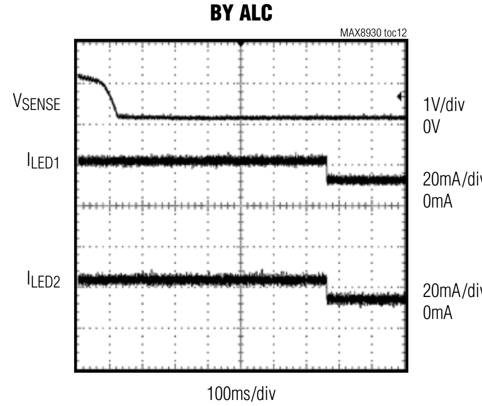
WLED—DIMMING CURRENT TRANSIENT BY CAI



WLED—DIMMING CURRENT TRANSIENT BY CAI AND I2C



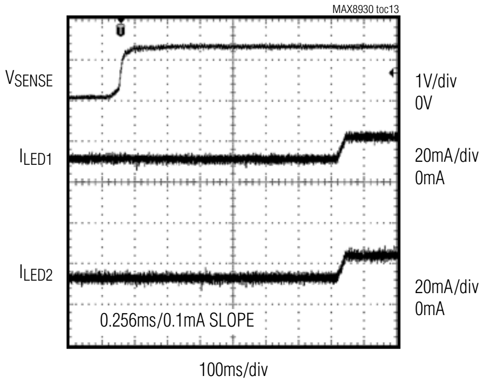
WLED—DIMMING CURRENT TRANSIENT BY ALC



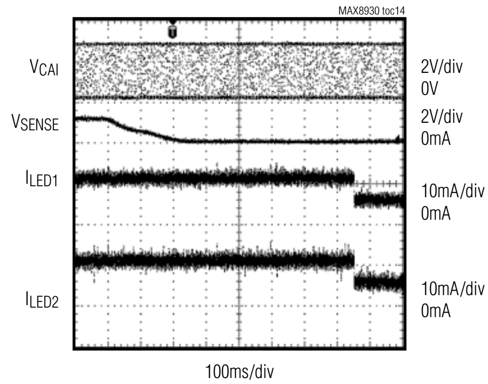
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

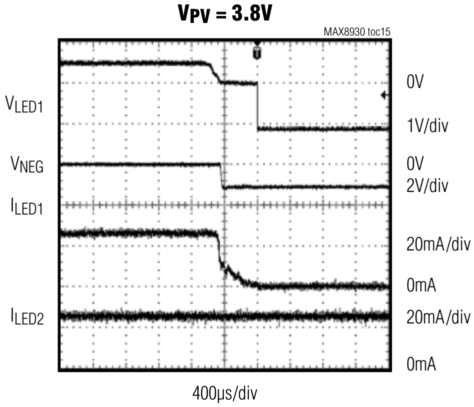
WLED—DIMMING CURRENT TRANSIENT BY ALC WITH SLOPE CONTROL



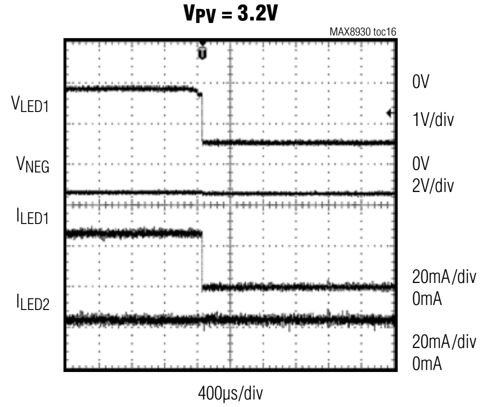
WLED—DIMMING CURRENT TRANSIENT BY ALC AND CAI



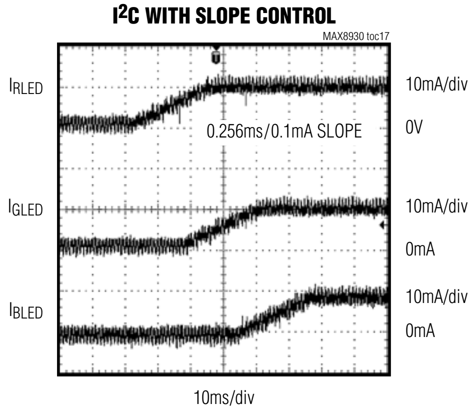
WLED—LED1 OPEN CIRCUIT, $V_{PV} = 3.8V$



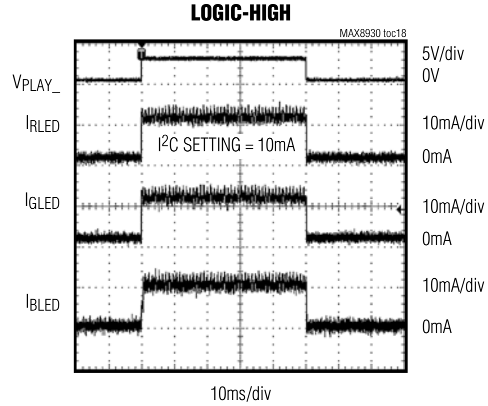
WLED—LED1 OPEN CIRCUIT, $V_{PV} = 3.2V$



RGB—CURRENT TRANSIENT BY I^2C WITH SLOPE CONTROL



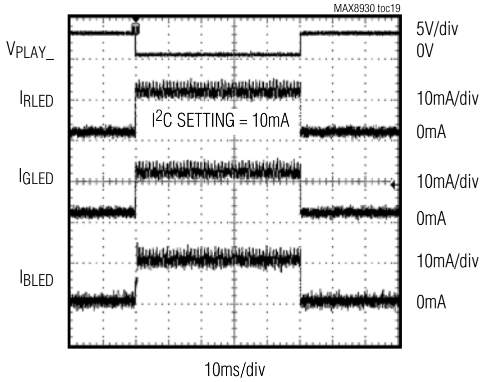
RGB—PLAY_ ON/OFF TRANSITION, LOGIC-HIGH



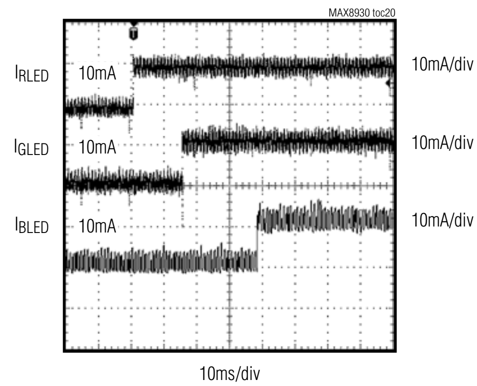
Typical Operating Characteristics (continued)

($V_{PV\_}$ = V_{EN} = 3.7V, circuit of Figure 1, T_A = +25°C, unless otherwise noted.)

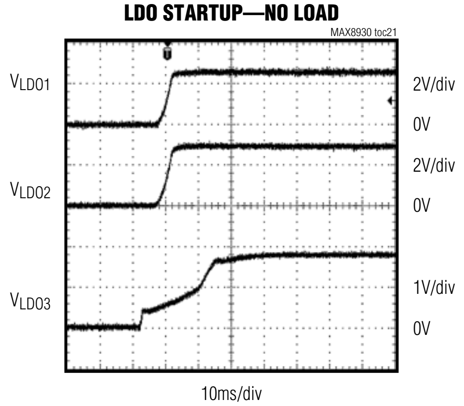
RGB—PLAY_ ON/OFF TRANSITION, LOGIC-LOW



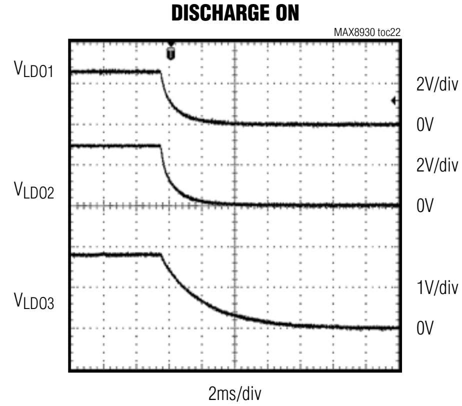
RGB—PLAY_ ON/OFF TRANSITION AND I2C COMING



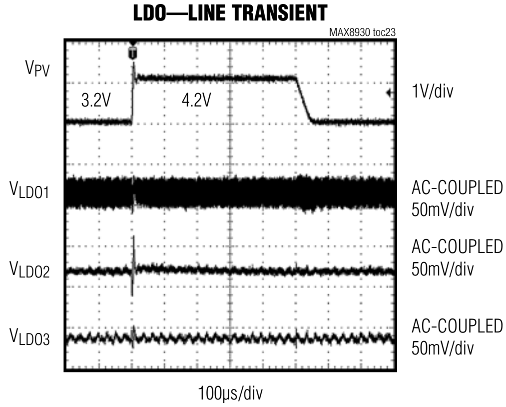
LDO STARTUP—NO LOAD



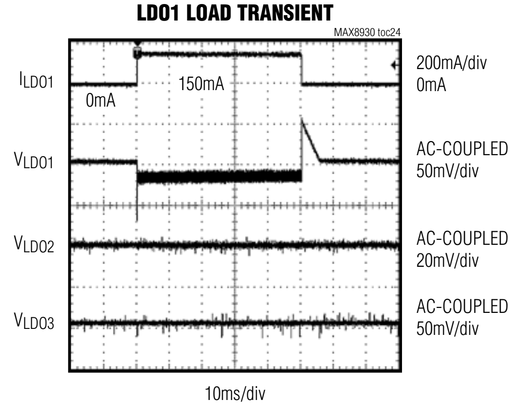
LDO SHUTDOWN—DEFAULT ACTIVE DISCHARGE ON



LDO—LINE TRANSIENT



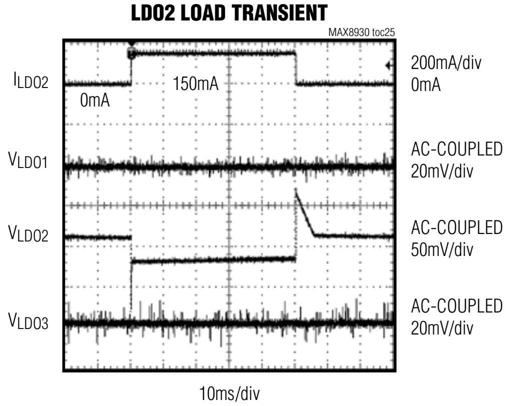
LDO1 LOAD TRANSIENT



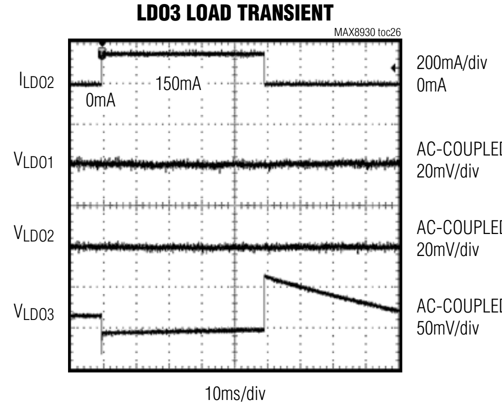
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

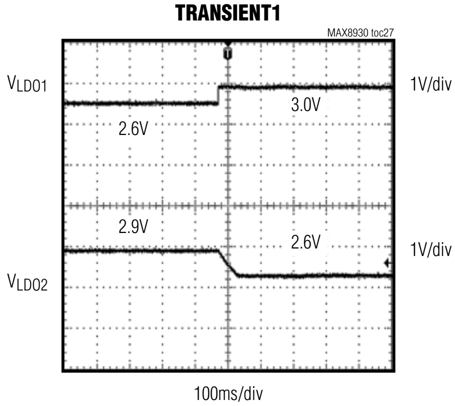
LDO2 LOAD TRANSIENT



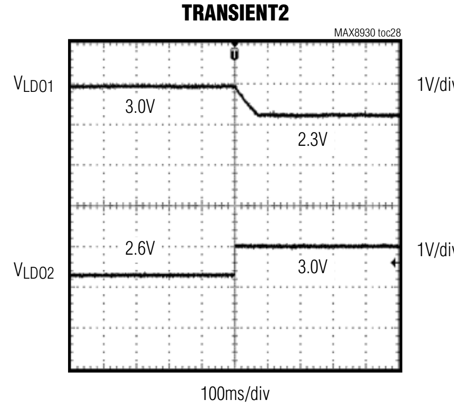
LDO3 LOAD TRANSIENT



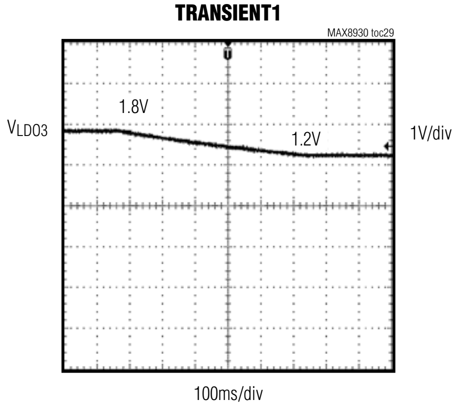
LDO1 AND LDO2—OUTPUT VOLTAGE TRANSIENT1



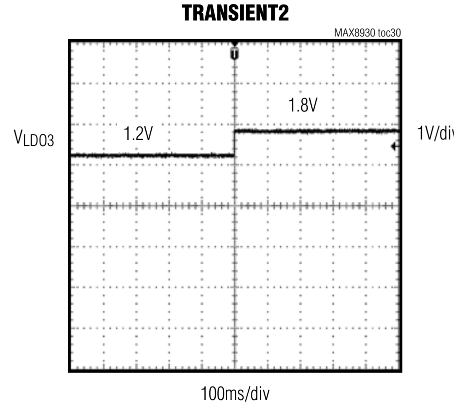
LDO1 AND LDO2—OUTPUT VOLTAGE TRANSIENT2



LDO3—OUTPUT VOLTAGE TRANSIENT1



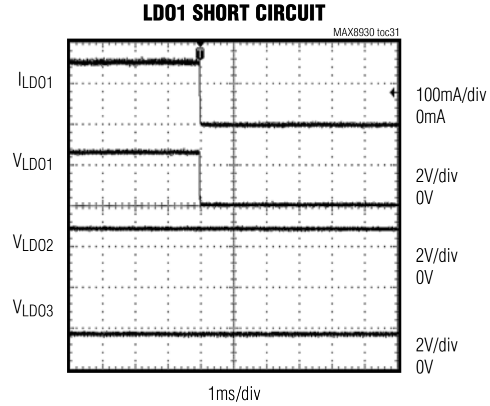
LDO3—OUTPUT VOLTAGE TRANSIENT2



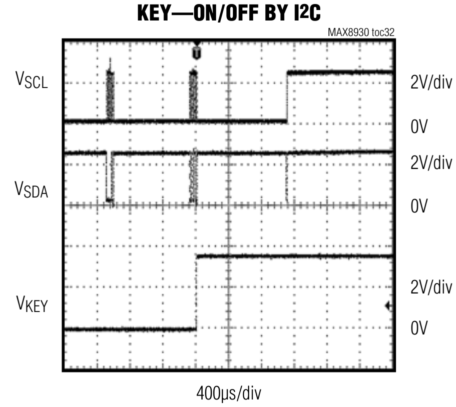
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

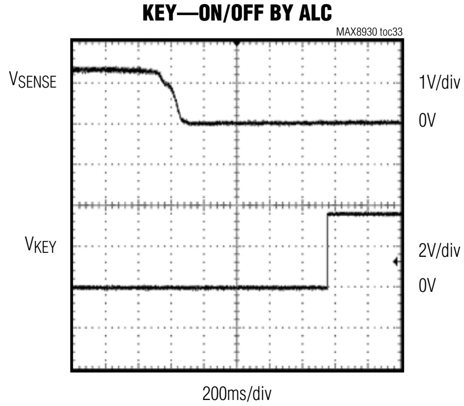
LDO1 SHORT CIRCUIT



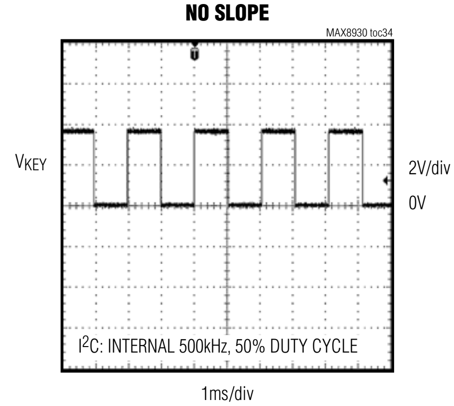
KEY—ON/OFF BY I2C



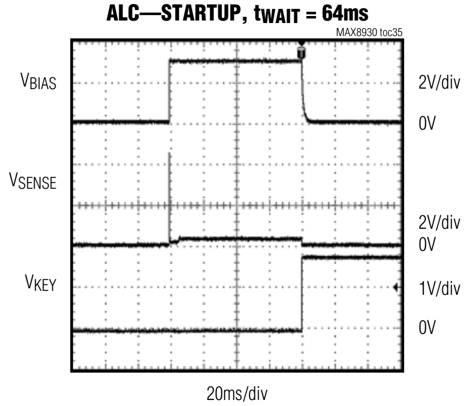
KEY—ON/OFF BY ALC



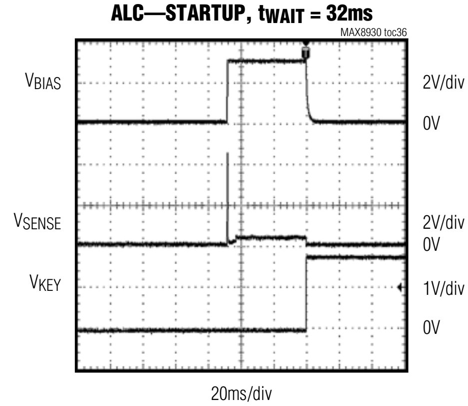
KEY—ON/OFF BY INTERNAL PWM, NO SLOPE



ALC—STARTUP, t_{WAIT} = 64ms



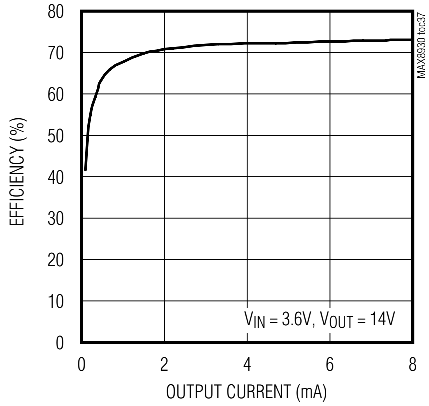
ALC—STARTUP, t_{WAIT} = 32ms



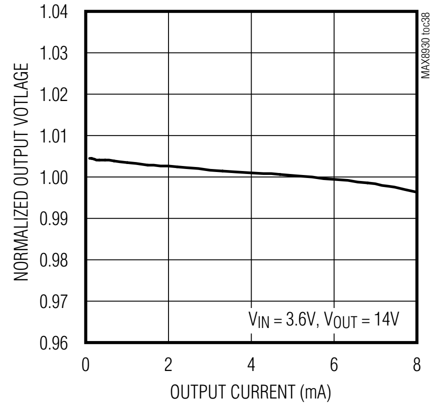
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

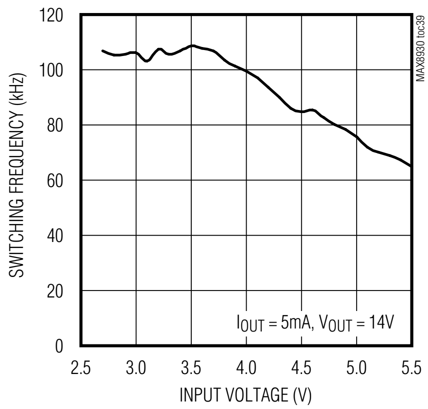
STEP-UP EFFICIENCY vs. LOAD CURRENT



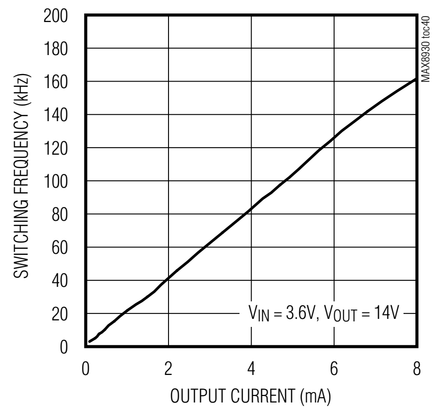
STEP-UP LOAD REGULATION vs. OUTPUT CURRENT



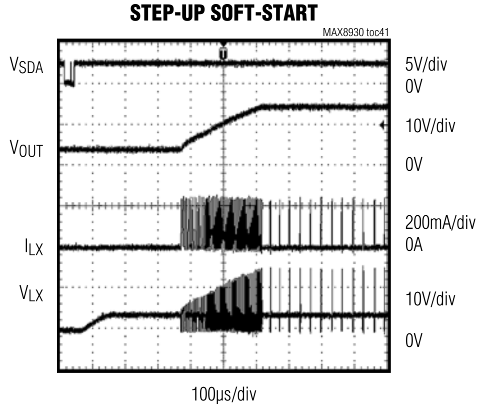
STEP-UP SWITCHING FREQUENCY vs. INPUT VOLTAGE



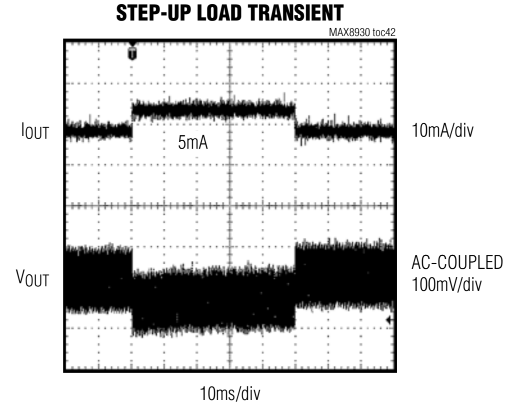
STEP-UP SWITCHING FREQUENCY vs OUTPUT CURRENT



STEP-UP SOFT-START



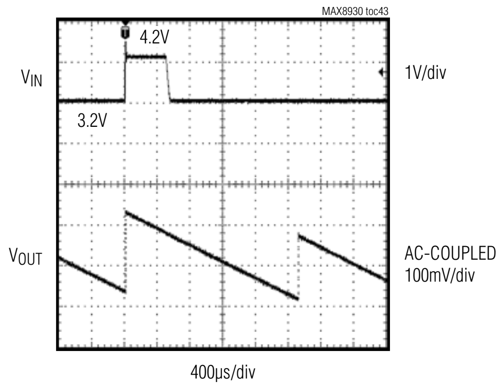
STEP-UP LOAD TRANSIENT



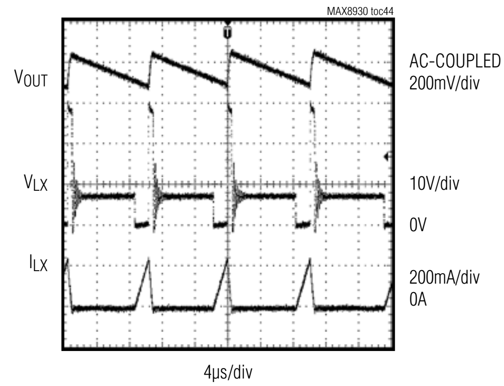
Typical Operating Characteristics (continued)

($V_{PV\_} = V_{EN} = 3.7V$, circuit of Figure 1, $T_A = +25°C$, unless otherwise noted.)

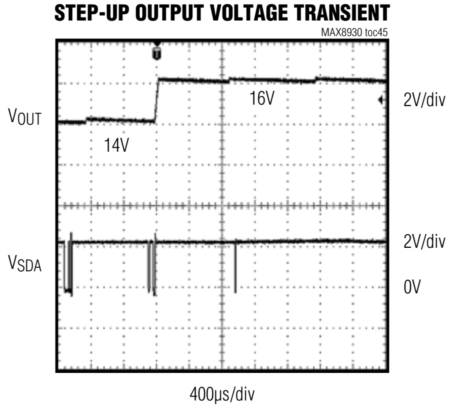
STEP-UP LINE TRANSIENT



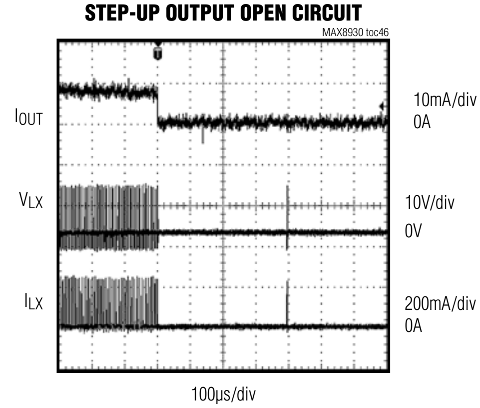
STEP-UP SWITCHING WAVEFORMS



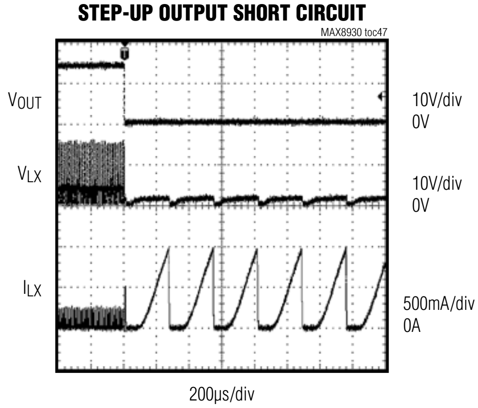
STEP-UP OUTPUT VOLTAGE TRANSIENT



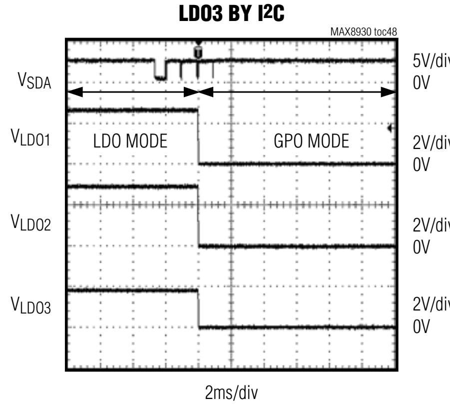
STEP-UP OUTPUT OPEN CIRCUIT



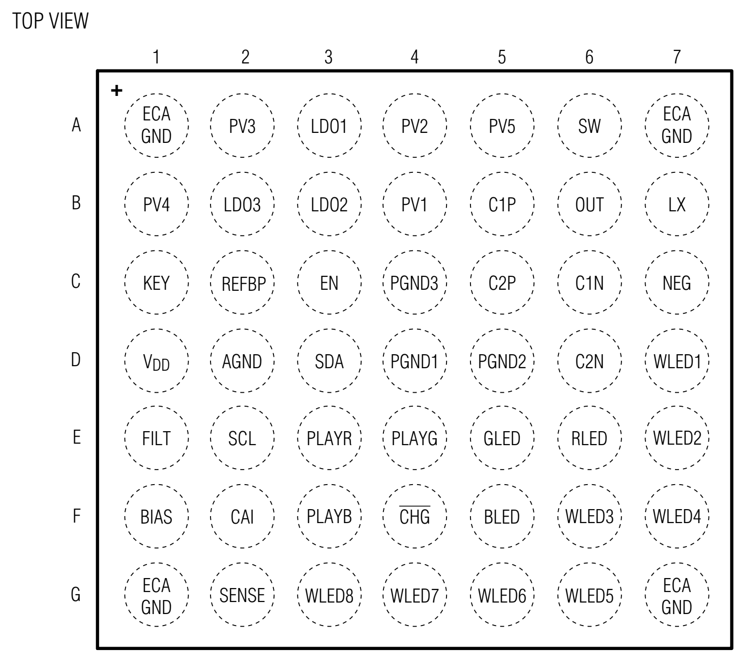
STEP-UP OUTPUT SHORT CIRCUIT



GPO—ON/OFF MODE LDO1, LDO2, LDO3 BY I2C



Pin Configuration



Pin Description

PIN	NAME	FUNCTION
EXTERNALLY CONNECTED TO PGND		
A1, A7, G1, G7	ECAGND	Connect to AGND
POWER INPUT SUPPLY AND POWER GROUND		
A2	PV3	Supply Voltage Input for Ref, Bias, LDO1, and LDO2. The input voltage range is 2.7V to 5.5V. Bypass PV3 to AGND with a 2.2µF ceramic capacitor as close as possible to the IC. PV3 is high impedance during shutdown. Connect PV3 to PV1, PV2, and PV5.
A4	PV2	Supply Voltage Input. Connect PV2 to PV1.
A5	PV5	Supply Voltage Input for the Step-Up Converter. The input voltage range is 2.7V to 5.5V. Bypass PV5 to PGND3 with a 1µF ceramic capacitor as close as possible to the IC. PV5 is high impedance during shutdown. Connect PV5 to PV1, PV2, and PV3.
B1	PV4	Supply Voltage Input for LDO3. The input voltage range is 1.7V to 5.5V. Bypass PV4 to AGND with a 2.2µF ceramic capacitor as close as possible to the IC. PV4 is high impedance during shutdown. If PV4 is not used separately, connect PV4 to PV1.
B4	PV1	Supply Voltage Input for Charge-Pump Circuitry. The input voltage range is 2.7V to 5.5V. Bypass PV1 to PGND1 and PGND2 with a 4.7µF to 10µF ceramic capacitor as close as possible to the IC. PV1 is high impedance during shutdown. Connect PV1 to PV2, PV3, and PV5.
C4	PGND3	Power Ground for the Step-Up Converter
D4	PGND1	Power Ground for the Charge-Pump Block
D5	PGND2	Power Ground for the Charge-Pump Block

Pin Description (continued)

PIN	NAME	FUNCTION
LDO FUNCTION		
A3	LDO1	Output of LDO1. The default value is 2.6V. Bypass LDO1 to AGND with a 1µF ceramic capacitor as close as possible to the IC.
B3	LDO2	Output of LDO2. The default value is 2.9V. Bypass LDO2 to AGND with a 1µF ceramic capacitor as close as possible to the IC.
B2	LDO3	Output of LDO3. The default value is 1.80V. Bypass LDO3 to AGND with a minimum 2.2µF ceramic capacitor as close as possible to the IC.
LOGIC AND ENABLE FUNCTION		
D1	V_{DD}	Logic-Supply Voltage Input. Bypass V_{DD} to AGND with a 0.1µF ceramic capacitor as close as possible to the IC. The input range is 1.7V to 5.5V.
D3	SDA	I^2C Data Input. Data is read on the rising edge of SCL. Connect a 1.5kΩ resistor from SDA to V_{DD}.
E2	SCL	I^2C Clock Input. Data is read on the rising edge of SCL. Connect a 1.5kΩ resistor from SCL to V_{DD}.
D2	AGND	Analog Ground. Connect AGND to the system ground plane.
C3	EN	Hardware Enable Input for the IC. Drive EN high to activate the IC. Drive EN low to disable the IC.
WLED AND RGB DIMMING RELATED FUNCTION		
F2	CAI	Brightness Control Input by Contents Adaptive Interface (DPWM signal). CAI varies the brightness of main WLEDs from 0% to 100%. The dimming frequency is typically 200Hz. When CAI is used as the main control method for main white LEDs, the ramp-up/ramp-down is automatically disabled.
E3	PLAYR	On/Off Input for the Red LED Current Regulator. The PLAYR signal can be either active high or active low. Program either active high or active low through the 20h register.
E4	PLAYG	On/Off Input for the Green LED Current Regulator. The PLAYG signal can be either active high or active low. Program either active high or active low through the 20h register.
F3	PLAYB	On/Off Input for the Blue LED Current Regulator. The PLAYB signal can be either active high or active low. Program either active high or active low through the 20h register.
E1	FILT	PWM Filter Capacitor. Connect a 0.1µF ceramic capacitor between FILT and AGND as close as possible to FILT.
C1	KEY	Key Backlight Control Output. Two threshold values for ON/OFF are available and programmable through the I^2C serial interface. KEY on/off function is controlled by the I^2C, ALC, or the internal 500Hz PWM signal. Program the settings for KEY through the I^2C interface.
C2	REFBP	1.20V Reference output. Bypass REFBP to AGND with 0.1µF ceramic capacitor as close as possible to the IC. Do not load REFBP.
AUTOMATIC LUMINANCE CONTROL		
F1	BIAS	Bias Output for an External Light Sensor. Bypass BIAS to AGND with a 1µF ceramic capacitor as close as possible to the IC. The BIAS output is 3.0V.
G2	SENSE	Input from Ambient Light Sensor. Connect a 5.1kΩ resistor from SENSE to AGND.
CHARGE-PUMP BLOCK		
B5	C1P	Transfer Capacitor 1 Positive Connection. Connect a 1µF ceramic capacitor from C1P to C1N.
C6	C1N	Transfer Capacitor 1 Negative Connection. Connect a 1µF ceramic capacitor from C1P to C1N.
C5	C2P	Transfer Capacitor 2 Positive Connection. Connect a 1µF ceramic capacitor from C2P to C2N.
C7	NEG	Charge-Pump Negative Output. Connect a 1µF to 2.2µF ceramic capacitor from NEG to PGND1. In shutdown, an internal 10kΩ resistor pulls NEG to PGND.
D6	C2N	Transfer Capacitor 2 Negative Connection. Connect a 1µF ceramic capacitor from C2P to C2N.

Pin Description (continued)

PIN	NAME	FUNCTION
WLED AND RGB		
D7	WLED1	WLED Current Sink Regulator. Current into WLED1 is based upon the programmed internal I^2C registers. Connect WLED1 to the cathodes of external LEDs. WLED1 is high impedance during shutdown. If unused, short WLED1 to PV3.
E7	WLED2	WLED Current Sink Regulator. Current into WLED2 is based upon the programmed internal I^2C registers. Connect WLED2 to the cathodes of external LEDs. WLED2 is high impedance during shutdown. If unused, short WLED2 to PV3.
F6	WLED3	WLED Current Sink Regulator. Current into WLED3 is based upon the programmed internal I^2C registers. Connect WLED3 to the cathode of an external WLED. WLED3 is high impedance during shutdown. If unused, short WLED3 to PV3.
F7	WLED4	WLED Current Sink Regulator. Current into WLED4 is based upon the programmed internal I^2C registers. Connect WLED4 to the cathode of an external LED. WLED4 is high impedance during shutdown. If unused, short WLED4 to P3.
G6	WLED5	WLED Current Sink Regulator. Current into WLED5 is based upon the programmed internal I^2C registers. Connect WLED5 to the cathode of an external WLED. WLED5 is high impedance during shutdown. If unused, short WLED5 to either PV3 or disable the regulator.
G5	WLED6	WLED Current Sink Regulator. Current into WLED6 is based upon the programmed internal I^2C registers. Connect WLED6 to the cathode of an external WLED. WLED6 is high impedance during shutdown. If unused, short WLED6 to either PV3 or disable the regulator.
G4	WLED7	WLED Current Sink Regulator. Current into WLED7 is based upon the programmed internal I^2C registers. Connect WLED7 to the cathode of an external WLED. WLED7 is high impedance during shutdown. If unused, short WLED7 to either PV3 or disable the regulator.
G3	WLED8	WLED Current Sink Regulator. Current into WLED8 is based upon the programmed internal I^2C registers. Connect WLED8 to the cathode of an external WLED. WLED8 is high impedance during shutdown. If unused, short WLED8 to either PV3 or disable the regulator.
E6	RLED	Red LED Connection. The brightness is set up by I^2C. ON/OFF is synchronized with the PWM signal applied to PLAYR pin. RLED maximum brightness is enabled/disabled through the serial interface.
E5	GLED	Green LED Connection. The brightness is set up by I^2C. ON/OFF is synchronized with the PWM signal applied to PLAYG pin. GLED maximum brightness is enabled/disabled through the serial interface.
F5	BLED	Blue LED Connection. The brightness is set up by I^2C. ON/OFF is synchronized with the PWM signal applied to PLAYB pin. BLED maximum brightness is enabled/disabled through the serial interface.
BOOST CONVERTER		
B6	OUT	Step-Up Converter Output. Bypass OUT to GND with a 1µF ceramic capacitor. During shutdown, OUT is pulled to PGND3 by an internal 1MΩ resistor.
A6	SW	Isolation Switch Output for the Step-Up Converter. SW is internally connected to the drain of a p-channel MOSFET and used to isolate the output of the step-up from the input during shutdown. If true shutdown is not required, SW can be left open with the input supply connected directly to the inductor.
B7	LX	Inductor Switching Connection. Connect the inductor between LX and SW. For most applications, use a 22µH inductor.
STATUS INDICATOR		
F4	$\overline{CHG}$	Charging Status Output. $\overline{CHG}$ is an open-drain output that goes low when the battery is charging. On/off is operated by I^2C. $\overline{CHG}$ is high impedance when the IC is in shutdown mode. Enable $\overline{CHG}$ through the I^2C interface.

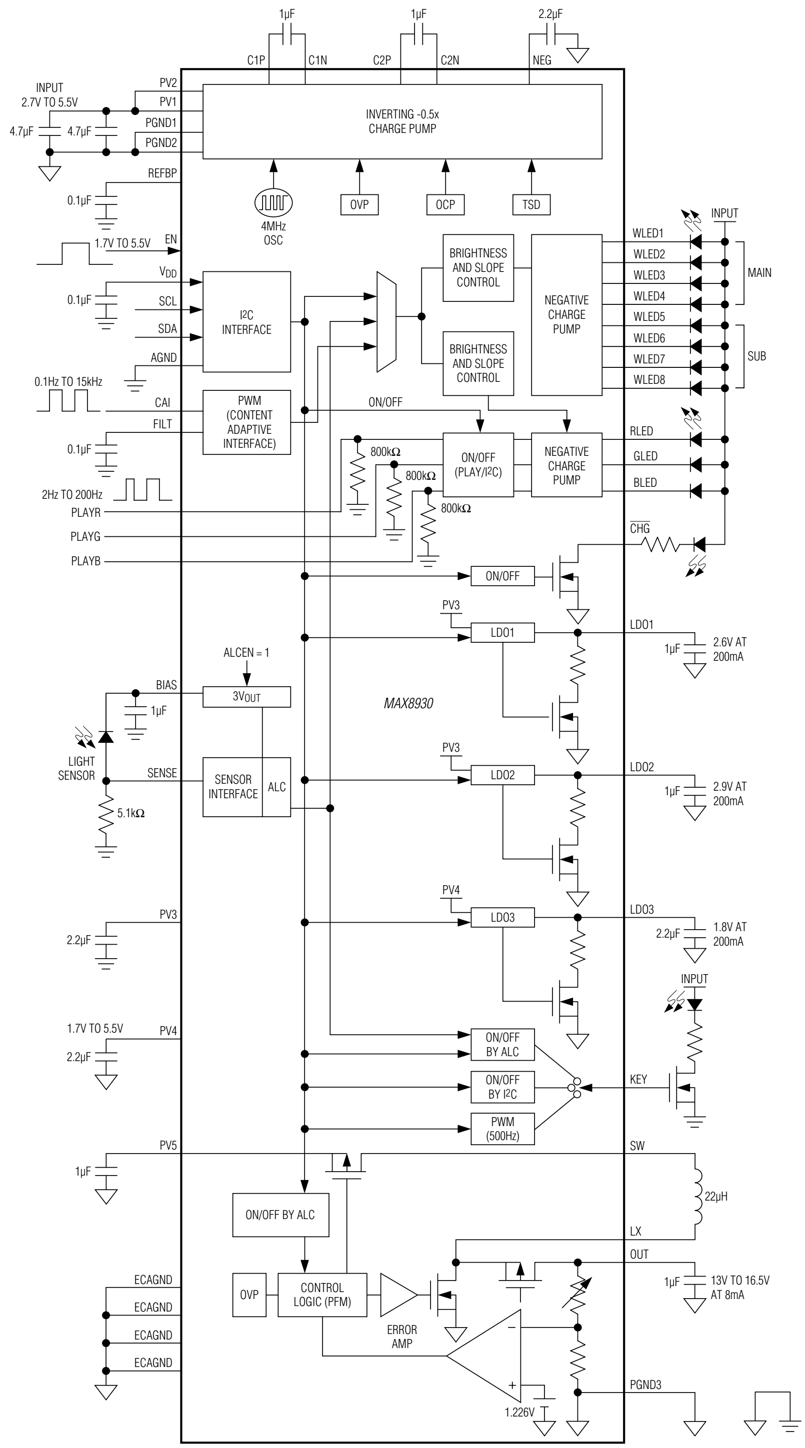


Figure 1. Typical Application and Block Diagram

External Components

PIN	EXTERNAL COMPONENTS	NOTES
PV1, PV2, PV3, PV5	10µF Total capacitance ≥ total LDO, boost, and charge-pump capacitance	System stability
PV4	2.2µF	LDO stability
V_{DD}	0.1µF	Decoupling
BIAS	1µF	LDO compensation
LDO1	1µF	LDO compensation
LDO2	1µF	LDO compensation
LDO3	2.2µF	LDO compensation
FILT	0.1µF	Noise filter
REFBP	0.1µF	Noise filter
C1P, C1N	1µF	Charge pump
C2P, C2N	1µF	Charge pump
NEG	2.2µF	Charge pump
WLED1–WLED8	White LED	—
RLED, GLED, BLED	Red, green, blue LED	—
$\overline{CHG}$	A resister, for example 10kΩ	Current limit
SW, LX	22µH	Boost converter
OUT	1µF	Boost stability
SENSE	5.1kΩ	Converter ambient light to a voltage
ALC	Toshiba TPS852	Any type (linear/log) of photo IC

Note: *All output capacitors are ceramic and X7R/X5R type.*

Detailed Description

The MAX8930 integrates a negative charge pump for both white LED display backlighting with ambient light control (ALC) function, content adaptive interface (CAI) function, and R/G/B LED. There is one step-up converter for passive matrix OLED (PMOLED) oriented application and three LDOs with programmable output voltage. The three LDO outputs are able to convert to GPO (general-purpose output) status through an I2C command. The MAX8930 includes soft-start, thermal shutdown, open-circuit, and short-circuit protection in the charge-pump circuitry.

Reset Control

The MAX8930 uses two different methods of reset: software and hardware.

Software Reset: All the registers are initiated by RESET = 1 at Register 00h. After that, the values in all registers come back to POR (power-on-reset) state. The bit of RESET in 00h is automatically returned to 0. Auto return to 0.

Hardware Reset: Hardware reset is done by toggling EN from logic-high to logic-low. All the registers under hardware reset conditions are returned to their initial values (POR) and stop receiving any commands.

Open-Circuit and Short-Circuit Protection

If any WLED/RGB fails as an open circuit, that LED pin pulls to ground, and the IC is forced into -0.5X mode. Therefore, connect any unused WLED_/RGB pins to PV1, PV2, or PV3 to disable the corresponding current regulator. The MAX8930 contains special circuitry to detect this condition and disables the corresponding current regulator to avoid wasting battery current.

Thermal Shutdown

The MAX8930 includes a thermal-limit circuit that shuts down the IC at about +160°C. The part turns on after the IC cools by approximately 20°C.

Thermal shutdown is applied to the following blocks:

- White and RGB LED driver
- Step-up converter
- LDO1, LDO2, LDO3
- SBIAS

LED Charge Pump

The charge pump drives up to 8 white LEDs (4 WLEDs for main and 4 WLEDs for sub) and 3 RGB LEDs with regulated constant current for both display backlight and fun light applications. By utilizing individually adaptive 1x/-0.5x negative charge-pump modes and extremely low-dropout current regulators, it is able to achieve high efficiency over the full 1-cell lithium battery input voltage range. High-frequency switching of 4MHz allows for tiny external components. The regulation scheme is optimized to ensure low EMI and low input ripple. Each channel for WLED and RGB LED has the capability of delivering 25.6mA with 256 dimming steps (0.1mA per step). The current-level adjustment is programmed by an I2C command. Figure 2 is the flow chart of the startup and mode-change algorithm.

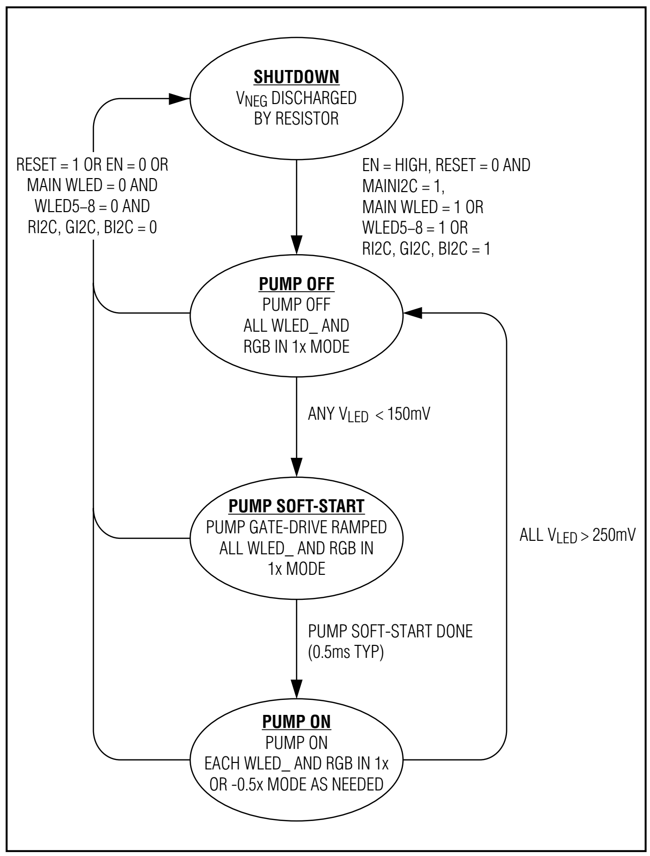


Figure 2. Startup and Mode Change Algorithm

WLED1–WLED8 Driver Operation

The white LED current regulators are composed of 4 main-group drivers (WLED1–WLED4) and 4 subgroup drivers (WLED5–WLED8). The current of the main-group LEDs can be selected by an I2C register. Both ambient light control (ALC) mode and ramp-up/ramp-down control are applied to only the main-group white LEDs.

The subgroup LEDs can choose either individual control or can belong to the main group based on the status of a bit in the register (01h and 02h). In this function, combinations can be adjusted as required. For example, main 4ch + sub 4ch or main 5ch + sub 3ch.

The CAI (PWM) signal from either the LCD driver module or baseband chipset controls only the main-group WLEDS. The up/down slope control can be programmed by the setting of the 0Ah register when the main LEDs are controlled by either I2C or ALC.

For main LEDs, there are three different dimming control methods, I2C, ALC, and CAI. The dimming range for main LEDs and sub LEDs is from 0.1mA to 25.6mA in 0.1mA increments.

RGB Driver Operation

The brightness for each color LED has 256 different steps (0.1mA to 25.6mA). The RGB LED can be activated by either the high/low status of the PLAY_ PWM signal or by I2C ON/OFF command. The default dimming control is I2C command. An I2C command for dimming can adjust the current of each RGB individually. The operation of ON/OFF by I2C command also allows individual control. However, the operation of ON/OFF by PWM to PLAY_ RGB is group control. To operate with either an active-high or active-low signal coming from the microprocessor such as audio processor, the register related to active high or active low should be selected first (the bit 1 in 20h). When a call comes in or music plays, all RGB LEDs are allowed to be activated by either a PWM signal applied to PLAY_ or a designated register by I2C.

The main purpose for the PLAY_ is for ON/OFF control function and not for dimming control. If the dimming current is set to 10mA on each RGB LED, the PWM signal to PLAY_ RGB turns all of the current regulators on or off at the same time. However, the dimming current for RGB can be set by I2C command during ON/OFF operation. When the PLAY_ is in active-high period, the RGB current regulator is on with 10mA current. When the PLAY_ is in the opposite state (active-low period), the RGB regulator is off with 0mA current. The default method to turn the RGB LED on is to pull the PLAY_ input high with a minimum on-time of 80µs in active-high mode. If bit 1 in 20h is set to 1, then all current regulators for RGB are activated by active-low signal with a minimum off-time of 80µs. The up/down slope control can be programmed by the setting of the 0Bh register when the RGB LEDs are controlled by I2C only.

If bit 7 in 20h is set to logic-low, then slope up/down is automatically deactivated.

CAI (Contents Adaptive Interface) Operation

A 200Hz PWM signal is applied to the CAI pin. The CAI signal can be from either the LCD driver module with gamma correction information or from the baseband chipset. The main WLED can be activated by either the high/low status of the CAI PWM signal or with either an active-high or active-low signal coming from either a LCD driver module or baseband chipset. The corresponding register bit (bit 0 in 02h) should be set to either, 1 or 0 by I2C command.

Depending on the duty cycle, the brightness varies from 0mA to 25.6mA with the resolution of 0.256mA per 1% duty variation. In control of CAI (PWM) independently, the existing brightness setting from either I2C or ALC is overwritten because CAI has the priority over I2C and ALC.

See the *Dimming by Digital PWM on CAI Only* and *Dimming by Both Digital PWM on CAI and Either I2C or ALC at the Same Time* sections for details on the CAI dimming control.

Dimming by Digital PWM on CAI Only

When the digital PWM (DPWM) signal (100Hz ~15kHz) is provided by either the baseband or CPU for dimming the brightness, the MAX8930 DPWM function takes over the responsibility of dimming the main WLEDs. The dimming by CAI is initiated by setting CAI (bit 7 of Register 02h) to 1. After the set-up, both I2C register dimming settings and ALC no longer control the dimming current for the main WLEDs. The frequency range on the CAI pin is from 100Hz to 15kHz, where 0% duty cycle corresponds to 0mA and 100% duty cycle corresponds to full current, 25.6mA.

When CAI is set to 1, the ramp-up/down slope for main WLED_ is automatically disabled by the MAX8930 control logic. Figure 3 is the timing diagram on initiating CAI. The MAX8930 maintains its previous dimming setting for t_B (10ms typ) to allow the PWM filter time to settle to its average value before activating CAI dimming. This is done automatically inside the IC. The bit of MAINI2C

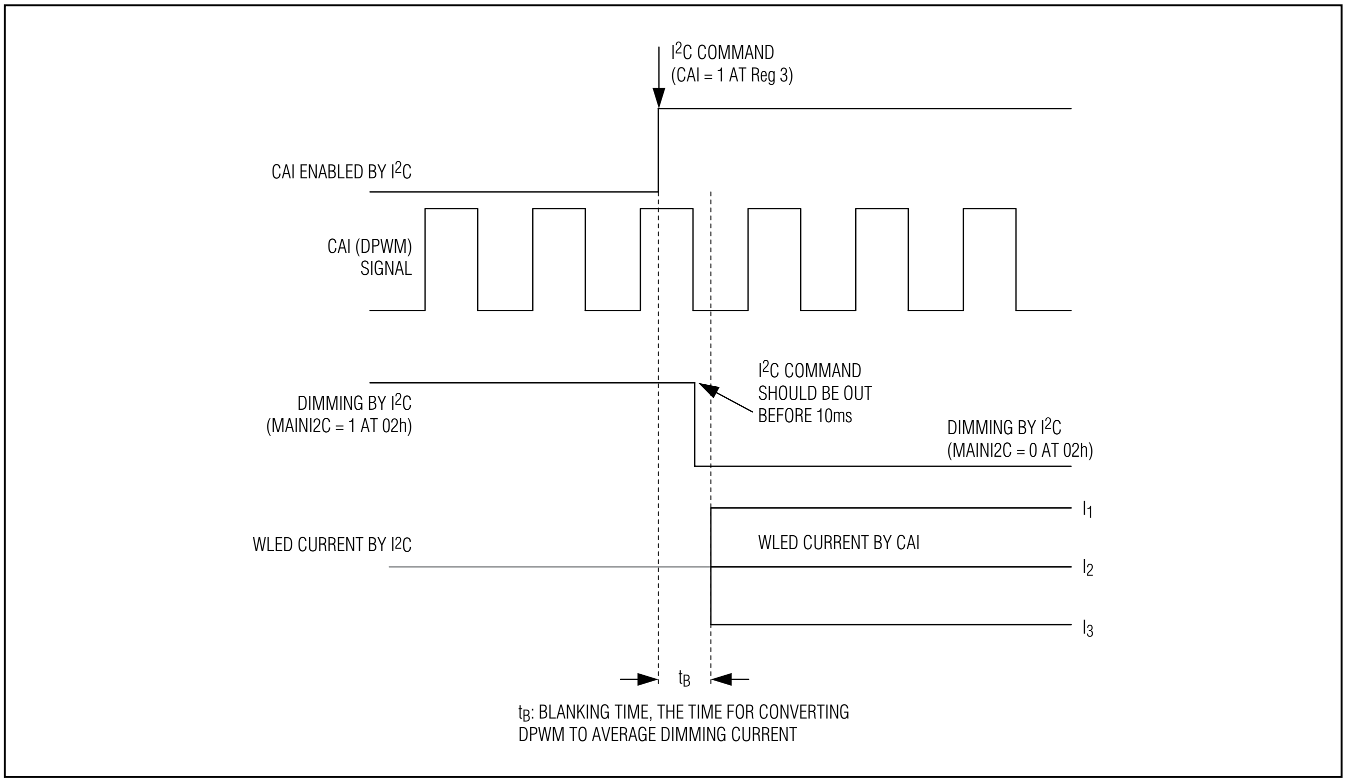


Figure 3. Timing Diagram of Stand-Alone CAI Dimming Operation

should be set to 0 in less than t_B, 10ms (typ) for CAI dimming to be exclusively through DPWM.

If this setup fails, the previous dimming current is still effective even though bit 7 in 02h (CAI) has been set to 1.

The current of I1, I2, and I3 of Figure 3 is different depending on the duty cycle of DPWM.

t_B is the settling time for the CAI input filter to calculate an average value for the dimming current.

Dimming by Both Digital PWM on CAI and Either I2C or ALC at the Same Time

If an end-user wants to see either TV or a movie, the LCD driver module may take care of dimming control independently. In this situation, the output signal from the LCD module has some color information. For example, (16mA/LED) + gamma correction can make the user feel the same brightness of the LCD screen compared to (20mA/LED) + no gamma correction.

In this combined dimming control, any dimming current set earlier by either the I2C register or the ALC register is the value corresponding with 100% duty cycle of the CAI signal.

Ambient Light Control Operation

Dimming of the LCD backlight and ON/OFF control of the keypad backlight are possible on the basis of the data detected by an external ambient light sensor. The ALC consists of the following segments:

- Bias function (3V output)
- 8-bit ADC with an average filter
- A slope process function
- A LOG scale conversion function

A wide range of ambient light sensors can be used with the MAX8930, including photo diode, photo transistor, photo IC (a linear output/LOG output), etc. The detected amount of ambient light is changed into digital data by

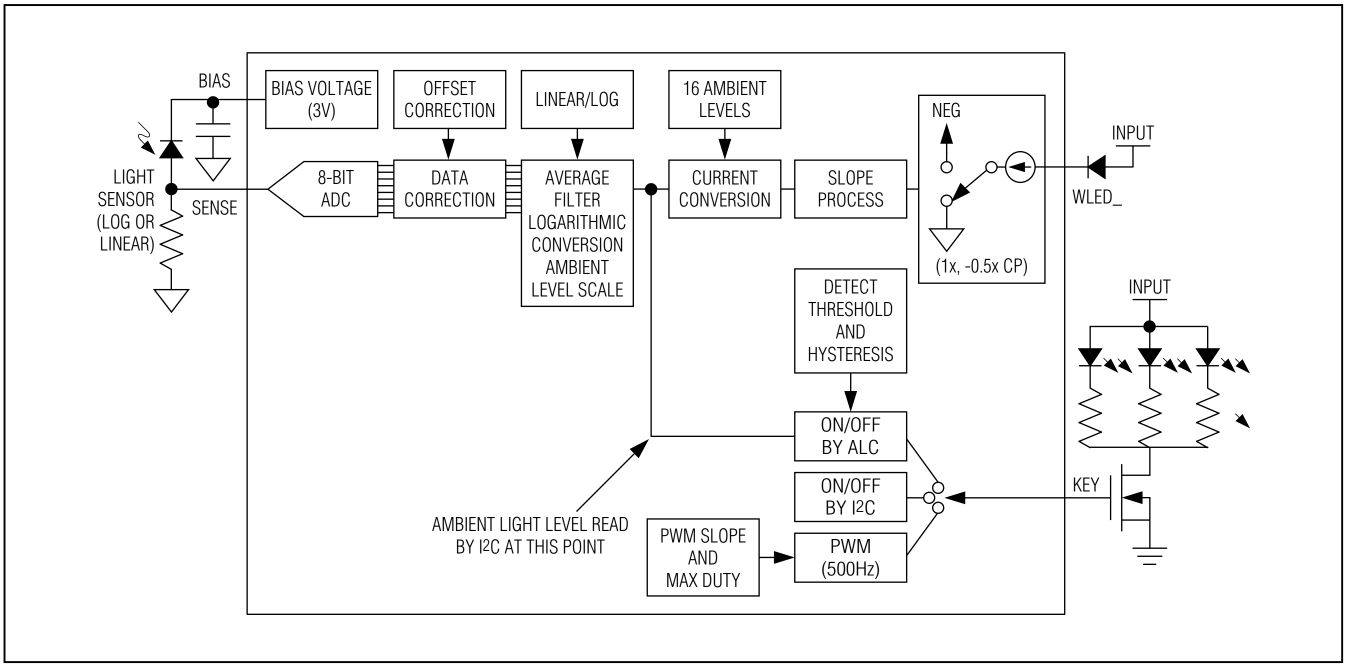


Figure 4. ALC Block Diagram

the embedded digital processing. This data can be read through the I2C (0Dh).

The conversion to LED current can be accomplished either through a built-in initial lookup table or a built-in user settable lookup table.

When ALC is activated, the brightness settings of the main LEDs are controlled through the ALC control circuitry and not by the baseband processor. The default setting on power-on reset is for control by the baseband processor.

ON/OFF of ALC Block for Main WLEDs

ALC operation can be activated independently for the main LED and the keypad backlight. The ALCEN bit in register 00h activates ambient light control. The KBALC bit in register 00h activates ON/OFF for the keypad backlight in ALC mode. For keypad backlight, the output is simple logic-high/logic-low.

Bias Voltage for a Sensor

An embedded LDO with a nominal 3V output provides the bias voltage for the ambient light sensor. This bias output is enabled as soon as the ALCEN bit is set to 1.

The operation of the bias output voltage has two options based on the value of the SBIAS bit (bit 7 in Register 0Ch). When this bit is set to 1, the bias output is synchronized with the measurement cycle. This means that the bias voltage generator is active only when a measurement cycle is being performed. The measurement cycle has four different times, 0.52s, 1.05s, 1.57s, and 2.10s. When this bit is set to 0, the bias output is always on as long as the ALCEN bit is set to 1.

Brightness Data Conversion

16 different dimming steps are available depending on the ambient light condition. The selection of the log or linear conversion is possible by the setting of the LSTY bit (bit 6 of register 0Ch).

Linear type sensor: LOG conversion

Log type sensor: Data bypass

The brightness data can be read through I2C (Register at 0Dh).

LED Current Conversion

The following is the initial current value to each level of ambient light. This value can be overwritten by I2C command.