19-3617; Rev 6; 7/07

EVALUATION KIT AVAILABLE

8-Channel PMICs for Digital Camera Power Supplies

MAX8610–MAX8613/MAX8611V

General Description

The MAX8610–MAX8613/MAX8611V are highly efficient complete power-supply solutions for digital still cameras (DSCs) and digital video cameras (DVCs). Seven internal-MOSFET DC-DC converters provide up to 95% efficiency and generate all critical power supplies in DSC systems. They also feature True Shutdown™, as well as internal compensation to minimize external component count. One additional converter operates with an external MOSFET for optimum design flexibility. In all, eight converter channels include:

- Synchronous-rectified step-up with True Shutdown.
- Two synchronous-rectified step-down (MAX8611/MAX8613/MAX8611V) or step-up (MAX8610/MAX8612) converters power DSC system, I/O, and AFE blocks.
- Low-V_{OUT} (down to 1V), synchronous-rectified step-down to power a DSP core.
- High-output-voltage step-up for CCD bias.
- Transformerless inverter for negative CCD bias.
- High-output-voltage step-up for white LEDs, OLED display, or other output.
- Auxiliary DC-DC boost (MAX8611/MAX8610/MAX8611V) or inverting (MAX8612/MAX8613) controller.

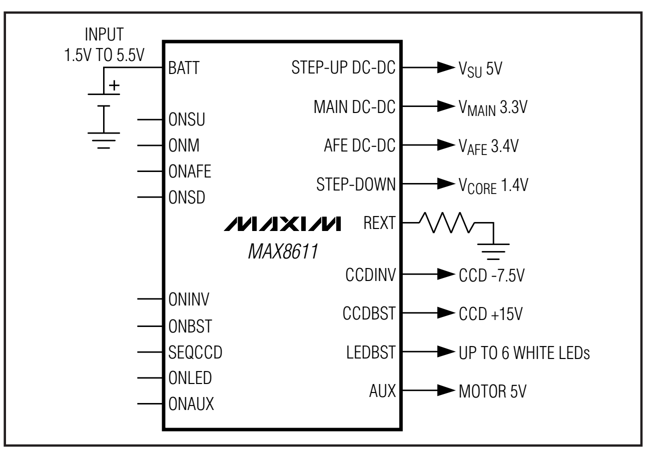
The MAX8611/MAX8613/MAX8611V operate in 1-cell lithium-ion (Li+) and dual-battery (Li+ and 2 AA) designs. The MAX8610/MAX8612 operate in 2 AA designs.

Applications

DSCs and DVCs

PDAs and MP3 Players

Typical Operating Circuit



Features

- ♦ 95% Efficient Synchronous-Rectified DC-DCs
- ♦ 90% Efficient Boost-Buck Operation
- ♦ 85% Efficient DC-DCs for CCD, LCD, WLED, and/or OLED
- ♦ Auxiliary Power for Motors (MAX8610/MAX8611/MAX8611V)
- ♦ Internal Compensation
- ♦ True Shutdown Step-Up Converters
- ♦ Overload Protection
- ♦ Soft-Start for Controlled Startup Current
- ♦ Low-Dropout (100% Duty Cycle) Step-Downs
- ♦ Regulated Current for Up to 6 White LEDS
- ♦ Open-LED Overvoltage Protection
- ♦ Transformerless Inverting Converter for CCD
- ♦ Adjustable 1MHz to 2MHz Switching Frequency
- ♦ 3% Frequency Accuracy
- ♦ 1µA Shutdown Supply Current
- ♦ CCD Voltage Sequencing
- ♦ Voltage Tracking for Core and Logic (MAX8611/MAX8613/MAX8611V)
- ♦ Compact 48-Pin, 6mm x 6mm Thin QFN Package

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	PKG CODE
MAX8610ETM+	-40°C to +85°C	48 TQFN-EP* 6mm x 6mm	T4866-1
MAX8611ETM+	-40°C to +85°C	48 TQFN-EP* 6mm x 6mm	T4866-1
MAX8611VETM+	-40°C to +85°C	48 TQFN-EP* 6mm x 6mm	T4866-1
MAX8612ETM+	-40°C to +85°C	48 TQFN-EP* 6mm x 6mm	T4866-1
MAX8613ETM+	-40°C to +85°C	48 TQFN-EP* 6mm x 6mm	T4866-1

**EP = Exposed paddle.*
+Denotes lead-free package.

Selector Guide and Pin Configuration appear at end of data sheet.

8-Channel PMICs for Digital Camera Power Supplies

ABSOLUTE MAXIMUM RATINGS

ON__, FB__, PV__, SU, SEQCCD, SWBST, SWLED, REXT, REF, BATT, GD to GND ....-0.3V to +6V
LXAFE, LXM, LXSD (Note 1) ....Current 1A
LXSU (Note 1) ....Current 2.5A
PG__ to GND ....-0.3V to +0.3V
LXINV ....(PVINV - 16V) to (PVINV + 0.3V)
DRVAUX to GND....................................-0.3V to (PVINV + 0.3V)
LXBST, LXLED to GND...-0.3V to +27V
CCAUX to GND ....-0.3V to max (BATT, PVSU) + 0.3V
Continuous Power Dissipation (T_A = +70°C)
48-Pin TQFN 6mm x 6mm ....2105mW (single-layer board)
48-Pin TQFN 6mm x 6mm............2963mW (multilayer board)
Operating Temperature Range ....-40°C to +85°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +165°C
Lead Temperature (soldering, 10s) ....+300°C

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

Note 1: For step-up converters (SU and MAIN/AFE (MAX8610/MAX8612)), LX__ has internal clamp diodes to the IC internal power node, VPWR (where V_{PWR} is the higher of BATT or PVSU), and PG__. For step-down converters (MAIN/AFE (MAX8611/MAX8613/MAX8611V) and SD)), LX__ has internal clamp diodes to PV__ and PG__. Applications that forward bias these diodes should take care not to exceed the devices’ power dissipation limits.

ELECTRICAL CHARACTERISTICS

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
GENERAL					
Input Voltage Range	(Note 1)	0.9		5.5	V
Minimum SU Startup Voltage			1.2	1.5	V
SU Step-Up Startup Frequency			2		MHz
Shutdown Supply Current	T_A = +25°C		0.1	10	µA
	T_A = +85°C		0.1		
Supply Current with SU Step-Up Enabled	ONSU = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		510	700	µA
Supply Current with SU Step-Up and SD Step-Down Enabled	ONSU = ONSD = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		550	775	µA
Supply Current with SU Step-Up and MAIN Enabled	ONSU = ONM = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		550	775	µA
Supply Current with SU Step-Up and AFE Enabled	ONSU = ONAFE = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		550	775	µA
Supply Current with SU Step-Up and LED Enabled	ONSU = ONLED = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		600	875	µA
Supply Current with SU Step-Up and CCD BST Enabled	ONSU = ONBST = 3.6V, SEQCCD = GND, I_{BATT} + I_{SU} (does not include switching losses)		560	875	µA
Supply Current with SU Step-Up and CCD INV Enabled	ONSU = ONINV = 3.6V, SEQCCD = GND, I_{BATT} + I_{SU} (does not include switching losses)		560	775	µA
Supply Current with SU Step-Up and AUX Enabled	ONSU = ONAUX = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)		615	875	µA
REFERENCE (REF)					
Reference Output Voltage	I_{REF} = 20µA	1.24	1.25	1.26	V
Reference Load Regulation	10µA < I_{REF} < 100µA		3	10	mV
Reference Line Regulation	3.3V < PVSU = SU < 5.5V		0	5	mV

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
OSCILLATOR (OSC)						
SU Step-Up/MAIN/AFE/SD Step-Down Switching Frequency	REXT = 100kΩ	T_A = +25°C	1.94	2	2.06	MHz
			1.95	2	2.08	
SU Step-Up/MAIN/AFE Maximum Duty Cycle	REXT = 100kΩ			85		%
CCD/LED Switching Frequency	REXT = 100kΩ	T_A = +25°C	0.97	1	1.03	MHz
			0.96	1	1.04	
CCD/LED Maximum Duty Cycle	REXT = 100kΩ			92.5		%
AUX Switching Frequency	REXT = 100kΩ	T_A = +25°C	0.485	0.5	0.515	MHz
			0.48	0.5	0.52	
AUX Maximum Duty Cycle	REXT = 100kΩ		86	87.5	89	%
SU STEP-UP DC-DC CONVERTER						
Step-Up Voltage Adjust Range			3.3		5.0	V
FBSU Regulation Voltage	No load		0.995	1.01	1.025	V
FBSU Load Regulation				-7.5		mV/A
FBSU Line Regulation				-10		mV/D
FBSU Input Leakage Current	FBSU = 1.01V, T_A = +25°C		-50	-5	+50	nA
	FBSU = 1.01V, T_A = +85°C			-5		
Idle-Mode™ Trip Level	(Note 2)	MAX8610–MAX8613		50		mA
		MAX8611V		125		
LXSU Leakage Current	LXSU = 0V, 3.6V, T_A = +25°C		-5	+0.1	+5	µA
	LXSU = 0V, 3.6V, T_A = +85°C			0.1		
n-Channel On-Resistance				0.1	0.175	Ω
p-Channel On-Resistance				0.14	0.25	Ω
n-Channel Current Limit			2.25	2.5	2.75	A
p-Channel Turn-Off Current				10		mA
Soft-Start Interval	Load dependent			15,000		OSC cycles
Overload Protection Fault Delay				200,000		OSC cycles
MAIN/AFE STEP-UP DC-DC CONVERTER (MAX8610/MAX8612)						
Step-Up Voltage Adjust Range			2.5		SU	V
FB_ Regulation Voltage	No load		0.995	1.01	1.025	V
FB_ Load Regulation				-7.5		mV/A
FB_ Line Regulation				-10		mV/D
FB_ Input Leakage Current	FB_ = 1.01V, T_A = +25°C		-50	-5	+50	nA
	FB_ = 1.01V, T_A = +85°C			-5		
Idle-Mode Trip Level	(Note 2)			50		mA

Idle Mode is a trademark of Maxim Integrated Products, Inc.

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
LX_ Leakage Current	LX_ = 0V, 3.6V, T_A = +25°C		-5	+0.1	+5	µA
	LX_ = 0V, 3.6V, T_A = +85°C			0.1		
n-Channel On-Resistance				0.1	0.175	Ω
p-Channel On-Resistance				0.14	0.25	Ω
n-Channel Current Limit			2.25	2.5	2.75	A
p-Channel Turn-Off Current				10		mA
Soft-Start Interval				15,000		OSC cycles
Overload Protection Fault Delay				200,000		OSC cycles
MAIN/AFE STEP-DOWN DC-DC CONVERTER (MAX8611/MAX8613/MAX8611V)						
Step-Down Voltage Adjust Range			1		SU	V
FB_ Regulation Voltage	No load		0.995	1.01	1.025	V
FB_ Load Regulation				-20		mV/A
FB_ Line Regulation				-10		mV/D
FB_ Input Leakage Current	FB_ = 1.01V, T_A = +25°C		-50	-5	+50	nA
	FB_ = 1.01V, T_A = +85°C			-5		
Idle-Mode Trip Level	(Note 2)	MAX8611/MAX8613		50		mA
		MAX8611V		125		
LX_ Leakage Current	LX_ = 0V, 3.6V, T_A = +25°C		-5	+0.1	+5	µA
	LX_ = 0V, 3.6V, T_A = +85°C			0.1		
n-Channel On-Resistance				0.1	0.175	Ω
p-Channel On-Resistance				0.14	0.25	Ω
p-Channel Current Limit			0.9	1	1.1	A
n-Channel Turn-Off Current				10		mA
Soft-Start Interval				15,000		OSC cycles
Overload Protection Fault Delay				200,000		OSC cycles
SD STEP-DOWN DC-DC CONVERTER						
SD Step-Down Voltage Adjust Range			1		SU	V
FBSD Regulation Voltage	No load		0.995	1.01	1.025	V
FBSD Load Regulation				-20		mV/A
FBSD Line Regulation				-10		mV/D
FBSD Input Leakage Current	FBSD = 1.01V, T_A = +25°C		-50	-5	+50	nA
	FBSD = 1.01V, T_A = +85°C			-5		
Idle-Mode Trip Level	(Note 2)	MAX8610–MAX8613		50		mA
		MAX8611V		125		

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
LXSD Leakage Current	LXSD = 0V, 3.6V, T_A = +25°C	-5	+0.1	+5	µA
	LXSD = 0V, 3.6V, T_A = +85°C		+0.1		
n-Channel On-Resistance			0.1	0.175	Ω
p-Channel On-Resistance			0.14	0.25	Ω
p-Channel Current Limit		0.9	1.0	1.1	A
n-Channel Turn-Off Current			10		mA
Soft-Start Interval			5000		OSC cycles
Overload Protection Fault Delay			200,000		OSC cycles
CCD BST DC-DC CONVERTER					
BST Voltage Adjust Range		BATT		27	V
FBBST Regulation Voltage	No load	0.995	1.01	1.025	V
FBBST Load Regulation			-15		mV/A
FBBST Line Regulation			-20		mV/D
FBBST Input Leakage Current	FBBST = 1.01V, T_A = +25°C	-50	-5	+50	nA
	FBBST = 1.01V, T_A = +85°C		-5		
SWBST Leakage Current	SWBST = 0V, PVBST = 3.6V, T_A = +25°C	-5	+0.1	+5	µA
	SWBST = 0V, PVBST = 3.6V, T_A = +85°C		0.1		
LXBST Leakage Current	LXBST = 26V, T_A = +25°C	-5	+0.1	+5	µA
	LXBST = 26V, T_A = +85°C		0.1		
Load Switch On-Resistance			0.09	0.15	Ω
DMOS On-Resistance			0.4		Ω
SWBST Current Limit		0.7	0.8	0.9	A
SWBST Short-Circuit Current Limit		0.95	1.05	1.15	A
Soft-Start Interval			15,000		OSC cycles
Overload Protection Fault Delay			200,000		OSC cycles
GD Leakage Current	GD = 3.6V, T_A = +25°C		0.1	5	µA
	GD = 3.6V, T_A = +85°C		0.1		
CCD INV DC-DC CONVERTER					
INV Voltage Adjust Range		PVINV - 16		0	V
FBINV Regulation Voltage	No load	+10	0	-10	mV
FBINV Load Regulation			23		mV/A
FBINV Line Regulation	(Note 3)		20		mV / (D - 0.5)

8-Channel PMICs for Digital Camera Power Supplies

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
FBINV Input Leakage Current	FBINV = 0V, T_A = +25°C		-50	-5	+50	nA
	FBINV = 0V, T_A =+85°C			-5		
LXINV Leakage Current	LXINV = -12V, PVINV = 3.6V, T_A = +25°C		-5	+0.1	+5	µA
	LXINV = -12V, PVINV = 3.6V, T_A = +85°C			0.1		
HVPMOS On-Resistance				0.575	1.0	Ω
HVPMOS Current Limit			0.65	0.75	0.85	A
Soft-Start Interval				15,000		OSC cycles
Overload Protection Fault Delay				200,000		OSC cycles
LED BST DC-DC CONVERTER						
LED Voltage Adjust Range			BATT		27	V
FBHLED Regulation Voltage	No load, FBLED = 0V		1.00	1.015	1.03	V
FBHLED Load Regulation				-15		mV/A
FBHLED Line Regulation				-20		mV/D
FBHLED Input Leakage Current	FBHLED = 1.01V, T_A = +25°C		-50	-5	+50	nA
	FBHLED = 1.01V, T_A = +85°C			-5		
FBLLED Regulation Voltage	No load, FBHLED = 0V		220	235	255	mV
		T_A = +25°C	225	235	245	
FBLLED Load Regulation				-15		mV/A
FBLLED Line Regulation				-20		mV/D
FBLLED Input Leakage Current	FBLLED = 0.225V, T_A = +25°C		-50	-5	+50	nA
	FBLLED = 0.225V, T_A = +85°C			-5		
SWLED Leakage Current	SWLED = 0V, PVLED = 3.6V, T_A = +25°C		-5	+0.1	+5	µA
	SWLED = 0V, PVLED = 3.6V, T_A = +85°C			0.1		
LXLED Leakage Current	LXLED = 26V, T_A = +25°C		-5	+0.1	+5	µA
	LXLED = 26V, T_A = +85°C			0.1		
Load Switch On-Resistance				0.09	0.15	Ω
DMOS On-Resistance				0.4		Ω
SWLED Current Limit			0.7	0.8	0.9	A
SWLED Short-Circuit Current Limit			0.95	1.05	1.15	A
Soft-Start Interval				15,000		OSC cycles
Overload Protection Fault Delay				200,000		OSC cycles
AUXILIARY CONTROLLER						
FBAUX Regulation Voltage (MAX8610/MAX8611/MAX8611V)			1.23	1.25	1.26	V

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
FBAUX Regulation Voltage (MAX8612/MAX8613)		-10	0	+10	mV
FBAUX Input Leakage Current	FBAUX = 1.25V (MAX8610/MAX8611/MAX8611V), FBAUX = 0V (MAX8612/MAX8613), T_A = +25°C	-50	-5	+50	nA
	FBAUX = 1.25V (MAX8610/MAX8611/MAX8611V), FBAUX = 0V (MAX8612/MAX8613), T_A = +85°C		-5		
FBAUX-CCAUX Open-Loop Voltage Gain			80		dB
FBAUX-CCAUX Unity-Gain Bandwidth			3		MHz
AUX Voltage Ramp			1.25		V
CCAUX Maximum Output Current	Sourcing or sinking	90			µA
DRVAUX On-Resistance	Output high or low		5	10	Ω
DRVAUX Drive Current			0.5		A
Soft-Start Interval			15,000		OSC cycles
Overload Protection Fault Delay			200,000		OSC cycles
LOGIC INPUTS					
ONSU Input Low Level	1.5V < PVSU = SU = BATT < 5.5V			0.5	V
ONSU Input High Level	1.5V < PVSU = SU = BATT < 5.5V, VH is higher of PVSU and BATT	VH - 0.2V with a max of 1.6V			V
ONM, ONAFE, ONSD, ONBST, ONINV, ONLED, ONAUX Input Low Level	3.3V < PVSU = SU = BATT < 5.5V			0.5	V
ONM, ONAFE, ONSD, ONBST, ONINV, ONLED, ONAUX Input High Level	3.3V < PVSU = SU = BATT < 5.5V	1.6			V
SEQCCD Input Low Level	3.3V < PVSU = SU = BATT < 5.5V			0.5	V
SEQCCD Input High Level	PVSU = SU = BATT = 3.3V	2.3			V
	PVSU = SU = BATT = 5.5V	3.4			
Input Bias Current	T_A = +25°C		0.1	1	µA
	T_A = +85°C		0.1		
THERMAL LIMIT					
Thermal Limit			+174		°C

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ELECTRICAL CHARACTERISTICS

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = -40°C to +85°C,** unless otherwise noted. Specifications to -40°C are guaranteed by design, not production tested.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
GENERAL					
Input Voltage Range	(Note 1)	0.9		5.5	V
Minimum SU Startup Voltage				1.5	V
Supply Current with SU Step-Up Enabled	ONSU = 3.6V, I_{BATT} + I_{VSU} (does not include switching losses)			700	µA
Supply Current with SU Step-Up and SD Step-Down Enabled	ONSU = ONSD = 3.6V, I_{BATT} + I_{VSU} (does not include switching losses)			775	µA
Supply Current with SU Step-Up and MAIN Enabled	ONSU = ONM = 3.6V, I_{BATT} + I_{VSU} (does not include switching losses)			775	µA
Supply Current with SU Step-Up and AFE Enabled	ONSU = ONAFE = 3.6V, I_{BATT} + I_{VSU} (does not include switching losses)			775	µA
Supply Current with SU Step-Up and LED Enabled	ONSU = ONLED = 3.6V, I_{BATT} + I_{VSU} (does not include switching losses)			875	µA
Supply Current with SU Step-Up and CCD BST Enabled	ONSU = ONBST = 3.6V, SEQCCD = GND, I_{BATT} + I_{VSU} (does not include switching losses)			875	µA
Supply Current with SU Step-Up and CCD INV Enabled	ONSU = ONINV = 3.6V, SEQCCD = GND, I_{BATT} + I_{SU} (does not include switching losses)			775	µA
Supply Current with SU Step-Up and AUX Enabled	ONSU = ONAUX = 3.6V, I_{BATT} + I_{SU} (does not include switching losses)			875	µA
REFERENCE (REF)					
Reference Output Voltage	I_{REF} = 20µA	1.24		1.26	V
Reference Load Regulation	10µA < I_{REF} < 100µA			10	mV
Reference Line Regulation	3.3V < PVSU = SU < 5.5V			5	mV
OSCILLATOR (OSC)					
SU Step-Up/MAIN/AFE/SD Step-Down Switching Frequency	REXT = 100kΩ	1.92		2.08	MHz
CCD/LED Switching Frequency	REXT = 100kΩ	0.96		1.04	MHz
AUX Switching Frequency	REXT = 100kΩ	0.475		0.525	MHz
AUX Maximum Duty Cycle	REXT = 100kΩ	86		89	%
SU STEP-UP DC-DC CONVERTER					
Step-Up Voltage Adjust Range		3.3		5.0	V
FBSU Regulation Voltage	No load	0.995		1.025	V
n-Channel On-Resistance				0.175	Ω
p-Channel On-Resistance				0.25	Ω
n-Channel Current Limit		2.25		2.75	A

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = -40°C to +85°C,** unless otherwise noted. Specifications to -40°C are guaranteed by design, not production tested.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
MAIN/AFE STEP-UP DC-DC CONVERTER (MAX8610/MAX8612)					
Step-Up Voltage Adjust Range		2.5		SU	V
FB_ Regulation Voltage	No load	0.995		1.025	V
n-Channel On-Resistance				0.175	Ω
p-Channel On-Resistance				0.25	Ω
n-Channel Current Limit		2.25		2.75	A
MAIN/AFE STEP-DOWN DC-DC CONVERTER (MAX8611/MAX8613/MAX8611V)					
Step-Down Voltage Adjust Range		1		SU	V
FB_ Regulation Voltage	No load	0.995		1.025	V
n-Channel On-Resistance				0.175	Ω
p-Channel On-Resistance				0.25	Ω
p-Channel Current Limit		0.9		1.1	A
SD STEP-DOWN DC-DC CONVERTER					
SD Step-Down Voltage Adjust Range		1		SU	V
FBSD Regulation Voltage	No load	0.995		1.025	V
n-Channel On-Resistance				0.175	Ω
p-Channel On-Resistance				0.25	Ω
p-Channel Current Limit		0.9		1.1	A
CCD BST DC-DC CONVERTER					
BST Voltage Adjust Range		BATT		27	V
FBBST Regulation Voltage	No load	0.995		1.025	V
Load Switch On-Resistance				0.15	Ω
SWBST Current Limit		0.7		0.9	A
SWBST Short-Circuit Current Limit		0.95		1.15	A
CCD INV DC-DC CONVERTER					
INV Voltage Adjust Range		PVINV - 16		0	V
FBINV Regulation Voltage	No load	+10		-10	mV
HVPMOS On-Resistance				1.0	Ω
HVPMOS Current Limit		0.65		0.85	A

ELECTRICAL CHARACTERISTICS (continued)

(BATT = PVINV = PVLED = PVBST = PVSD = PVM = PVAFE = 3.6V, PVSU = SU = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2 = 0V, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND, **T_A = -40°C to +85°C,** unless otherwise noted. Specifications to -40°C are guaranteed by design, not production tested.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
LED BST DC-DC CONVERTER					
LED Voltage Adjust Range		BATT		27	V
FBHLED Regulation Voltage	No load, FBLED = 0V	1.00		1.03	V
FBLLED Regulation Voltage	No load, FBHLED = 0V	215		255	mV
Load Switch On-Resistance				0.15	Ω
SWLED Current Limit		0.7		0.9	A
SWLED Short-Circuit Current Limit		0.95		1.15	A
AUXILIARY CONTROLLER					
FBAUX Regulation Voltage (MAX8610/MAX8611/MAX8611V)		1.23		1.26	V
FBAUX Regulation Voltage (MAX8612/MAX8613)		-10		+10	mV
CCAUX Maximum Output Current	Sourcing or sinking	90			µA
DRVAUX On-Resistance	Output high or low			10	Ω
LOGIC INPUTS					
ONSU Input Low Level	1.5V < PVSU = SU = BATT < 5.5V			0.5	V
ONSU Input High Level	1.5V < PVSU = SU = BATT < 5.5V, VH is higher of PVSU and BATT	VH - 0.2V with a max of 1.6V			V
ONM, ONAFE, ONSD, ONBST, ONINV, ONLED, ONAUX Input Low Level	3.3V < PVSU = SU = BATT < 5.5V			0.5	V
ONM, ONAFE, ONSD, ONBST, ONINV, ONLED, ONAUX Input High Level	3.3V < PVSU = SU = BATT < 5.5V	1.6			V
SEQCCD Input Low Level	3.3V < PVSU = SU = BATT < 5.5V			0.5	V
SEQCCD Input High Level	PVSU = SU = BATT = 3.3V	2.3			V
	PVSU = SU = BATT = 5.5V	3.4			

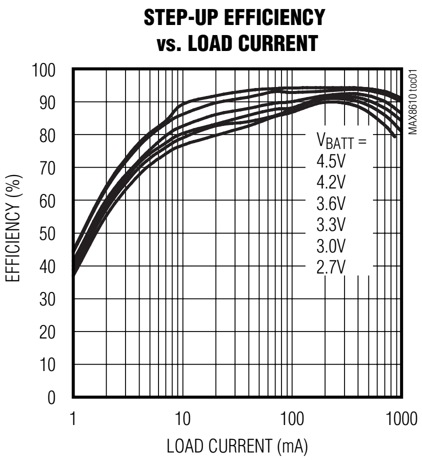
Note 1: Once the step-up has reached regulation, the battery can decay to 0.9V without loss of regulation.

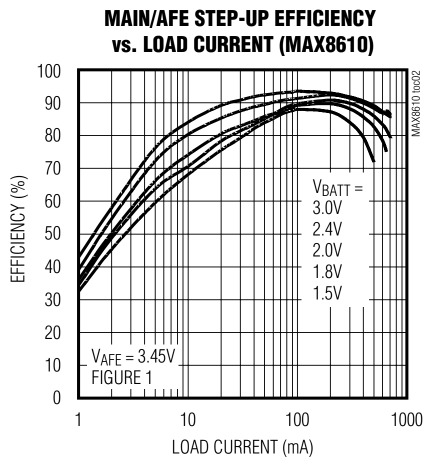
Note 2: The idle-mode current threshold is the transition point between fixed-frequency PWM operation and idle-mode operation. The specification is given in terms of output load current for an inductor value of 2µH. For the step-up, the idle-mode transition varies with input to the output-voltage ratio.

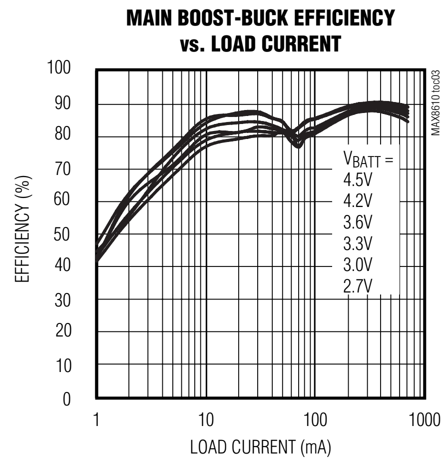
Note 3: Inverter line regulation is mostly a function of the converter duty factor, D, and is typically 20mV(D - 0.5).

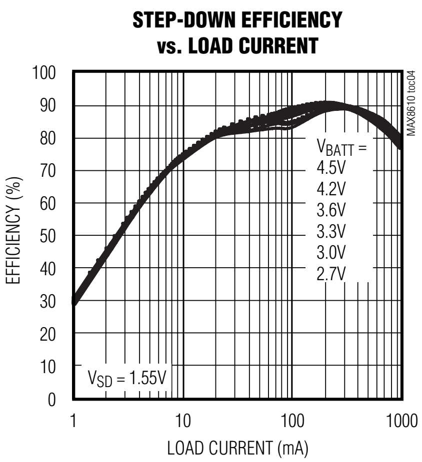
Typical Operating Characteristics

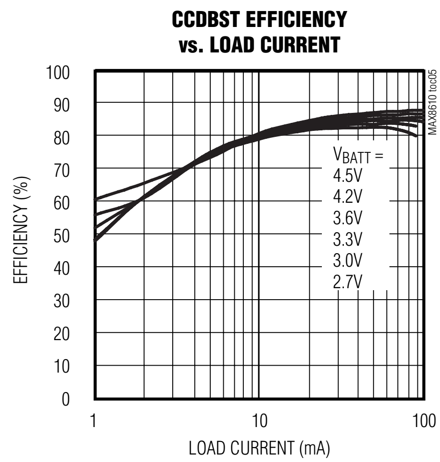
(V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE} = 3.6V, V_{PVSU} = V_{SU} = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, C_{REF} = 0.22μF, R_{REXT} = 100kΩ to GND. T_A = +25°C (Circuit of Figure 2), unless otherwise noted.)

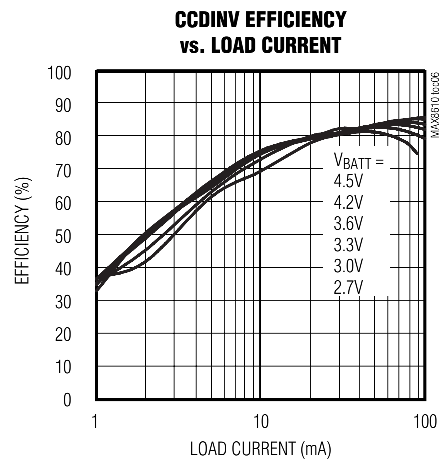


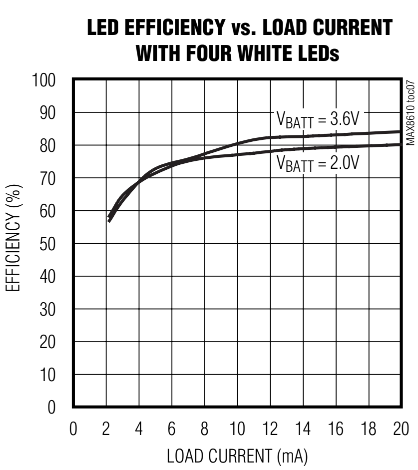


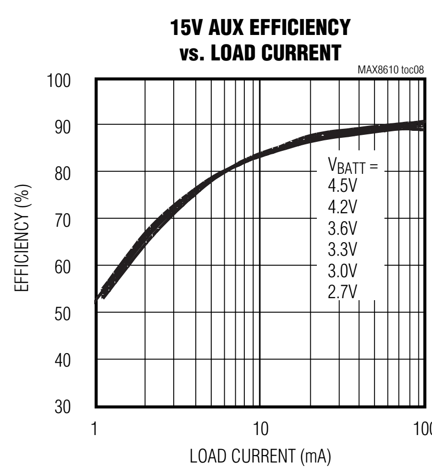










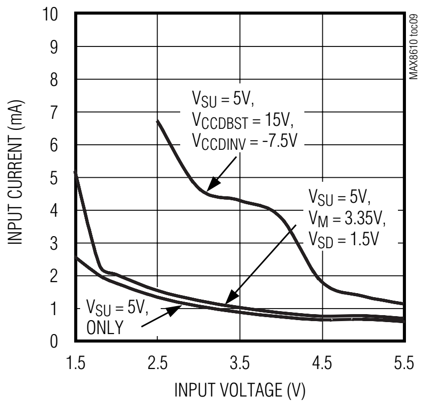


8-Channel PMICs for Digital Camera Power Supplies

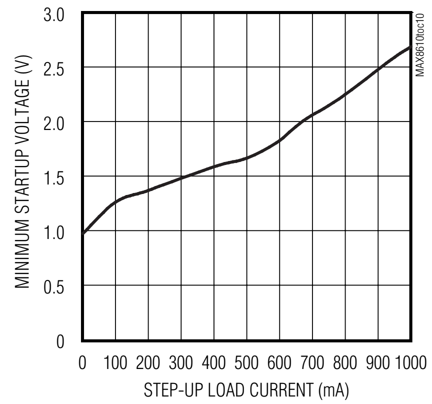
Typical Operating Characteristics (continued)

($V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE}$ = 3.6V, $V_{PVSU} = V_{SU}$ = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND. T_A = +25°C (Circuit of Figure 2), unless otherwise noted.)

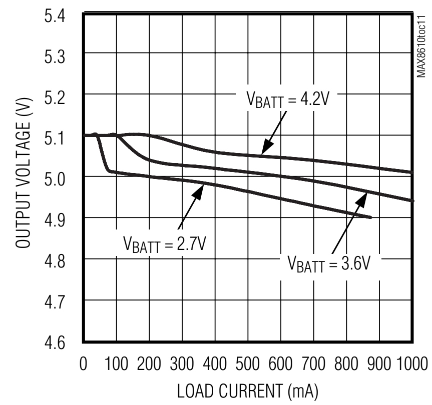
NO-LOAD INPUT CURRENT vs. INPUT VOLTAGE (INCLUDES SWITCHING LOSSES)



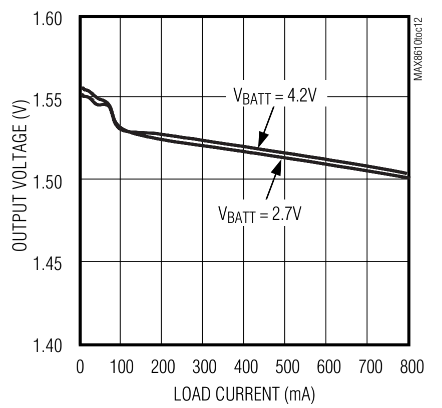
MINIMUM STARTUP VOLTAGE vs. STEP-UP LOAD CURRENT



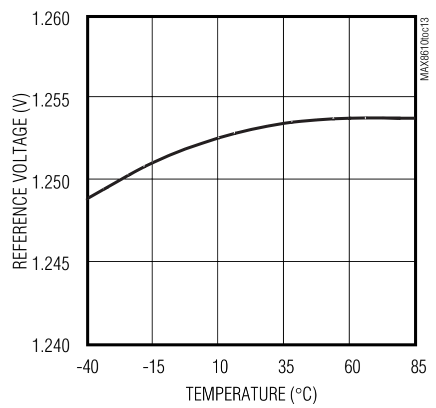
STEP-UP OUTPUT VOLTAGE vs. LOAD CURRENT



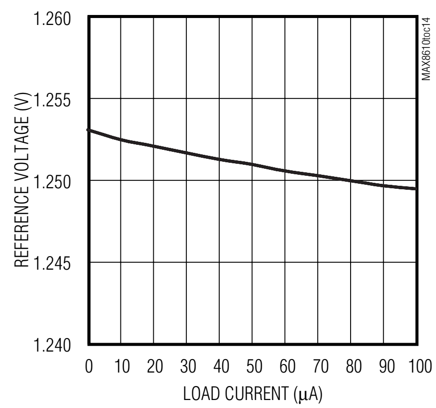
STEP-DOWN OUTPUT VOLTAGE vs. LOAD CURRENT



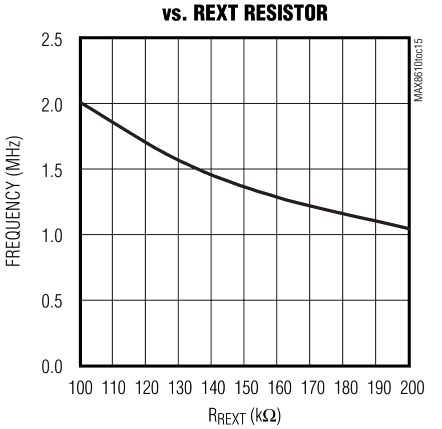
REFERENCE VOLTAGE vs. TEMPERATURE



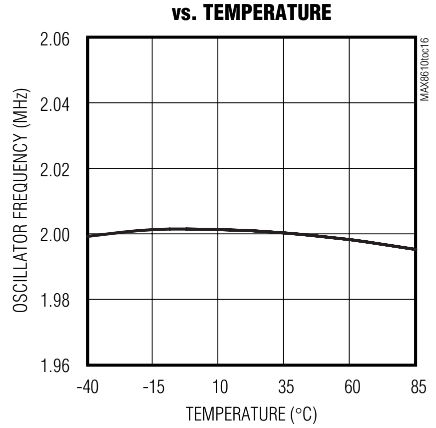
REFERENCE VOLTAGE vs. LOAD CURRENT



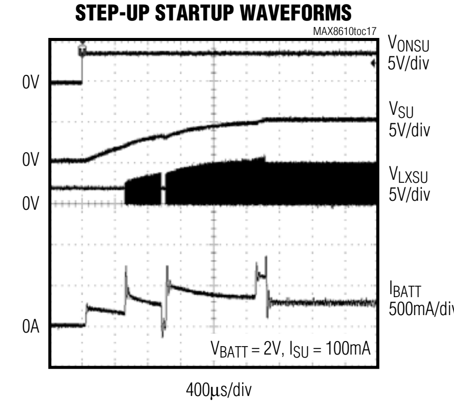
OSCILLATOR FREQUENCY vs. REXT RESISTOR



OSCILLATOR FREQUENCY vs. TEMPERATURE



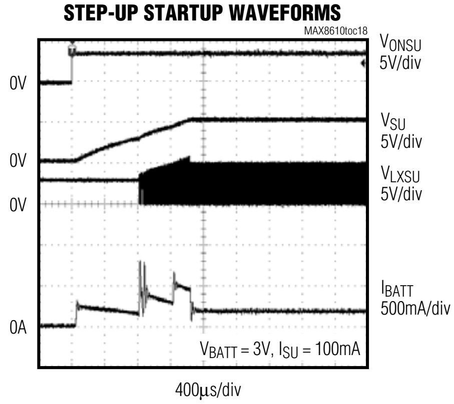
STEP-UP STARTUP WAVEFORMS



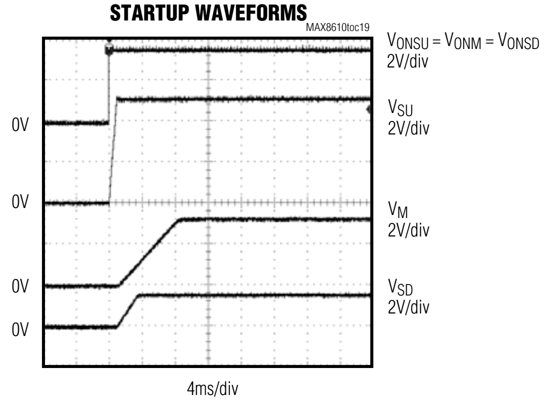
Typical Operating Characteristics (continued)

($V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE} = 3.6V$, $V_{PVSU} = V_{SU} = 5V$, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, $C_{REF} = 0.22µF$, $R_{REXT} = 100kΩ$ to GND. $T_A = +25°C$ (Circuit of Figure 2), unless otherwise noted.)

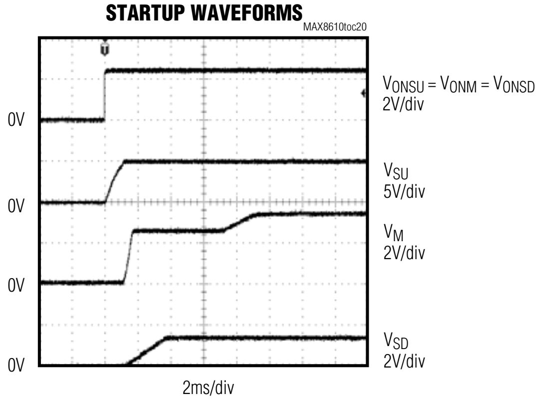
STEP-UP STARTUP WAVEFORMS



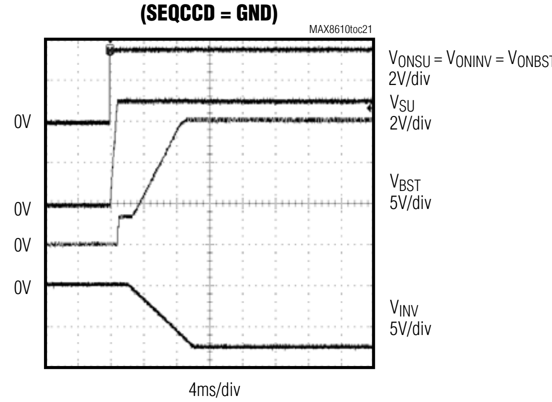
MAX8611
MAIN AND STEP-DOWN
STARTUP WAVEFORMS



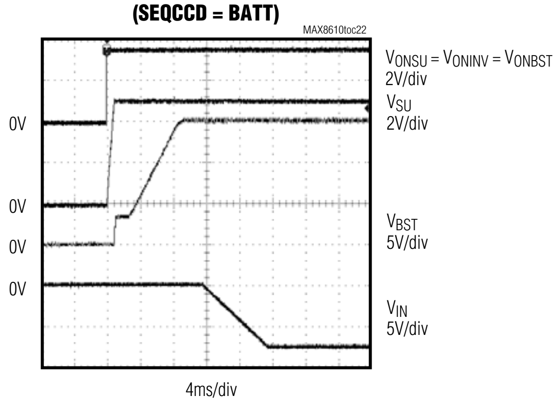
MAX8610
MAIN AND STEP-DOWN
STARTUP WAVEFORMS



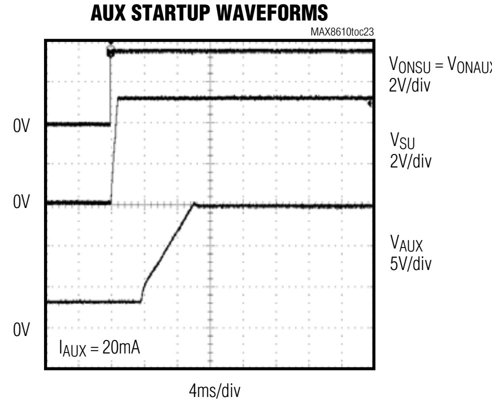
CCD STARTUP WAVEFORMS
(SEQCCD = GND)



CCD STARTUP WAVEFORMS
(SEQCCD = BATT)



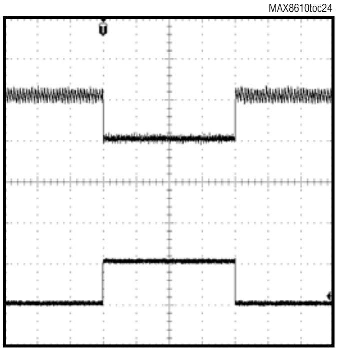
AUX STARTUP WAVEFORMS



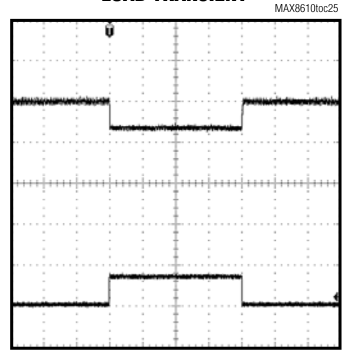
Typical Operating Characteristics (continued)

(V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE} = 3.6V, V_{PVSU} = V_{SU} = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND. T_A = +25°C (Circuit of Figure 2), unless otherwise noted.)

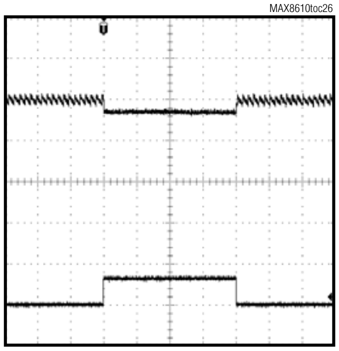
STEP-UP (V_{SU}) LOAD TRANSIENT



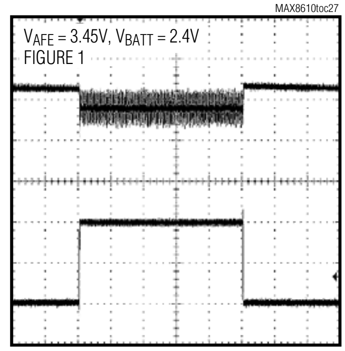
STEP-DOWN (V_{SD}) LOAD TRANSIENT



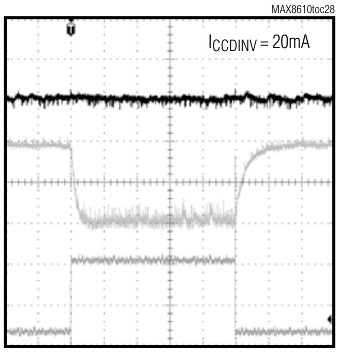
MAX8611 MAIN AS STEP-DOWN LOAD TRANSIENT



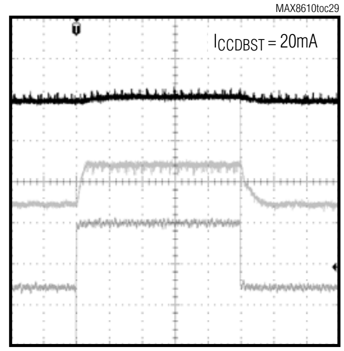
MAX8610 AFE AS STEP-UP LOAD TRANSIENT



CCDBST LOAD TRANSIENT



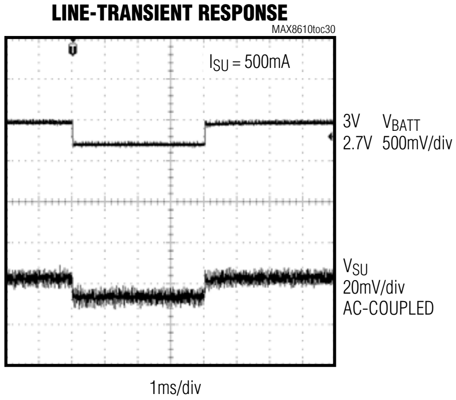
CCDINV LOAD TRANSIENT



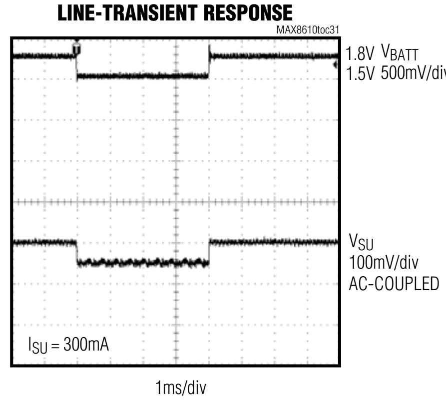
Typical Operating Characteristics (continued)

($V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE}$ = 3.6V, $V_{PVSU} = V_{SU}$ = 5V, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, C_{REF} = 0.22µF, R_{REXT} = 100kΩ to GND. T_A = +25°C (Circuit of Figure 2), unless otherwise noted.)

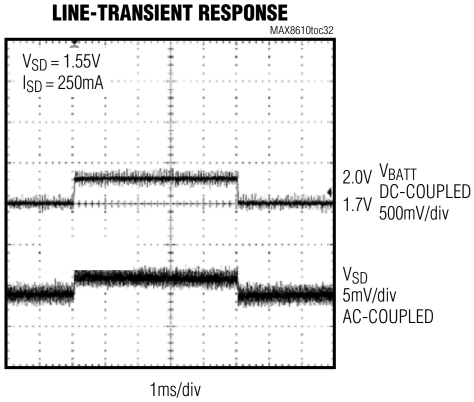
STEP-UP LINE-TRANSIENT RESPONSE



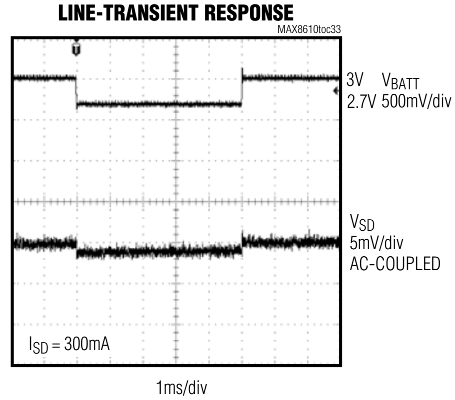
STEP-UP LINE-TRANSIENT RESPONSE



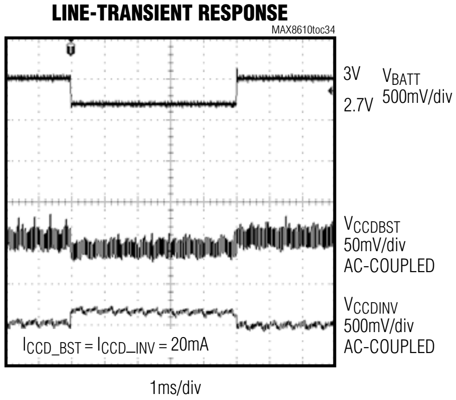
STEP-DOWN LINE-TRANSIENT RESPONSE



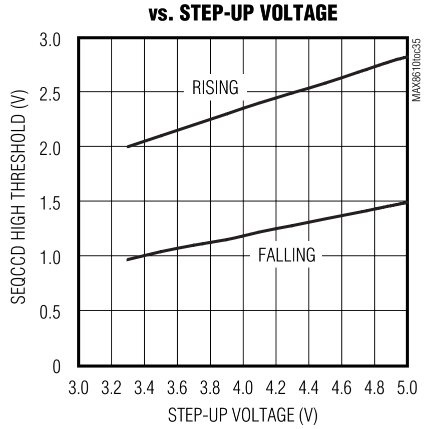
STEP-DOWN LINE-TRANSIENT RESPONSE



CCD LINE-TRANSIENT RESPONSE



SEQCCD HIGH THRESHOLD vs. STEP-UP VOLTAGE

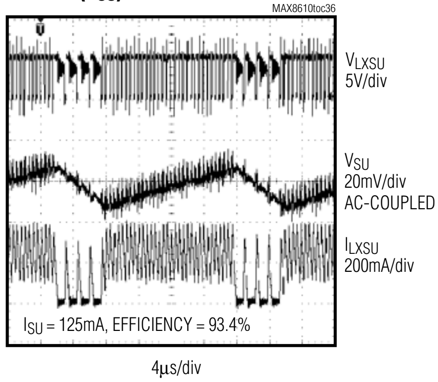


8-Channel PMICs for Digital Camera Power Supplies

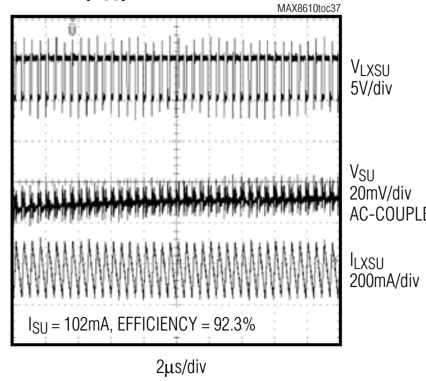
Typical Operating Characteristics (continued)

($V_{BATT} = V_{PVINV} = V_{PVLED} = V_{PVBST} = V_{PVSD} = V_{PVM} = V_{PVAFE} = 3.6V$, $V_{PVSU} = V_{SU} = 5V$, GND = PGSU = PGM = PGAFE = PGSD = PG1 = PG2, $C_{REF} = 0.22\mu F$, $R_{REXT} = 100k\Omega$ to GND. $T_A = +25°C$ (Circuit of Figure 2), unless otherwise noted.)

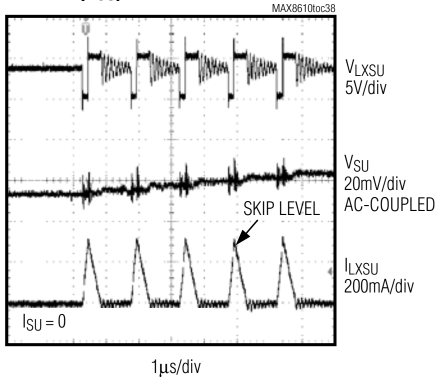
MAX8611V
STEP-UP (V_{SU}) SWITCHING WAVEFORMS



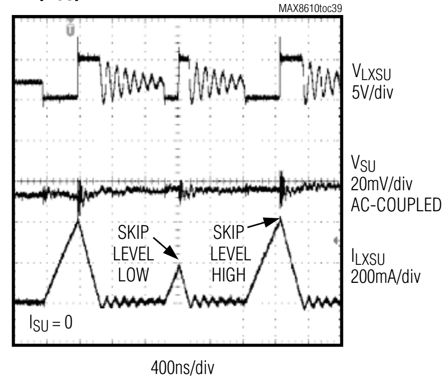
MAX8611
STEP-UP (V_{SU}) SWITCHING WAVEFORMS



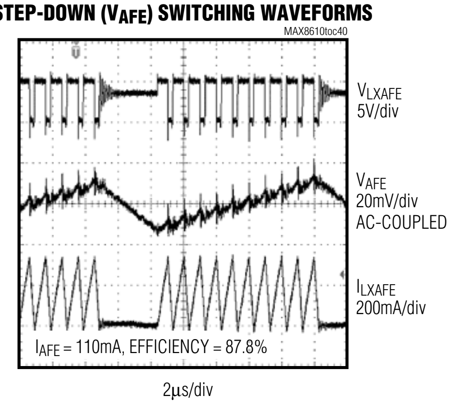
MAX8611V
STEP-UP (V_{SU}) SWITCHING WAVEFORMS



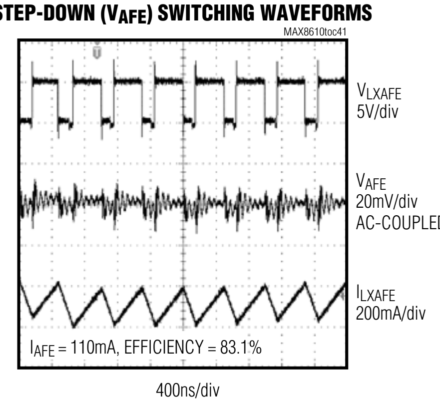
MAX8611
STEP-UP (V_{SU}) DUAL SKIP SWITCHING WAVEFORMS



MAX8611V
STEP-DOWN (V_{AFE}) SWITCHING WAVEFORMS



MAX8611
STEP-DOWN (V_{AFE}) SWITCHING WAVEFORMS



Pin Description

<table>
<tr><th>PIN</th><th>NAME</th><th colspan="2">FUNCTION</th></tr>
<tr><td>1</td><td>ONINV</td><td colspan="2">On/Off Control for the CCD Inverting Converter. Logic-high = on. The turn-on sequencing is governed by the SEQCCD pin; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
<tr><td>2</td><td>FBM</td><td colspan="2">Main Converter Feedback Input. The feedback threshold is 1.01V. This pin is high impedance in shutdown.</td></tr>
<tr><td>3</td><td>ONM</td><td colspan="2">Main Converter On/Off Control. Logic-high = on; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">PVM</td><td colspan="2">MAX8610/MAX8612: Main Configured as a Step-Up with PVM as the Power Output. PVM is pulled to ground in shutdown.</td></tr>
<tr><td colspan="2">MAX8611/MAX8613/MAX8611V: Main Configured as a Step-Down with PVM as the Power Input</td></tr>
<tr><td>5</td><td>LXM</td><td colspan="2">Main Converter Switching Node. LXM is high impedance in shutdown.</td></tr>
<tr><td>6</td><td>PGM</td><td colspan="2">Main Power Ground. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.</td></tr>
<tr><td>7</td><td>PGAFE</td><td colspan="2">AFE Power Ground. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.</td></tr>
<tr><td>8</td><td>LXAFE</td><td colspan="2">AFE Converter Switching Node. LXAFE is high impedance in shutdown.</td></tr>
<tr><td rowspan="2">9</td><td rowspan="2">PVAFE</td><td colspan="2">MAX8610/MAX8612: AFE Configured as a Step-Up with PVAFE as the Power Output. PVAFE is pulled to GND in shutdown.</td></tr>
<tr><td colspan="2">MAX8611/MAX8613/MAX8611V: AFE Configured as a Step-Down with PVAFE as the Power Input</td></tr>
<tr><td>10</td><td>ONAFE</td><td colspan="2">AFE Converter On/Off Control. Logic-high = on; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
<tr><td>11</td><td>FBAFE</td><td colspan="2">AFE Converter Feedback Input. The feedback threshold is 1.01V. This pin is high impedance in shutdown.</td></tr>
<tr><td>12</td><td>FBSD</td><td colspan="2">Step-Down Converter Feedback Input. The feedback threshold is 1.01V. This pin is high impedance in shutdown.</td></tr>
<tr><td>13</td><td>PVSD</td><td colspan="2">Step-Down Converter Input. Bypass to GND with a 10µF ceramic capacitor.</td></tr>
<tr><td>14</td><td>ONAUX</td><td colspan="2">Auxiliary Controller On/Off Control. Logic-high = on; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
<tr><td>15</td><td>ONSD</td><td colspan="2">SD Step-Down Converter On/Off Control. Logic-high = on; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
<tr><td>16</td><td>LXSD</td><td colspan="2">Step-Down Converter Switching Node. LXSD is high impedance in shutdown.</td></tr>
<tr><td>17</td><td>PGSD</td><td colspan="2">Step-Down Power Ground. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.</td></tr>
<tr><td>18</td><td>PG1</td><td colspan="2">Power Ground for One CCD Inverting Converter and Auxiliary Controller. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.</td></tr>
<tr><td rowspan="2">19</td><td rowspan="2">DRVAUX</td><td rowspan="2">AUX Controller Gate-Drive Output. DRVAUX drives between PVINV and PG1.</td><td>MAX8610/MAX8611/MAX8611V: DRVAUX drives an n-channel FET in a boost configuration. DRVAUX is driven to GND in shutdown.</td></tr>
<tr><td>MAX8612/MAX8613: DRVAUX drives a p-channel FET in an inverter configuration. DRVAUX is driven to PVINV in shutdown.</td></tr>
<tr><td>20</td><td>PVINV</td><td colspan="2">CCD Inverting Converter Input. Bypass to GND with a 1µF ceramic capacitor.</td></tr>
<tr><td>21</td><td>LXINV</td><td colspan="2">CCD Inverting Converter Switching Node. LXINV is high impedance in shutdown.</td></tr>
<tr><td>22</td><td>ONBST</td><td colspan="2">On/Off Control for the CCD Boosting Converter. Logic-high = on. The turn-on sequencing is governed by the SEQCCD pin; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.</td></tr>
</table>

Pin Description (continued)

PIN	NAME	FUNCTION
23	FBAUX	**MAX8610/MAX8611/MAX8611V:** Auxiliary Boost Controller Feedback Input. The feedback threshold is 1.25V. This pin is high impedance in shutdown in the MAX8610/MAX8611V. This pin is shorted to GND in shutdown for MAX8611..
		MAX8612/MAX8613: Auxiliary Inverter Controller Feedback Input. The feedback threshold is 0V. This pin is shorted to GND in shutdown.
24	CCAUX	Auxiliary Controller Compensation Node. This pin is pulled to GND in shutdown.
25	FBINV	CCD Inverting Converter Feedback Input. The feedback threshold is 0V. This pin is shorted to GND in shutdown.
26	FBBST	CCD BST Converter Feedback Input. The feedback threshold is 1.01V. This pin is high impedance in shutdown.
27	SEQCCD	When **SEQCCD is low**, the inverter and the boost start simultaneously if ONBST and ONINV are connected together. If not connected together, ONBST and ONINV have independent control. When **SEQCCD is high**, the inverter is held off until the boost completes soft-start and is in regulation, and then begins its own soft-start.
28	GD	Gate-Drive Input for Internal MOSFET on the CCD BST and LED BST. Connect to BATT for Li+ and connect to PVSU for 2 AA. This pin is high impedance in shutdown.
29	PVBST	CCD BST Converter Input. Bypass to GND with a 1µF ceramic capacitor.
30	SWBST	CCD BST True Shutdown Switch. The CCD BST inductor is connected between SWBST and LXBST. This pin is high impedance in shutdown.
31	LXBST	CCD BST Open-Drain Switching Inductor Node. The CCD BST inductor is connected between SWBST and LXBST. This pin is high impedance in shutdown.
32	PG2	Power Ground to the CCDBST and LEDBST Converters. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.
33	LXLED	LED Open-Drain Switching Inductor Node. The LED inductor is connected between SWLED and LXLED. This pin is high impedance in shutdown.
34	SWLED	LED True Shutdown Switch. The LED BST inductor is connected between SWLED and LXLED. This pin is high impedance in shutdown.
35	PVLED	LED BST Converter Power Input. Bypass to GND with a 1µF ceramic capacitor.
36	ONLED	LED Converter On/Off Control. Logic-high = on; however, turn-on is locked out until the SU step-up DC-DC converter output has reached its final value.
37	FBLLED	The LED Boost Has Two Feedback Inputs, One for Current (FBLLED) and One for Maximum Voltage (FBHLED). The FBLLED feedback threshold is 0.24V. The FBHLED threshold is 1.01V. Soft-start is implemented by sensing the output voltage with the FBHLED pin. The FBHLED input must be connected to provide a feedback path for soft-start. FBLLED and FBHLED are high impedance in shutdown. Connect FBLLED to GND if using only the FBHLED feedback.
38	FBHLED	
39	REXT	Connect a 100kΩ resistor from REXT to GND to program the internal OSC to 2MHz. Connect a 200kΩ resistor from REXT to GND to program the internal OSC to 1MHz. See the *Setting the Switching Frequency* section.
40	REF	1.25V Reference Output. Bypass REF to GND with a 0.22µF ceramic capacitor. This pin is internally pulled to GND in shutdown.
41	GND	Analog Ground. Connect to all PG_ pins as close to the device as possible.
42	FBSU	Step-Up Converter Feedback Input. The feedback threshold is 1.01V. This pin is high impedance in shutdown.
43	SU	Device Input Power Bootstrapped from PVSU. Connect PVSU and SU together.
44	PVSU	Step-Up Converter Output

Pin Description (continued)

PIN	NAME	FUNCTION
45	BATT	Power-Supply Input. Bypass with a 47µF ceramic capacitor.
46	ONSU	Step-Up Converter On/Off Control. Logic-high = on. All other ON_ pins are locked out until the SU step-up DC-DC converter output has reached its final value. ONSU must be pulled high or toggled low then high after BATT is present for the SU to start up.
47	LXSU	SU Step-Up Converter Switching Node. LXSU is high impedance in shutdown.
48	PGSU	SU Step-Up Power Ground. Connect all PG_ pins to GND with short, wide traces as close to the device as possible.
—	EP	Exposed Metal Pad. This pad is internally connected to ground through a soft connect, meaning there is no internal metal or bond wire physically connecting the exposed pad to the GND pin. Connecting the exposed pad to ground does not remove the requirement for a good ground connection to the appropriate pins. For good thermal dissipation, the exposed pad must be connected to the power ground plane.

Detailed Description

The MAX8610–MAX8613/MAX8611V can accept inputs from a variety of sources including 1-cell Li+ batteries, 2-cell alkaline or NiMH batteries, and systems designed to accept both battery types. All devices include seven DC-DC converter channels and one controller channel to build a multiple-output DSC power-supply system:

- Step-up DC-DC synchronous-rectified converter (_SU pins) with on-chip power FETs and True Shutdown.
- Main DC-DC synchronous-rectified converter (_M pins) with on-chip power FETs configured as a True Shutdown step-up (MAX8610/MAX8612) or step-down (MAX8611/MAX8613/MAX8611V) DC-DC converter.
- Analog front-end (AFE) DC-DC synchronous-rectified converter (_AFE pins) with on-chip power FETs configured as a True Shutdown step-up (MAX8610/MAX8612) or step-down (MAX8611/MAX8613/MAX8611V) DC-DC converter.
- Core step-down DC-DC synchronous-rectified converter (_SD pins) with on-chip power FETs.
- CCD step-up DC-DC converter (_BST pins) with on-chip power FET and an internal switch for True Shutdown.
- CCD inverting DC-DC converter (_INV pins) with on-chip power FET.
- WLED step-up DC-DC converter (_LED pins) with on-chip power FET and an internal switch for True Shutdown; includes constant current drive for white LEDs and open LED overvoltage protection. Can also be used for conventional boost applications.
- AUX DC-DC controller driving an external n-MOSFET for boost converters (MAX8610/MAX8611/MAX8611V) or driving an external p-MOSFET for inverters (MAX8612/MAX8613).

A typical application circuit for the MAX8610 using 2 AA cell batteries is shown in Figure 1. Figure 2 shows a typical application circuit for a single-cell Li+ battery input using the MAX8611. Figure 2 can also operate in systems designed to be powered from both Li+ and 2 AA cells.

All converters operate in a low-noise PWM mode with constant frequency and modulated pulse width under moderate to heavy loading. Efficiency is enhanced at light loads by switching to an idle mode where the converter switches only as needed to service the load. The synchronous-rectified converters (SU, MAIN, AFE, and SD) switch at a frequency set by an external resistor REXT (see the *Setting the Switching Frequency* section). The CCD and LED converters switch at one-half the frequency of the synchronous-rectified converters. The AUX controller switches at one-quarter the set switching frequency. Table 2 (see the *Oscillator* section) gives the switching frequency for each channel for oscillator frequencies of 1MHz and 2MHz.

Individual ON_ pins are provided for independent on/off control. The MAX8610–MAX8613/MAX8611V guarantee startup with an input voltage as low as 1.5V and remain operational with input voltages down to 0.9V. The MAX8610–MAX8613/MAX8611V also include overload protection and soft-start circuitry. See Figure 3 for the functional diagram.

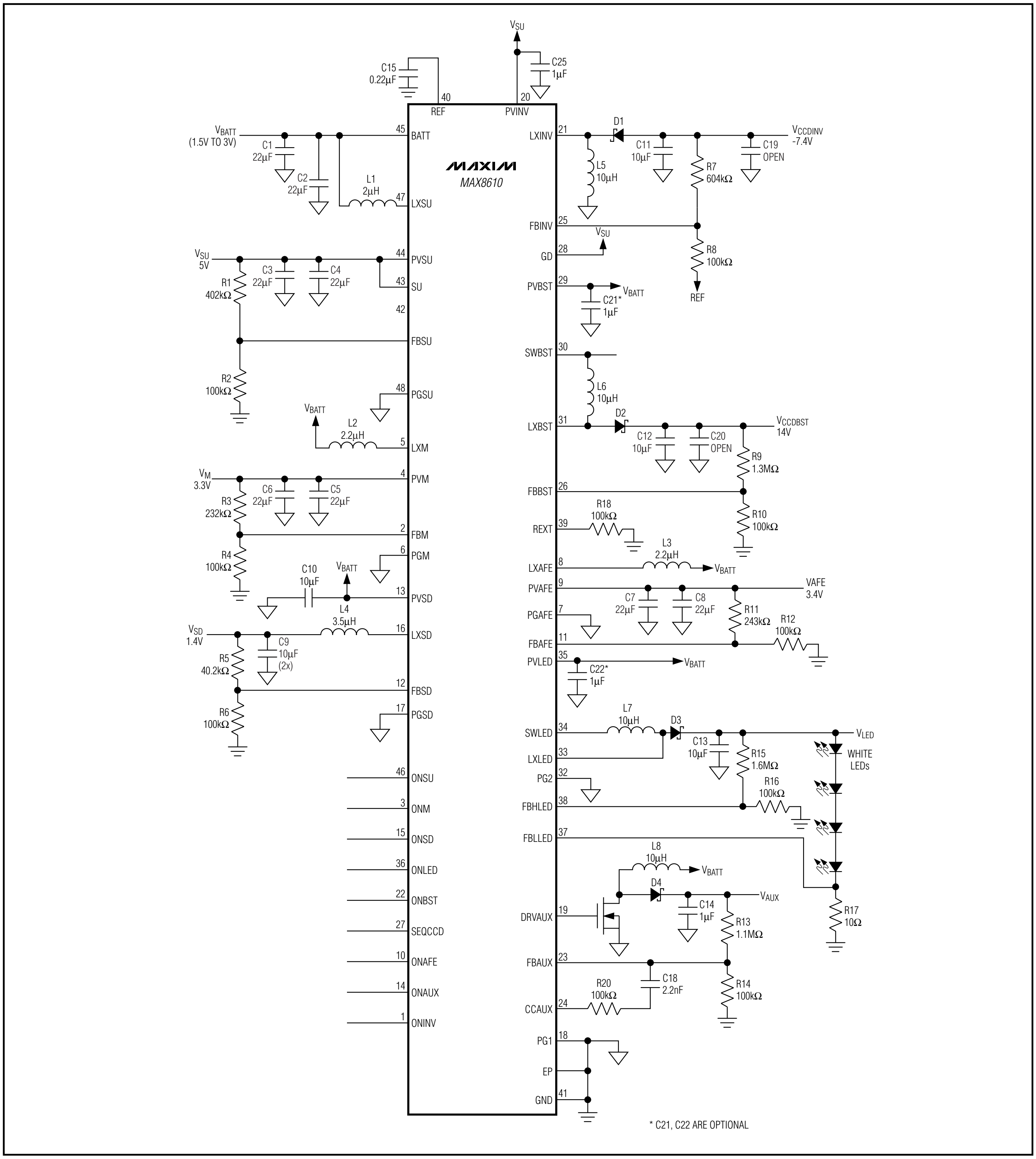


Figure 1. MAX8610 (2 AA Input) Typical Application Circuit. The MAIN and AFE outputs operate as step-up converters.

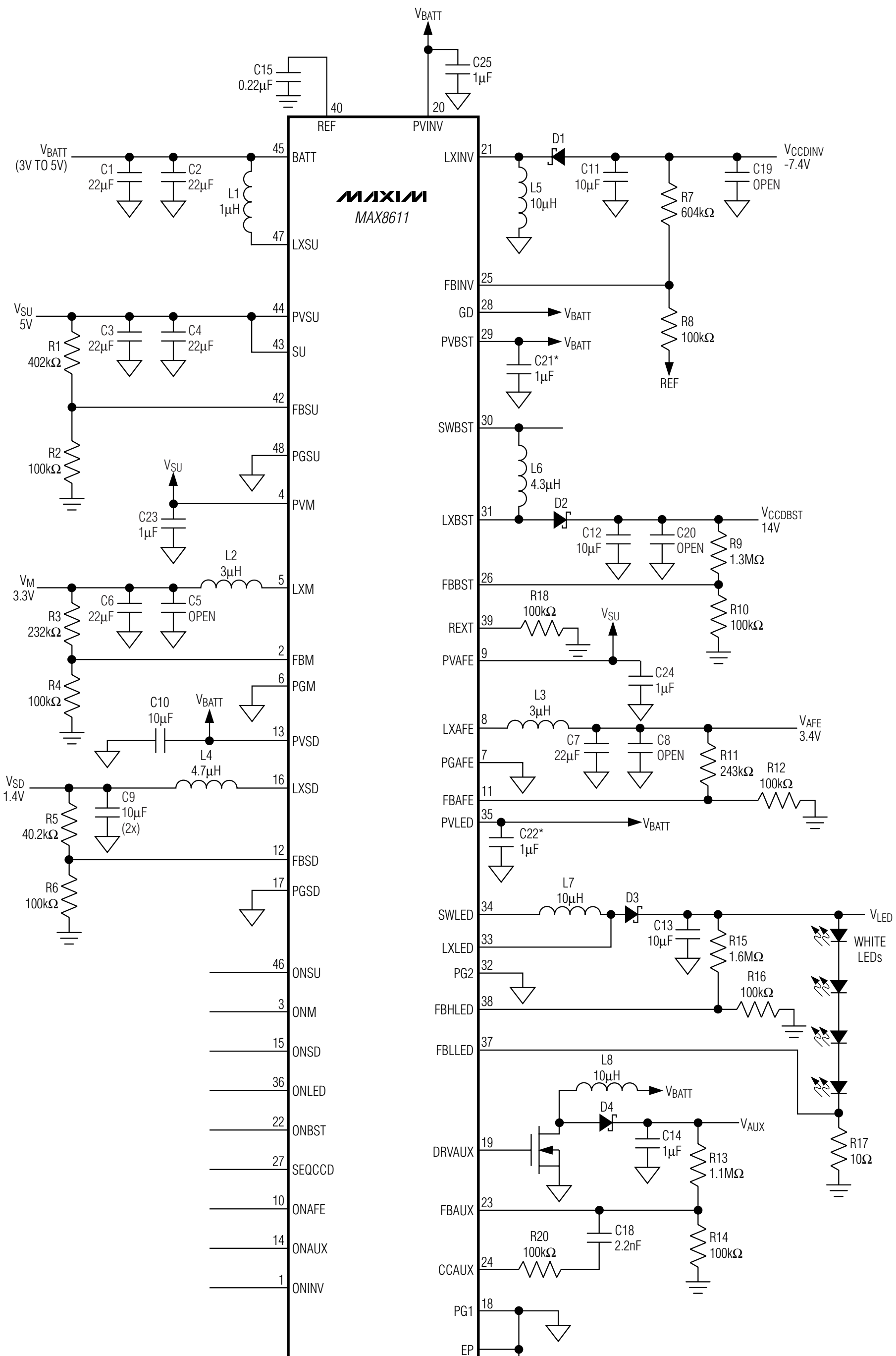


Figure 2. MAX8611 (Li+ or Combination Li+/2 AA Input) Typical Application Circuit. The MAIN (M) and AFE outputs operate as step-down converters and are powered from the step-up (SU) for efficient boost-buck operation.

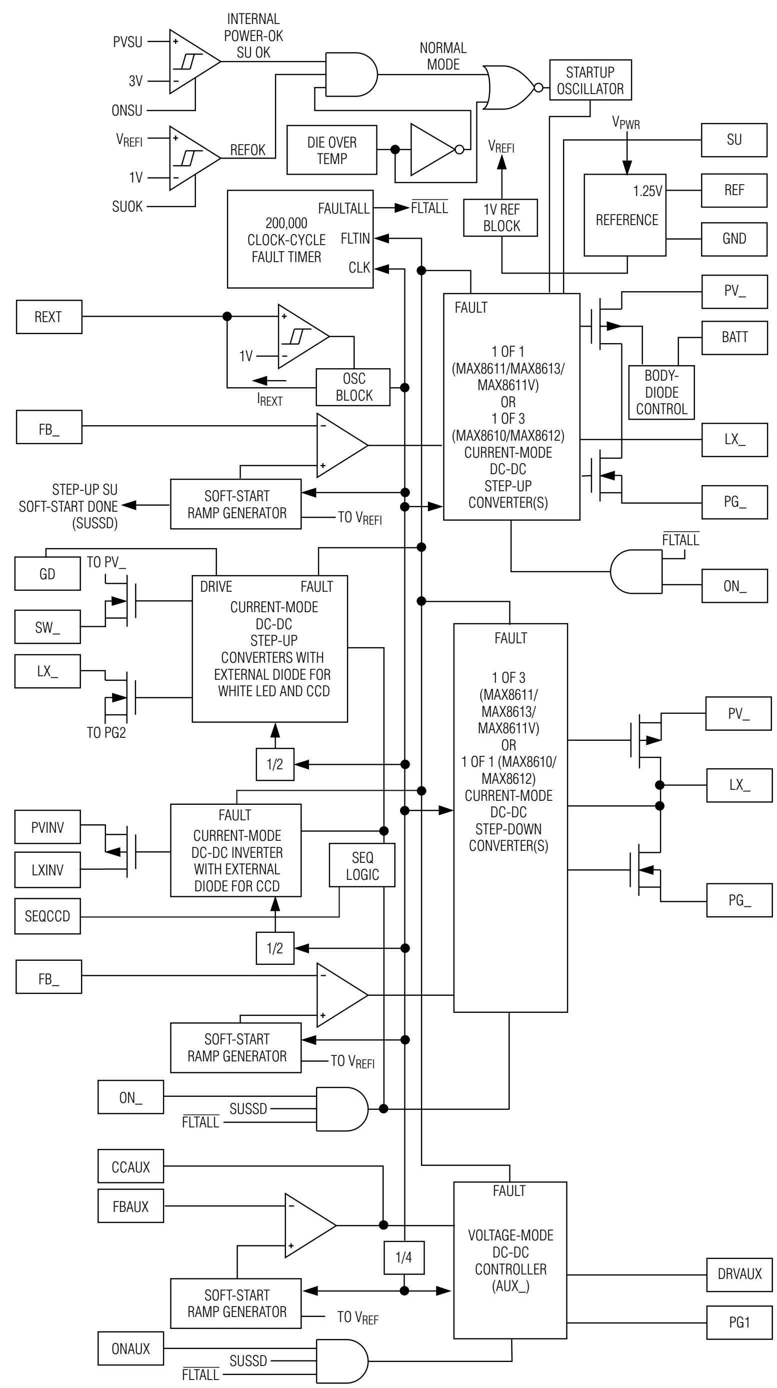


Figure 3. MAX8611 Functional Diagram

The seven converter channels all use peak current-mode control and are internally compensated. These converters utilize a load line architecture to allow the output capacitor to be the dominant pole by lowering the loop gain. As a result, the MAX8610–MAX8613/MAX8611V match the load and line regulation to the voltage droop seen during transients. This is sometimes called voltage positioning. This architecture minimizes the voltage overshoot when the load is removed, and voltage droop during transition from a light load to full load (see the Load Transient graphs in the *Typical Operating Characteristics*). Thus, the voltage delivered to the load remains within spec more effectively than with regulators that might have tighter initial DC accuracy. This type of response is of great importance in digital cameras where the load may vary significantly in small time durations. See more details in the *Load-Transient Response* section. The AUX controller employs voltage-mode control and needs external compensation (see the *AUX Compensation* section).

SU Step-Up DC-DC Converter

The SU step-up DC-DC switching converter typically generates a 5V output voltage from a 1.5V to 4.2V battery input voltage, but any voltage from 3.3V to 5V can be set. The SU output voltage must be greater than or equal to the voltage output of the MAIN, AFE, and SD converters. An internal nFET switch and internal synchronous rectifier allow conversion efficiencies as high as 95%. Under moderate to heavy loading, the converter operates in a low-noise PWM mode with constant frequency and modulated pulse width. Switching harmonics generated by fixed-frequency operation are consistent and easily filtered.

The SU step-up is a current-mode converter. The difference between the feedback voltage and a 1V reference signal generates an error signal that programs the peak inductor current to regulate the output voltage. The peak inductor current limit is typically 2.5A. Inductor current is sensed across the internal switch and summed with an internal slope-compensation signal.

At light loads (less than 50mA (MAX8610–MAX8613)/ 125mA (MAX8611V) when boosting to 5V from a 3.6V input), efficiency is enhanced by an idle mode in which switching occurs only as needed to service the load. This idle-mode threshold is determined by comparing the current-sense signal to an internal reference (Figure 3). In idle mode, the synchronous rectifier shuts off once its current falls to 10mA, preventing negative inductor current.

In idle mode, the peak inductor current is fixed and the repetition rate is varied as required to keep the output voltage within the specified limits. In the MAX8610–MAX8613, there are two skip levels for this peak inductor current in idle mode. For loads less than 50mA (at V_{IN} = 3.6V and V_{SU} = 5V), a larger skip pulse (400mA) is used to increase the time between pulses and enhance efficiency (see the MAX8611 Step-Up (V_{SU}) Dual Skip Switching Waveforms in the *Typical Operating Characteristics*). For loads greater than 100mA, a smaller skip pulse (200mA) is used to ensure that a pulse is given for every clock cycle (constant frequency operation) (see the MAX8611 Step-Up (V_{SU}) Dual Skip Switching Waveforms in the *Typical Operating Characteristics*). In the MAX8611V, only a single skip level (300mA) is used when the converter is in the idle-mode operation (see the MAX8611V Step-Up (V_{SU}) Switching Waveforms in the *Typical Operating Characteristics*). A single skip level results in higher efficiency for loads between 100mA and 125mA.

The step-up output, PVSU, can start up into a load (see the *Typical Operating Characteristics*). The soft-start duration is proportional to the size of the output cap and load resistor with a maximum of 7.5ms. Under normal operation PVSU provides power to the device. After PVSU reaches regulation, the input voltage can drop as low as 0.9V without affecting circuit operation (although available output power from the boost is reduced at very low inputs). All other outputs are locked out until the SU step-up reaches its regulation voltage. The step-up features True Shutdown, which eliminates the “sneak” body-diode path from input to output and allows the boost output to fall to GND in shutdown.

MAIN and AFE Step-Up DC-DC Converter (M and AFE, MAX8610/MAX8612)

MAIN and AFE are configured as step-up converters in the MAX8610 and MAX8612. MAIN and AFE typically generate 3.3V for system I/O and 3.4V for the CCD analog front end, respectively. However, any voltage from BATT to V_{SU} can be set.

An internal nFET switch and internal synchronous rectifier allow conversion efficiencies as high as 93%. Under moderate to heavy loading, the converter operates in a low-noise PWM mode with constant frequency and modulated pulse width. Switching harmonics generated by fixed-frequency operation are consistent and easily filtered.

At light loads (less than 50mA when boosting to 5V from a 1.8V input), efficiency is enhanced by an idle mode in which switching occurs only as needed to service the load. The idle-mode current threshold is determined by comparing the current-sense signal to an internal reference (Figure 3). In idle mode, the synchronous rectifier shuts off once its current falls to 10mA, preventing negative inductor current.

8-Channel PMICs for Digital Camera Power Supplies

The MAIN and AFE converters have True Shutdown. The output of the MAIN and AFE converters are pulled to GND in shutdown.

MAIN and AFE Step-Down DC-DC Converter (M and AFE, MAX8611/MAX8613/MAX8611V)

MAIN and AFE are configured as step-downs in the MAX8611/MAX8613/MAX8611V. MAIN and AFE derive power from PVM and PVAFE, respectively. These pins can be connected directly to BATT as long as the output is less than the battery voltage, or can be connected to the step-up output for efficient boost-buck operation. MAIN and AFE typically generate 3.3V for the system I/O and 3.4V for CCD sensor, respectively. However, any voltage from 1V to 5V that is less than or equal to the output of the step-up converter V_{SU} can be set.

An internal-MOSFET switch and synchronous rectifier allow conversion efficiencies as high as 90% (boost-buck operation). Under moderate to heavy loading, the converter operates in a low-noise PWM mode with constant frequency and modulated pulse width. Switching harmonics generated by fixed-frequency operation are consistent and easily filtered. At light loads (typically less than 50mA (MAX8611/MAX8613)/125mA (MAX8611V)), efficiency is enhanced by an idle mode in which switching occurs only as needed to service the load.

In idle mode, the peak inductor current is fixed and the repetition rate is varied as required to keep the output voltage within the specified limits. In the MAX8610–MAX8613, there are two skip levels for this peak inductor current in idle mode. For loads less than 50mA (at V_{IN} = 3.6V and V_{SU} = 5V), a larger skip pulse (400mA) is used to increase the time between pulses and enhance efficiency (see the MAX8611 Step-Up (V_{SU}) Dual Skip Switching Waveforms in the *Typical Operating Characteristics*). For loads greater than 100mA, a smaller skip pulse (200mA) is used to ensure that a pulse is given for every clock cycle (constant-frequency operation) (see the MAX8611 Step-Up (V_{SU}) Dual Skip Switching Waveforms in the *Typical Operating Characteristics*). In the MAX8611V, only a single skip level (300mA) is used when the converter is in the idle-mode operation (see the MAX8611V Step-Up (V_{SU}) Switching Waveforms in the *Typical Operating Characteristics*). A single skip level results in higher efficiency for loads between 100mA and 125mA.

Li+ to 3.3V Boost-Buck Operation

When generating 3.3V or a similar voltage from a Li+ cell, boost-buck operation may be needed so that a regulated output can be maintained for input voltages above and below 3.3V. In that case, it may be best to use the MAIN and AFE converters as step-downs (with the MAX8611/MAX8613/MAX8611V) and to connect the inputs, PVM and PVAFE, to the step-up output (PVSU in Figure 2). The compound efficiency with this connection is typically up to 90%. This connection is also suitable for designs that must operate from both 1-cell Li+ and 2 AA cells. Note that the step-up output supplies both the step-up load and the input current of the MAIN and AFE step-downs so the MAIN and AFE input current reduces the available step-up output current for other loads.

2 AA Operation

In designs that operate only from 2 AA cells, the MAIN and AFE DC-DC converters operate as step-ups in the MAX8610/MAX8612. This connection is shown in Figure 1.

Step-Down DC-DC Converter (SD)

The SD step-down DC-DC converter is optimized to generate low output voltages (down to 1V) at high efficiency, typically to power a DSP core. The SD step-down is powered from PVSD. PVSD can be connected directly to the battery if there is sufficient headroom; otherwise, it can be powered from the output of another converter. The SD step-down can also operate from the SU step-up (or another boost in the MAX8610/MAX8612) for boost-buck operation.

Under moderate to heavy loading, the SD converter operates in a low-noise PWM mode with constant frequency and modulated pulse width. Efficiency is enhanced under light (50mA typ) loading by assuming an idle mode during which the step-down switches only as needed to service the load.

In idle mode, the peak inductor current is fixed and the repetition rate is varied as required to keep the output voltage within the specified limits. In the MAX8610–MAX8613 there are two skip levels for this peak inductor current in idle mode. For loads less than 50mA (at V_{IN} = 3.6V and V_{SU} = 5V), a larger skip pulse (400mA) is used to increase the time between pulses and to enhance efficiency. For loads greater than 100mA, a smaller skip pulse (200mA) is used to ensure that a pulse is given for every clock cycle (constant frequency operation). In the MAX8611V, only a single skip level (300mA) is used when the converter is in the idle-mode operation. A single skip level results in higher efficiency for loads between 100mA and 125mA.

The soft-start time for SD is shorter relative to M and AFE in order to maintain tracking during power-up. SD typically has a lower output voltage, so if SD is set to 1.2V and M or AFE (MAX8611/MAX8613/MAX8611V) is set to 3.3V, the two outputs track up to the point where both reach 1.2V, if the two converters are enabled at the same time. The SD step-down DC-DC converter is inactive until the SU step-up DC-DC converter is in regulation.

Table 1. Truth Table for SEQCCD, ONBST, and ONINV

ONINV	ONBST	SEQCCD	BST O/P	INV O/P
H	H	L	On	On
H	L	L	Off	On
L	H	L	On	Off
L	L	L	Off	Off
X	L	H	Off	Off
L	H	H	On	Off
H	H	H	On	On (turns on after BST is in regulation)

LED and CCD, BST, and INV Converters

The MAX8610–MAX8613/MAX8611V include a boost and inverting DC-DC converter to supply both positive and negative CCD (and/or LCD) bias and WLED supply. All converters use a fixed-frequency, PWM current-mode control scheme. The heart of the current-mode PWM controllers is a comparator that compares the feedback error signal against the sum of the amplified current-sense signal and a slope-compensation ramp. At the beginning of each clock cycle, the internal power switch turns on until the PWM comparator trips. During this time the current in the inductor ramps up, storing energy in the inductor's magnetic field. When the power switch turns off, the inductor releases the stored energy while the current ramps down, providing current to the output. These converters operate at one-half the frequency of the SU, M, AFE, and SD converters.

LED and CCD Boost Converter (BST)

The CCD boost converter generates a positive output voltage up to 27V. An internal power switch, internal True Shutdown switch, and external catch diode allow conversion efficiencies as high as 90%.

The internal True Shutdown switch disconnects the battery from the load by opening the battery connection to the inductor. The True Shutdown switch stays on at all times during normal operation. The boost converter also features soft-start to limit inrush current and minimize battery loading at startup. This is accomplished by ramping the reference voltage at the input of the error amplifier. The boost reference is ramped from 0 to 1V (where 1V is the desired feedback voltage). During startup, the boost-converter load switch turns on before the boost-converter reference voltage is ramped up. This effectively limits startup inrush current to below 500mA and provides short-circuit protection (SCP).

CCD Inverter (INV)

The inverter generates output voltages down to -10V. An internal power switch and external catch diode allow conversion efficiencies as high as 90%. The inverter soft-starts by ramping the reference input of the error amplifier from 1.25V to 0V (where 0V is the inverter's normal operating feedback point).

Power-On Sequencing (SEQ)

The CCD boost and inverter have pin-selectable power-on sequencing as set by the SEQCCD pin (see Table 1 and the *Typical Operating Characteristics*). This covers all typical sequencing options required by CCD imagers. The SEQCCD should be connected to V_{SU} for a high level and to GND for a low level. See the *Typical Operating Characteristics* for the SEQCCD threshold as a function of the SU converter output voltage V_{SU}.

When SEQCCD = 0 and both ONBST and ONINV are pulled high together, both outputs reach regulation at approximately the same time. The inverter is held off while the boost load switch slowly turns ON to pull SWBST to V_{BATT}. The positive output rises to a diode drop below V_{BATT}. Once the boost output reaches this voltage, the boost and the inverter then ramp their respective references over a period of 7.5ms. This brings the two outputs into regulation at approximately the same time.

When SEQCCD = 1 and both ONBST and ONINV are pulled high together, the boost output powers on first. The inverter is held off until the boost completes its entire soft-start cycle and the positive output is in regulation. Then the inverter starts its soft-start cycle and achieves regulation in approximately 7.5ms.

When SEQCCD = 0 if ONBST and ONINV are not connected together, then there is no internal power-up sequencing and the two converters can be independently controlled with the respective ON pins.

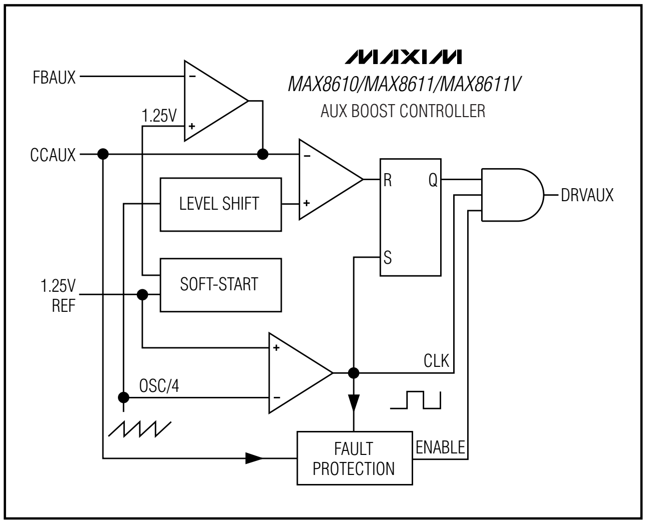


Figure 4. AUX Boost-Controller Block Diagram

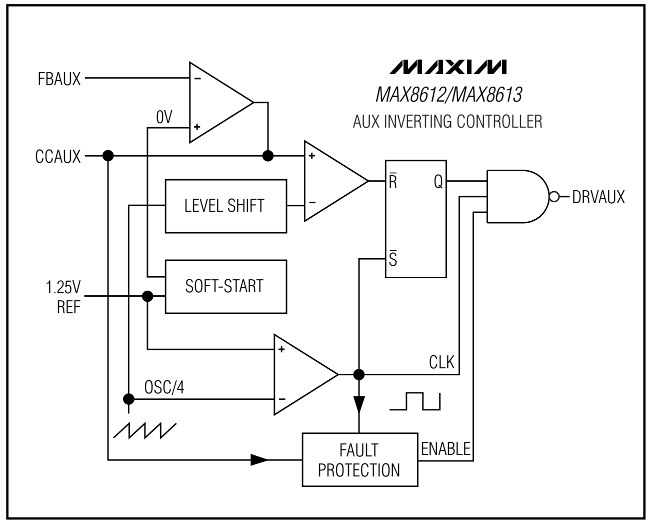


Figure 5. AUX Inverter-Controller Block Diagram

AUX Controller

One auxiliary DC-DC controller is provided for an additional boost or inverter channel. On the MAX8610/MAX8611/MAX8611V, the AUX controller drives an external n-channel MOSFET in a boost configuration. On the MAX8612/MAX8613, the AUX controller drives an external p-channel MOSFET in an inverter configuration. Since the controller does not include internal power MOSFETs, output power and efficiency is determined largely by external components.

The AUX controller regulates output voltage by modulating the pulse width of DRVAUX based on the feedback input at FBAUX. The controller is voltage mode and requires external compensation at CCAUX. AUX operates at 1/4 the frequency of the SU, MAIN, AFE, and SD converters.

Figures 4 and 5 show functional diagrams of AUX boost and inverter controllers. A sawtooth oscillator signal at OSC governs timing. At the start of each cycle, during normal operation DRVAUX goes high on the MAX8610/MAX8611/MAX8611V, turning on the external nFET switch (DRVAUX goes low on the MAX8612/MAX8613 to turn on a pFET switch for the inverter). The switch then turns off when the internally level-shifted sawtooth crosses CCAUX or when the maximum duty cycle is exceeded. The switch remains off until the start of the next cycle.

Maximum Duty Cycle

The AUX PWM controllers have a guaranteed maximum duty cycle of 86% and typically can reach 87.5%. In designs that require continuous inductor current (where the inductor does not discharge to zero at the end of each switching cycle), the maximum duty cycle limits the boost ratio so that:

$$D_{BST} = 1 - (V_{IN} / V_{OUT}) < 86\%$$

or, for inverters, it limits the ratio so that:

$$D_{INV} = |V_{OUT}| / (|V_{OUT}| + V_{IN}) < 86\%$$

Note that with discontinuous inductor current, no such limit exists for the input/output ratio since the inductor has time to fully discharge before the next cycle begins.

Soft-Start

All DC-DC converter channels feature soft-start to limit inrush current and prevent excessive battery loading at startup by ramping the output voltage of each channel up to the regulation voltage. This is accomplished by ramping the internal reference inputs to each channel error amplifier when a channel is enabled.

The soft-start ramps for most channels take 15,000 OSC cycles (or 15ms for a 1MHz oscillator). One exception is the SD step-down converter, where the soft-start ramp takes 5000 OSC cycles. The soft-start time for SD is less relative to other channels in order to match power-up tracking since SD typically has a lower output voltage. Note, however, that no channels start until the SU step-up reaches regulation.

Fault Protection

The MAX8610–MAX8613/MAX8611V have robust fault and overload protection. After power-up, the device is set to detect an out-of-regulation state that could be caused by an overload or short. If any DC-DC converter channel remains faulted for 200,000 clock cycles

Table 2. Switching Frequency for Each Converter Channel

REXT (kΩ)	SU (MHz)	MAIN (MHz)	AFE (MHz)	SD (MHz)	CCDBST (MHz)	CCDINV (MHz)	LEDBST (MHz)	AUX (MHz)
100	2	2	2	2	1	1	1	0.5
200	1	1	1	1	0.5	0.5	0.5	0.25

(200ms at 1MHz OSC), then **all** outputs latch off until the step-up DC-DC converter is reinitialized by the ONSU pin.

Once the step-up output is in regulation, if the SU hits current limit for 200,000 consecutive clock cycles, the device enters a fault condition. If the step-up output (PVSU) is dragged 10% below its regulation voltage or is shorted, the device enters a fault state immediately. The step-up then shuts down all channels. **All** outputs stay latched off until the step-up DC-DC converter is reinitialized by the ONSU pin.

If the short at SU exists prior to ONSU being pulled high, then the SU DC-DC converter continuously cycles through soft-start once ONSU is pulled high since V_{SU} never goes above its 3V UVLO threshold. The part continues to draw approximately 1A of input current in this condition. The user is recommended to monitor such a condition and pull ONSU low to prevent thermal runaway.

In systems where a submicroprocessor (sub-µP) is used, the output of the MAIN converter is diode-ORed with the backup power supply to supply power to the sub-µP. The sub-µP also controls the power-on signal going to ONSU to turn on the MAX8610–MAX8613/MAX8611V. Under these circumstances, the sub-µP can be used to monitor the 3.3V MAIN supply and pull ONSU low if a startup into a short-circuit prevents the 3.3V MAIN supply from turning on within a specified time (1s, for example).

In the CCDBST and LEDBST converters an overload/short condition stops converter switching immediately. The True Shutdown switch limits the inductor current to 1A maximum for 200,000 clock cycles. If the overload/short-circuit condition persists beyond this time, then the device enters a fault condition. All channels are shut down and stay latched off until the step-up DC-DC converter is reinitialized by the ONSU pin. If the overload/short-circuit condition is removed within the 200,000 clock cycles, soft-start is reinitiated.

For all other channels an overload/short-circuit condition for over 200,000 clock cycles on the output are detected as a fault. Once in fault, **all** channels are shut down and stay latched off until the step-up DC-DC converter is reinitialized by the ONSU pin.

Reference

The MAX8610–MAX8613/MAX8611V have a precise 1.250V reference at REF. Bypass REF to GND with a 0.22µF ceramic capacitor. REF can source up to 100µA for external loads. REF is enabled whenever ONSU is high and PVSU is above 3V. During shutdown REF is internally pulled to GND.

Oscillator

The operating frequency is set by a resistor connected from REXT to GND. The range of usable settings is from 1MHz to 2MHz. Note that although all converter channels are synchronized, they do not operate at the same frequency. The SU, MAIN, AFE, and SD converters all switch at the set oscillator frequency. The CCDBST and INV converters, as well as the LEDBST, switch at one-half the oscillator frequency, and the AUX controller switches at one-quarter the oscillator frequency. The CCDBST, INV, and AUX converters switch at reduced rates to optimize efficiency for those channels. Table 2 details each converter's operating frequency for 1MHz and 2MHz oscillators. See also *Setting the Switching Frequency* in the *Design Procedure* section.

Shutdown

The SU step-up converter is activated with a high input signal at ONSU. All other converters are individually activated with logic-high levels on their respective ON_ inputs. For automatic startup of any channel, connect its ON_ pin to PVSU or a logic level greater than 1.6V. Connecting all ON_ to GND or logic 0 places the MAX8610–MAX8613/MAX8611V in shutdown mode and reduces supply current to 0.1µA. In shutdown, the control circuitry, internal switching MOSFETs, and synchronous rectifiers turn off and LX_ becomes high impedance.

All converter channels (except AUX) provide True Shutdown so that no current flows from the battery to the load during shutdown. Unlike conventional boost converters, no external switch circuitry is needed to block battery drain in shutdown.

SEQCCD does not have a logic-level threshold. SEQCCD should be connected to V_{SU} for a high level and to GND for a low level. See the *Typical Operating Characteristics* for the SEQCCD threshold as a function of the SU converter output voltage V_{SU}.

8-Channel PMICs for Digital Camera Power Supplies

Design Procedure

Setting the Switching Frequency

Choose a switching frequency to optimize external component size or circuit efficiency for the particular application. Typically, switching frequencies between 1MHz and 2MHz offer a good balance between component size and circuit efficiency—higher frequencies generally allow smaller components, while lower frequencies give better conversion efficiency. The switching frequency is set with an external timing resistor connected from REXT to GND. The REXT value for a particular oscillator frequency is:

$$REXT\ (k\Omega) = (200)/f_{OSC}(MHz)$$

Setting Output Voltages

All MAX8610–MAX8613/MAX8611V output voltages are resistor set. The FB_ threshold is 1V for all channels except for FBLLED (0.24V), FBINV (0V), and FBAUX (1.25V) for the AUX boost on the MAX8610/MAX8611/MAX8611V, and (0V) for the AUX inverter on the MAX8612/MAX8613. When setting the output voltage for any boost or step-down channel, connect a resistive voltage-divider from the channel output to the corresponding FB_ input and then to GND. The FB_ input bias current is less than 50nA, so choose the bottom-side (R_{BOTTOM} from FB_ to GND) resistor to be 100kΩ or less. Then calculate the top-side (R_{TOP} from output to FB_) resistor:

$$R_{TOP} = R_{BOTTOM}[(V_{OUT} / V_{FB\_}) - 1]$$

where V_{FB} is the feedback regulation voltage of the particular DC-DC converter channel (1V for FBSU, FBM, FBAFE, FBSD, FBBST, and FBHLED, or 1.25V for the MAX8610/MAX8611/MAX8611V FBAUX).

Setting Inverter Output Voltages

All devices feature a CCD inverter. The CCD inverter feedback input is at FBINV and has a threshold of 0V. To set the negative output voltage, connect a resistive voltage-divider from the negative output (V_{CCDINV}) to the FBINV input, and then to REF. The FBINV input bias current is less than 50nA, so choose the FBINV-to-REF resistor, R_{REF} (R8 in Figures 1 and 2), to be 100kΩ or less. Then calculate the output-to-FBINV resistor, R_{INV} (R7 in Figures 1 and 2), as follows:

$$R_{INV} = R_{REF}(|V_{CCDINV}| / 1.25)$$

A second inverter is available by using the AUX controller on the MAX8612/MAX8613. The formula for calculating feedback resistors for the inverting AUX controller is the same as above.

Setting LED Current and Voltage

When using the LED boost as a current source to drive white (or other) LEDs, connect an LED current-sense resistor from FBLLED to GND. Select the LED current-setting resistor (R17 in Figures 1 and 2) using the following formula:

$$R17 = 0.24V / I_{LED}$$

where I_{LED} is the regulated current in the series LED string. The LED boost also allows a voltage limit to be set with FBHLED so that if the LED string becomes open circuit, the output voltage is still regulated. The limit voltage should be selected to be 1V higher than the maximum-expected LED forward voltage (V_{MAXLED}), but no higher than 27V. Choose the bottom-side (R16 from FBHLED to GND in Figures 1 and 2) resistor to be 100kΩ or less. Then calculate the top-side (R15 from V_{LED} to FBHLED in Figures 1 and 2) resistor:

$$R15 = R16\ [V_{MAXLED}]$$

Note that the V_{LED} output V_{BOOST} can instead be used as a high-voltage boost for any function, by using only R15 and R16 to set voltage and by omitting R17 and grounding FBLLED. In that case:

$$R15 = R16\ [V_{BOOST} - 1]$$

Filter Capacitor Selection

The input capacitor in a DC-DC converter reduces current peaks drawn from the battery or other input power source and reduces switching noise in the controller. The impedance of the input capacitor at the switching frequency should be less than that of the input source so high-frequency switching currents do not pass through the input source.

The DC-DC converter output filter capacitors keep output ripple small and ensure control-loop stability. The output capacitor must also have low impedance at the switching frequency. Ceramic, polymer, and low-ESR tantalum capacitors are suitable, with ceramic exhibiting the lowest ESR and high-frequency impedance. Output ripple with a ceramic output capacitor is approximately as follows:

$$V_{RIPPLE} = I_{L(PEAK)}\ [1 / (2\pi\ f_{OSC}\ C_{OUT})]$$

If the capacitor has significant ESR, the output ripple component due to capacitor ESR is as follows:

$$V_{RIPPLE(ESR)} = I_{L(PEAK)}\ ESR$$

Step-Up Component Selection

This section describes component selection for the SU step-up, as well as for the MAIN and AFE step-up that are found on the MAX8610 and MAX8612. The external components required for the step-up are an inductor and input and output filter capacitors. The inductor is typically selected to operate with continuous current for best efficiency. An exception might be if the step-up ratio, (V_{OUT} / V_{IN}), is greater than 1 / (1 - D_{MAX}), where

D_{MAX} is the maximum PWM duty factor stated in the *Electrical Characteristics* table.

In most step-up designs, a reasonable inductor value (L_{IDEAL}) can be derived from the following equation, which sets continuous peak-to-peak inductor current at 1/3 the DC inductor current:

$$L_{IDEAL} = [3.5V_{IN(MIN)}\ D\ (1 - D)] / (I_{OUT}\ f_{OSC})$$

where D is the duty factor given by:

$$D = 1 - (V_{IN} / V_{OUT})$$

Given L_{IDEAL}, the consistent peak-to-peak inductor current is I_{OUT} / [3(1 - D)]. The peak inductor current, $I_{L(PEAK)}$ = 1.25 I_{OUT} / (1 - D). Inductance values smaller than L_{IDEAL} can be used to reduce inductor size; however, if much smaller values are used, inductor ripple current rises and a larger output capacitance may be required to suppress output ripple.

Step-Down Component Selection

This section describes component selection for the SD step-down converter and for the MAIN and AFE step-downs that are found on the MAX8611/MAX8613/MAX8611V. The external components required for the step-down are an inductor and input and output filter capacitors. The step-down converters provide best efficiency with continuous inductor current. A reasonable inductor value (L_{IDEAL}) can be derived from the following equation:

$$L_{IDEAL} = [3(V_{IN}) \times D_{SD}(1 - D_{SD})] / (I_{OUT}\ f_{OSC})$$

This sets the peak-to-peak inductor current at 1/3 the DC inductor current. D_{SD} is the step-down switch duty cycle: $D_{SD} = V_{OUT} / V_{IN}$.

Given L_{IDEAL}, the peak-to-peak inductor current is I_{OUT} / 3. The absolute-peak inductor current is 1.25 I_{OUT}. Inductance values smaller than L_{IDEAL} can be used to reduce inductor size; however, if much smaller values are used, inductor ripple current for a given load rises, and a larger output capacitance may be required to suppress output ripple. Larger values than L_{IDEAL} can be used to obtain higher output current, but typically with larger inductor size.

LED and CCD Component Selection

CCD/LED Inductor Selection

The LED boost, CCD boost, and CCD inverter's high switching frequency (f_{OSC} / 2) allows for the use of small inductors. The 10µH inductors (L5, L6, and L7) shown in the typical operating circuits are recommended for most applications. Smaller inductances require less board space, but may cause greater peak current due to current-sense comparator propagation delay.

Use inductors with a ferrite core or equivalent. Powder iron cores are not recommended for use with high switching frequencies. The inductor's incremental saturation rating must meet or exceed the LXBST, LXINV, and LXLED current limits. For highest efficiency, use inductors with a low DC resistance (under 100mΩ). Table 3 is the LED and CCD inductor selection guide.

Table 3. LED and CCD Inductor Selection Guide

OUTPUT VOLTAGES AND LOAD CURRENT	INDUCTOR	L (µH)	DCR (mΩ)	I_{SAT} (A)	SIZE (mm)
15V, 50mA; -7.5V, 100mA	TOKO DP418C S1024AS-4R3M	4.3	47	1.2	4 x 4 x 1.7
	Sumida CDRH2D14-4R7	4.7	170	1	3.2 x 3.2 x 1.55
	TOKO DP418C S1024AS-100M	10	100	0.8	4 x 4 x 1.7
15V, 20mA; -7.5V, 40mA	TOKO DP418C S1024AS-4R3M	4.3	47	1.2	4 x 4 x1.7
	Sumida CDRH2D14-4R7	4.7	170	1	3.2 x 3.2 x 1.55
	TOKO DP3015C S1068AS-4R7M	4.7	155	0.9	3 x 3 x 1.5

CCD/LED Diode Selection

High switching frequency (f_{OSC} / 2) demands a high-speed rectifier. Schottky diodes, such as the CMHSH5-2L or MBR0530L, are recommended. Make sure that the diode's peak current rating exceeds the selected current limit, and that its breakdown voltage exceeds the output voltage. Schottky diodes are preferred due to their low forward voltage. However, ultra-high-speed silicon rectifiers are also acceptable.

CCD/LED Output Filter Capacitors

For most applications, 10µF ceramic output filter capacitors are suitable for the CCD outputs. Lower values may be acceptable to save space at low output currents or if higher ripple can be tolerated. The minimum capacitor values required for stability are calculated as follows:

For CCD and LED boost output stability, the filter capacitor, C_{BST}, should satisfy:

$$C_{BST} > (10\ L\ I_{BST}) / (R_{CS}\ (1 - D_{BST})\ V_{BST}^2)$$

where I_{BST} is the output current, V_{BST} is the output voltage, R_{CS} = 0.015, and D_{BST} is the boost switch duty cycle: $D_{BST} = 1 - (V_{BATT} / V_{BST})$.

For CCD inverter stability, the filter capacitor, C_{INV}, should satisfy the following:

$$C_{INV} > \frac{3L\ V_{REF}\ I_{INV}}{R_{CS}\ (I - D_{INV})\ (V_{REF} - V_{INV})\ V_{INV}}$$

where I_{INV} is the output current, V_{INV} is the output voltage, R_{CS} = 0.015, and D_{INV} is the inverter switch duty cycle: $D_{INV} = |V_{INV}| / (|V_{INV}| + V_{PVINV})$.

Table 3 lists representative inductors for the LED and CCD outputs.

AUX Controller Component Selection

External MOSFET

The AUX controller drives an external logic-level MOSFET. Significant MOSFET selection parameters are as follows:

- On-resistance ($R_{DS(ON)}$)
- Maximum drain-to-source voltage ($V_{DS(MAX)}$)
- Total gate charge (Q_G)
- Reverse transfer capacitance (C_{RSS})

On the MAX8610/MAX8611/MAX8611V the AUX driver, DRVAUX, is designed for n-channel MOSFETs. On the MAX8612/MAX8613, AUX is a DC-DC inverting controller, so DRVAUX is designed to drive a p-channel MOSFET. In all devices, DRVAUX swings between PVINV and PG1. Use a MOSFET with on-resistance specified with a gate drive at or below the PVINV voltage.

The MOSFET gate charge, Q_G, includes all capacitance associated with charging the gate and helps to predict MOSFET transition time between on and off states. MOSFET power dissipation is a combination of on-resistance and transition losses. The on-resistance loss is as follows:

$$P_{RDSON} = D\ I_L^2\ R_{DS(ON)}$$

where D is the duty cycle, I_L is the average inductor current, and $R_{DS(ON)}$ is MOSFET on-resistance. The transition loss is approximately as follows:

$$P_{TRANS} = (V_{OUT}\ I_L\ f_{OSC}\ t_T) / 3$$

where V_{OUT} is the output voltage, I_L is the average inductor current, f_{OSC} is the switching frequency, and t_T is the transition time. The transition time is approximately Q_G / I_G, where Q_G is the total gate charge, and I_G is the gate-drive current (0.5A typ). The total power dissipation in the MOSFET is as follows:

$$P_{MOSFET} = P_{RDSON} + P_{TRANS}$$

Diode

For most AUX applications, a Schottky diode rectifies the output voltage. The Schottky low forward voltage and fast recovery time provide the best performance in most applications. Silicon signal diodes (such as 1N4148) are sometimes adequate in low-current (<10mA), high-voltage (>10V) output circuits where the output voltage is large compared to the diode forward voltage.

AUX Compensation

The auxiliary controller employs voltage-mode control to regulate the output voltage. Optimum compensation depends on whether the design uses continuous or discontinuous inductor current. Note that in the following discussions, f_{AUX}, the auxiliary controller switching frequency, is 1/4 of the oscillator frequency set by REXT.

MAX8610/MAX8611/MAX8611V AUX Step-Up, Discontinuous Inductor Current

When the inductor current falls to zero on each switching cycle, it is described as discontinuous. The inductor is not utilized as efficiently as with continuous current, but in light-load applications this often has little negative impact since the coil losses may already be low compared to other losses. A benefit of discontinuous inductor current is more flexible loop compensation and no maximum duty-cycle restriction on boost ratio. To ensure discontinuous operation, the inductor must have a sufficiently low inductance to fully discharge on each cycle. This occurs when:

$$L < [V_{IN}^2\ (V_{OUT} - V_{IN}) / V_{OUT}^3]\ [R_{LOAD} / (2f_{AUX})]$$

A discontinuous current boost has a single pole at the following frequency:

$$f_P = (2V_{OUT} - V_{IN}) / (2\pi\ R_{LOAD}\ C_{OUT}\ V_{OUT})$$

A type 2 compensation is recommended as shown in Figure 6.

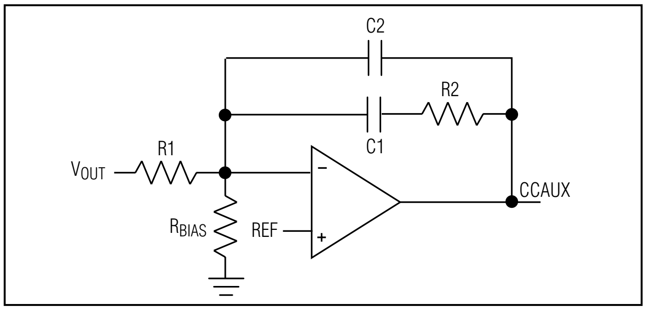


Figure 6. Type 2 Compensation Circuit

The crossover frequency for the boost loop is given by:

$$C1 = [1 / (2\pi \times f_C \times R1)]\ [V_{FB} / V_{RAMP}]\ [R_{LOAD} V_{OUT} / (2Lf_{AUX} (V_{OUT} - V_{IN}))]^{1/2}\ [2V_{IN} / (2V_{OUT} - V_{IN})]$$

where V_{RAMP} is the internal slope-compensation voltage ramp of 1.25V.

The frequency of the pole and zero are defined by the equations below. R2 and C1 introduce a zero at a frequency given by:

$$f_Z = 1 / (2\pi\ R2\ C1)$$

While a pole is introduced at the frequency:

$$f_{P2} = 1 / (2\pi\ R2\ C2)$$

The following is a typical procedure for selecting the compensation components for a discontinuous-conduction mode boost.

- Choose the compensation so the unity-gain crossover, f_C, occurs at f_{AUX} / 10 or lower.
- Set the resistor-divider formed by R1 and R_{BIAS} to set the desired output regulation voltage as specified in the *Setting Output Voltages* section. R1 = R_{BIAS} (V_{OUT} / 1.25 - 1) where R_{BIAS} is chosen to be 100kΩ or lower. Note that R_{BIAS} only sets the DC operating point of the loop and has no effect on the AC characteristics.
- Set the zero f_Z formed by R2 and C1 at approximately the boost pole f_P.
- Set the pole f_{P2} formed by R2 and C2 approximately equal to the ESR zero of the output capacitor or in case of ceramic capacitors, a decade below the crossover frequency f_C.

MAX8610/MAX8611/MAX8611V AUX Step-Up, Continuous Inductor Current

Continuous inductor current can sometimes improve boost efficiency by lowering the ratio between peak inductor current and output current. It does this at the expense of a larger inductance value that requires larger size for a given current rating. With continuous-inductor-current boost operation, there is a right-half-plane zero, Z_{RHP}, at:

$$Z_{RHP} = (1 - D)^2 R_{LOAD} / (2\pi\ L)$$

where D is the switch duty factor and (1 - D) = V_{IN} / V_{OUT} (in a boost converter).

There is a complex pole pair at:

$$f_0 = V_{IN} / [2\pi\ V_{OUT} (L\ C_{OUT})^{1/2}]$$

A type 3 error-amplifier compensation network can be used to optimize the loop response for the continuous conduction mode. The type 3 amplifier circuit is shown in Figure 7.

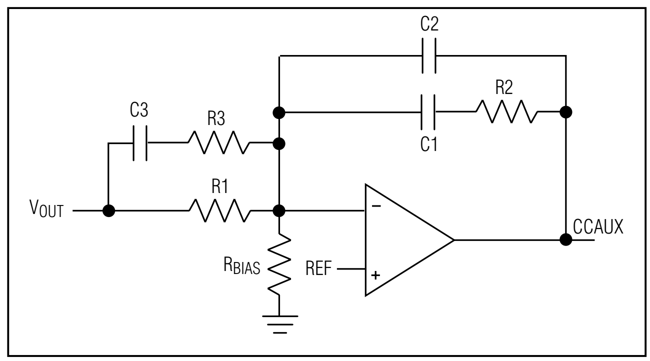


Figure 7. Type 3 Error-Amplifier Circuit

The frequency of the poles and zeros introduced by this compensation network are defined by the following equations.

The zeros are:

$$f_{Z1} = 1 / (2\pi\ R2\ C1)$$

$$f_{Z2} = 1 / (2\pi\ R1\ C3)\ (\text{assuming } R1 >> R3)$$

The poles are:

$$f_{P1} = 1 / (2\pi\ R3\ C3)$$

$$f_{P2} = 1 / (2\pi\ R2\ C2)\ (\text{assuming } C1 >> C2)$$

Also, the unity-gain frequency or crossover frequency is:

$$f_C = 1 / (2\pi\ R1\ C1)$$

With voltage-mode control the goal of the loop design is to set the crossover frequency above the complex pole pair frequency but below the RHP zero. This is accomplished by placing the two zeros below the complex pole pair as this provides a phase boost. The two poles are then placed a decade above the crossover frequency.The following is a typical procedure for selecting the compensation components for a continuous-conduction-mode boost:

1) Choose the compensation so the unity-gain crossover, f_C, occurs approximately a decade above the complex pole pair but at least before 1/6 the RHP zero frequency and 1/10 the switching frequency f_{AUX}.
2) Set the resistor-divider formed by R1 and R_{BIAS} to set the desired output regulation voltage as specified in the *Setting Output Voltages* section:

   $$R1 = R_{BIAS} (V_{OUT} / 1.25 - 1)$$

   where R_{BIAS} is chosen to be 100kΩ or lower.

   Note that R_{BIAS} only sets the DC operating point of the loop and has no effect on the AC characteristics.
3) Compute C1 knowing the crossover frequency f_C and R1.
4) Set the zero f_{Z2} formed by R1 and C3 approximately halfway between the complex pole pair and the crossover frequency f_C to compensate for the phase loss.
5) Set the other zero f_{Z1} formed by R2 and C1 approximately one-half decade above the complex pole pair.
6) If the zero due to the output capacitance and ESR ($Z_{COUT} = 1 / (2\pi\ C_{OUT}\ R_{ESR})$) is within a decade of the crossover frequency, then set the pole formed by R3 and C3 to cancel the ESR zero. If Z_{COUT} is much higher than f_C (as is typical with ceramic output capacitors) and continuous conduction is required, then set the pole formed by R3 and C3 more than a decade higher than the crossover frequency.
7) Set the second pole formed by R2 and C2 (f_{P2}) more than one-half a decade above the crossover frequency.

MAX8612/MAX8613 AUX Inverter, Discontinuous Inductor Current

If the output power is very low (≤250mW), discontinuous current is preferred for simple loop compensation and freedom from duty-cycle restrictions on the inverter input-output ratio. To ensure discontinuous operation, the inductor must have a sufficiently low inductance to fully discharge on each cycle. This occurs when:

$L < [V_{IN} / (|V_{OUT}| + V_{IN})]^2 R_{LOAD} / (2f_{AUX})$ A discontinuous-current inverter has a single pole at:

$$f_P = 2 / (2\pi\ R_{LOAD}\ C_{OUT})$$

A type 2 compensation is recommended as shown in Figure 6 except that the RBIAS resistor is connected to REF for the inverter and the reference voltage at the error amplifier is 0V.

The crossover frequency for the inverter loop is given by:

$$C1 = [1 / (2\pi \times f_C \times R1)]\ [V_{IN} / V_{RAMP}]\ [R_{LOAD} / (2\ L\ f_{AUX})]^{1/2}\ [V_{REF} / (|V_{OUT}| + V_{REF})]$$

where V_{RAMP} is the internal slope-compensation voltage ramp of 1.25V.

The frequency of the pole and zero are defined by the equations below. R2 and C1 introduce a zero at a frequency given by:

$$f_Z = 1 / (2\pi\ R2\ C1)$$

While a pole is introduced at the frequency:

$$f_{P2} = 1 / (2\pi\ R2\ C2)$$

The following is a typical procedure for selecting the compensation components for a discontinuous-conduction-mode inverter:

1) Choose the compensation so the unity-gain crossover, f_C, occurs at f_{AUX} / 10 or lower.
2) Set the resistor-divider formed by R_1 and R_{BIAS} to set the desired output regulation voltage as specified in the *Setting Output Voltages* section.

   $R1 = R_{BIAS} (|V_{OUT}| / 1.25)$ where R_{BIAS} is chosen to be 100kΩ or lower.

   Note that R_{BIAS} only sets the DC operating point of the loop and has no effect on the AC characteristics.
3) Set the zero f_Z formed by R2 and C1 to cancel the inverter pole at frequency f_P.
4) Set the pole formed by R2 and C2 to cancel the ESR zero of the output capacitor or a decade below the crossover frequency if using ceramic output capacitors

MAX8612/MAX8613 AUX Inverter, Continuous Inductor Current

Continuous inductor current may be more suitable for larger load currents (50mA or more). It improves efficiency by lowering the ratio between peak inductor current and output current. It does this at the expense of a larger inductance value that requires larger size for a given current rating. With continuous-inductor-current inverter operation, there is a right-half-plane zero, Z_{RHP}, at:

$$Z_{RHP} = [(1 - D)^2 / D] \times R_{LOAD} / (2\pi L)$$

where $D = |V_{OUT}| / (|V_{OUT}| + V_{IN})$ (in an inverter).

There is a complex pole pair at:

$$f_0 = (1 - D) / (2\pi (LC)^{1/2})$$

If the zero due to the output-capacitor capacitance and ESR is less than 1/10 the right-half-plane zero:

$$Z_{COUT} = 1 / (2\pi C_{OUT} R_{ESR}) < Z_{RHP} / 10$$

A type 3 compensation is recommended as shown in Figure 7 except that the R_{BIAS} resistor is connected to REF for the inverter and the reference voltage at the error amplifier is 0V. The frequency of the poles and zeros introduced by type 3 compensation network (Figure 7) are defined by the following equations.

The zeros are:

$$f_{Z1} = 1 / (2\pi R2 C1)$$

$$f_{Z2} = 1 / (2\pi R1 C3) \text{ (assuming R1>>R3)}$$

The poles are:

$$f_{P1} = 1 / (2\pi R3 C3)$$

$$f_{P2} = 1/(2\pi R2 C2) \text{ (assuming C1>>C2)}$$

Also, the unity-gain frequency or crossover frequency is:

$$f_C = 1 / (2\pi R1 C1) [1 / D(1 - D)]$$

With voltage-mode control the goal of the loop design is to set the crossover frequency above the complex pole pair frequency but below the RHP zero. This is accomplished by placing the two zeros below the complex pole pair as this provides a phase boost. The two poles are then placed a decade above the crossover frequency.

The following is a typical procedure for selecting the compensation components for a continuous-conduction-mode inverter:

1) Choose the compensation so the unity-gain crossover, f_C, occurs approximately a decade above the complex pole pair but at least before 1/6 the RHP zero frequency and 1/10 the switching frequency f_{AUX}.
2) Set the resistor-divider formed by R1 and R_{BIAS} to set the desired output regulation voltage as specified in the *Setting Output Voltages* section:

   $$R1 = R_{BIAS} (|V_{OUT}| / 1.25)$$

   where R_{BIAS} is chosen to be 100kΩ or lower.

   Note that R_{BIAS} only sets the DC operating point of the loop and has no effect on the AC characteristics.
3) Compute C1 knowing the crossover frequency f_C and R1.
4) Set the zero f_{Z2} formed by R1 and C3 approximately halfway between the complex pole pair and the crossover frequency f_C to compensate for the phase loss.
5) Set the other zero f_{Z1} formed by R2 and C1 approximately one-half decade above the complex pole pair.
6) If the zero due to the output capacitance and ESR ($Z_{COUT} = 1 / (2\pi C_{OUT} R_{ESR})$) is within a decade of the crossover frequency, then set the pole formed by R3 and C3 to cancel the ESR zero. If Z_{COUT} is much higher than f_C (as is typical with ceramic output capacitors) and continuous conduction is required, then set the pole formed by R3 and C3 more than a decade higher than the crossover frequency.
7) Set the second pole formed by R2 and C2 (f_{P2}) more than one-half a decade above the crossover frequency.

Applications Information

Typical Operating Circuits

Figures 1 and 2 show connections for Li+ and 2 AA battery arrangements. Figures 8 and 9 show various connections for the AUX controller.

Figure 1. 2 AA Cell Operation

Figure 1 is optimized for 2-cell AA inputs (1.5V to 3.6V). The SU step-up boost converter generates 5V from the battery. Likewise, the 3.4V analog front-end (AFE) supply and 3.3V MAIN logic supplies operate as boost converters (MAX8610/MAX8612) from the battery input. The 1.5V supply for the DSP core is stepped down from the battery. The -7.5V for CCD is powered by V_{SU}, the SU converter output. The remaining supplies, +14V for the CCD, 20mA bias for the white LED backlight, and the supply generated by the AUX boost controller, are all derived directly from the battery.

Figure 2. Li+ Cell or Dual-Battery Operation

In the connection in Figure 2, the input voltage range is 3V to 5V, covering the operating range of a Li+ battery and AC adapter. Figure 2 will also operate in dual-battery systems that operate from both Li+ and 2 AA cells. The SU step-up supplies 5V. Since boost-buck operation is often needed for the 3.3V MAIN and 3.4V AFE outputs, they are operated as step-down converters (in the MAX8611/MAX8613/MAX8611V) from the SU step-up output (PVSU). By cascading a high-efficiency step-up and step-down converter, boost-buck efficiency reaches 90% while still providing a regulated output over a wide input voltage range. The SD step-down 1.5V (DSP core) output is powered directly from the battery.

AUX Controller Applications

The MAX8610/MAX8611/MAX8611V AUX boost controller can be used for a wide variety of step-up applications. These include generating an additional 5V supply or some other voltage for motor or actuator drive or for generating an additional high-voltage supply. Figure 8 shows an example of an AUX boost application.

On the MAX8612/MAX8613, AUX is set up to drive an external p-channel MOSFET in an inverting configuration. DRVAUX drives low to turn on the MOSFET, and FBAUX has a 0V threshold. This is useful for generating a 2nd negative voltage, particularly if more output current is required from the negative supply than can be supplied by the CCD inverter or for the OLED power supply. Figure 9 shows an example circuit.

Designing a PC Board

Good PC board layout is important to achieve optimal performance from the MAX8610–MAX8613/MAX8611V. Poor design can cause excessive conducted and/or radiated noise. Conductors carrying discontinuous currents and any high-current path should be made as short and wide as possible. A separate low-noise ground plane containing the reference and signal grounds should connect to the power-ground plane at only one point to minimize the effects of power-ground currents. Typically, the ground planes are best connected right at the device. Keep the voltage-feedback network very close to the device, preferably within 0.2in (5mm) of the FB_ pin. Nodes with high dV/dt (switching nodes) should be kept as small as possible and should be routed away from high-impedance nodes such as FB_. Refer to the MAX8610–MAX8613/MAX8611V EV kit data sheet for a full PC board example.

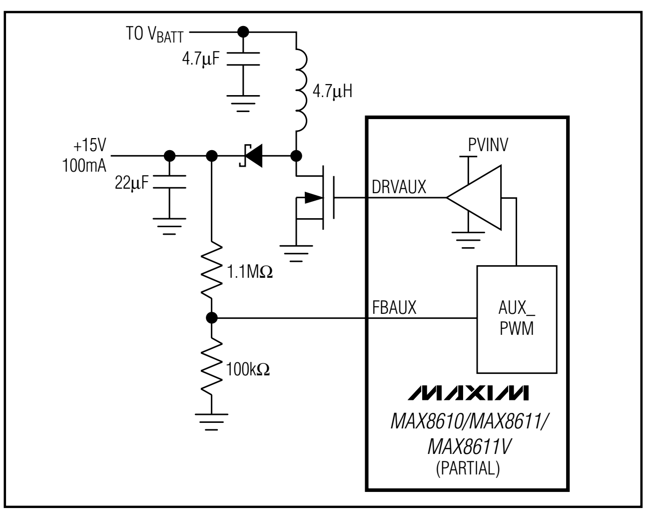


Figure 8. Typical Application for the AUX Boost Controller on the MAX8610/MAX8611/MAX8611V

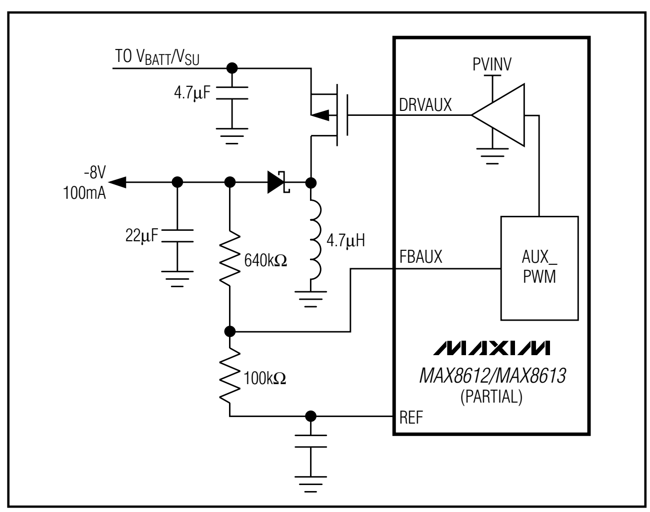
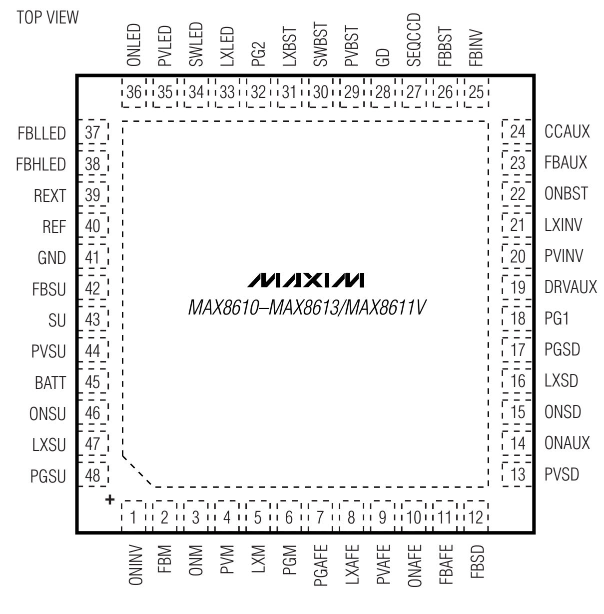


Figure 9. Typical Application for the AUX Inverting Controller on the MAX8612/MAX8613

Pin Configuration



THIN QFN

Selector Guide

PART	MAIN AND AFE DC-DC FUNCTION	AUX DC-DC FUNCTION	SKIP LEVELS
MAX8610ETM	Boost	Boost	Dual
MAX8611ETM	Buck	Boost	Dual
MAX8612ETM	Boost	Inverter	Dual
MAX8613ETM	Buck	Inverter	Dual
MAX8613VETM	Buck	Boost	Single

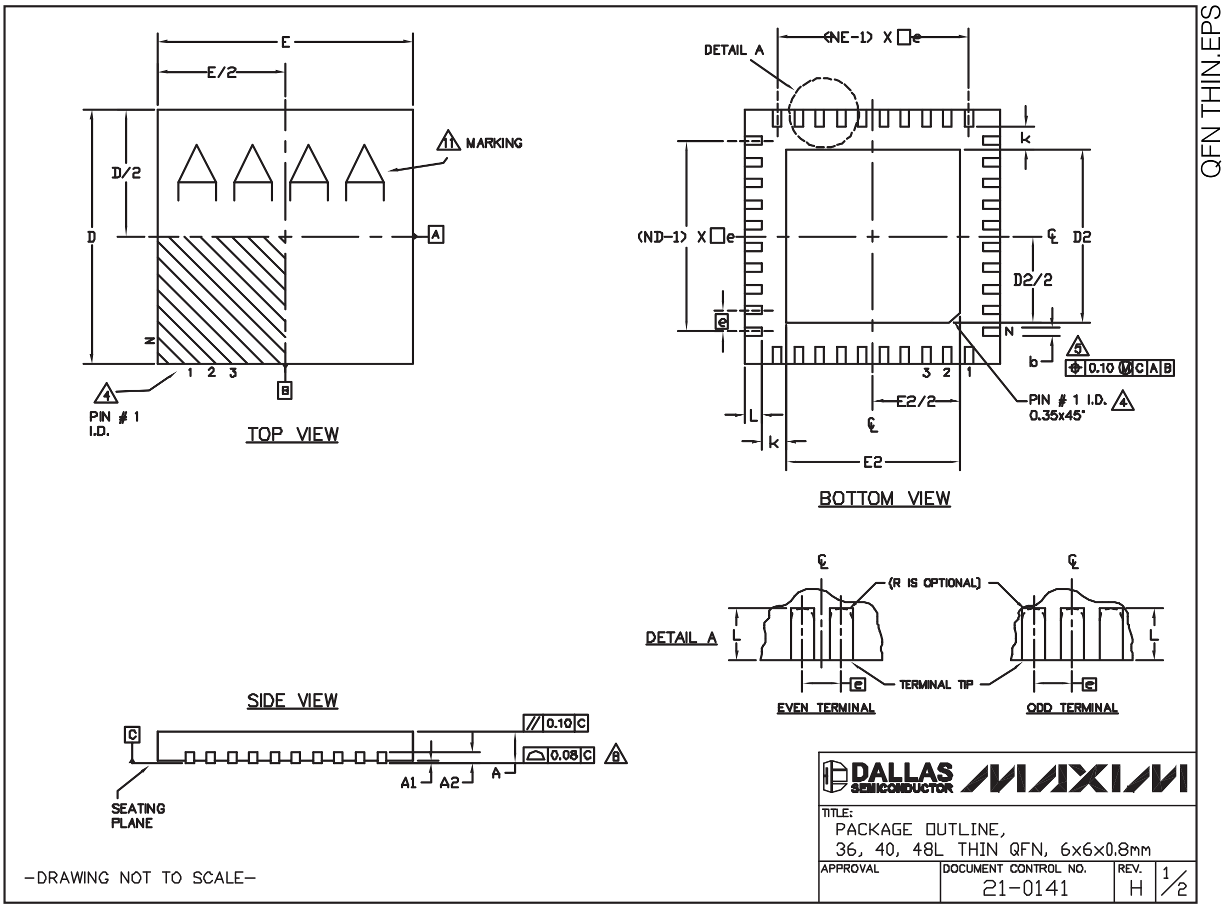
Chip Information

TRANSISTOR COUNT: 28,001

PROCESS: BiCMOS

Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)



Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

COMMON DIMENSIONS

PKG.	36L 6x6			40L 6x6			48L 6x6		
SYMBOL	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80
A1	0	0.02	0.05	0	0.02	0.05	0	–	0.05
A2	0.20 REF.			0.20 REF.			0.20 REF.		
b	0.20	0.25	0.30	0.20	0.25	0.30	0.15	0.20	0.25
D	5.90	6.00	6.10	5.90	6.00	6.10	5.90	6.00	6.10
E	5.90	6.00	6.10	5.90	6.00	6.10	5.90	6.00	6.10
e	0.50 BSC.			0.50 BSC.			0.40 BSC.		
k	0.25	–	–	0.25	–	–	0.25	–	–
L	0.45	0.55	0.65	0.30	0.40	0.50	0.30	0.40	0.50
N	36			40			48		
ND	9			10			12		
NE	9			10			12		
JEDEC	WJJD-1			WJJD-2			–		

EXPOSED PAD VARIATIONS

PKG. CODES	D2			E2		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
T3666-2	3.60	3.70	3.80	3.60	3.70	3.80
T3666-3	3.60	3.70	3.80	3.60	3.70	3.80
T3666N-1	3.60	3.70	3.80	3.60	3.70	3.80
T3666MN-1	3.60	3.70	3.80	3.60	3.70	3.80
T4066-2	4.00	4.10	4.20	4.00	4.10	4.20
T4066-3	4.00	4.10	4.20	4.00	4.10	4.20
T4066-4	4.00	4.10	4.20	4.00	4.10	4.20
T4066-5	4.00	4.10	4.20	4.00	4.10	4.20
T4866-1	4.40	4.50	4.60	4.40	4.50	4.60
T4866-2	4.40	4.50	4.60	4.40	4.50	4.60

NOTES:

1. DIMENSIONING & TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
3. N IS THE TOTAL NUMBER OF TERMINALS.
4. THE TERMINAL #1 IDENTIFIER AND TERMINAL NUMBERING CONVENTION SHALL CONFORM TO JESD 95-1 SPP-012. DETAILS OF TERMINAL #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE TERMINAL #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE.
5. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TIP.
6. ND AND NE REFER TO THE NUMBER OF TERMINALS ON EACH D AND E SIDE RESPECTIVELY.
7. DEPOPULATION IS POSSIBLE IN A SYMMETRICAL FASHION.
8. COPLANARITY APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
9. DRAWING CONFORMS TO JEDEC MO220, EXCEPT FOR 0.4mm LEAD PITCH PACKAGE T4866-1.
10. WARPAGE SHALL NOT EXCEED 0.10 mm.
11. MARKING IS FOR PACKAGE ORIENTATION REFERENCE ONLY.
12. NUMBER OF LEADS SHOWN FOR REFERENCE ONLY.

-DRAWING NOT TO SCALE-

DALLAS SEMICONDUCTOR MAXIM

TITLE: PACKAGE OUTLINE, 36, 40, 48L THIN QFN, 6x6x0.8mm

APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21-0141	H	2/2

Revision History

Pages changed at Rev 4: 1, 6, 10, 19, 36, 37

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