15V/250mA Nanopower Buck DC/DC with Programmable Peak Input Current

FEATURES

- **Input Voltage Range: 2.5V to 15V**
- **Output Current: Up to 250mA**
- **I_{VIN} = 65nA (In Regulation, No Load)**
- **Output Voltage Range: 1.2V to 5V**
- 16 Fixed Output Voltages Programmed via 4 Pin-Strapped Inputs
- 4 Peak V_{IN} Currents Programmed via 2 Pin-Strapped Inputs (10mA/30mA/100mA/300mA)
- Low I_Q Dropout Mode
- Power Good (PGOOD) Output
- 12-Lead 2mm × 2mm LQFN Package

APPLICATIONS

- Low Power Primary Battery Powered Systems (e.g., 1× – 3× Li-Ion Primary, 3× – 8× AAA)
- Remote Industrial Sensors (e.g., Meters, Alarms)
- Asset Trackers
- Electronic Door Locks
- Keep-Alive Supplies/Battery Backup
- SmartMesh® Applications

DESCRIPTION

The LTC®3336 is a compact high efficiency nanopower hysteretic buck DC/DC which can deliver up to 250mA of output current from a 2.5V to 15V input. Input quiescent current is typically 80nA with the output in regulation at no load for output voltages less than 2.4V; this number is reduced further for higher output voltages at which internal circuits can be boot-strapped from the output.

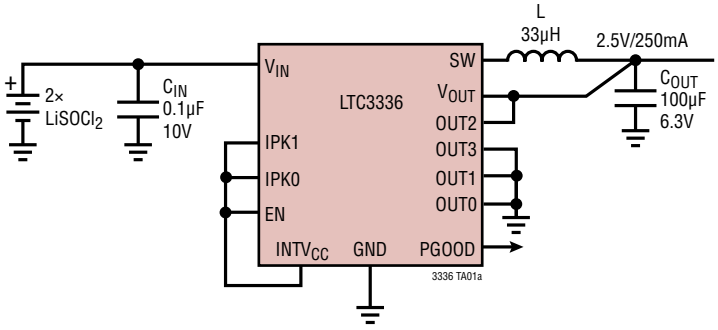
Performance specifications are ideal for primary (i.e., non-rechargeable) battery powered applications: low I_Q plus the ability to set the peak current to a level matched to the battery's maximum capacity point.

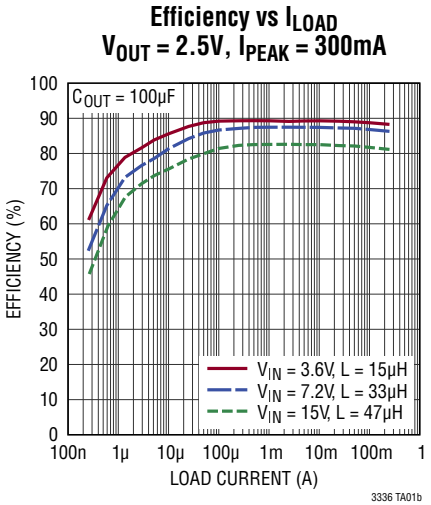
The peak input currents of 10mA, 30mA, 100mA, and 300mA are pin selectable as well as the output voltages of 1.2V, 1.5V, 1.6V, 1.8V, 2.0V, 2.4V, 2.5V, 2.8V, 3.0V, 3.2V, 3.3V, 3.6V, 3.7V, 4.1V, 4.2V, and 5.0V.

The LTC3336 is offered in a compact 12-lead 2mm × 2mm LQFN package.

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TYPICAL APPLICATION



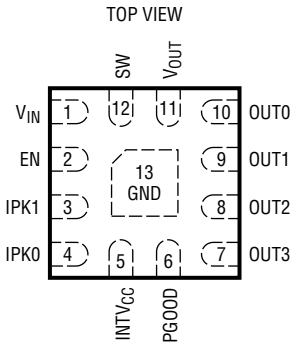


ABSOLUTE MAXIMUM RATINGS

(Note 1)

V_{IN} Voltage ..... –0.3V to 16.5V
EN, IPK[1:0], OUT[3:0] Voltage ..... –0.3V to 6V
PGOOD Voltage..... –0.3V to (V_{OUT} + 0.3V)
PGOOD Current..... ±1mA
SW Current 400mA
Operating Junction Temperature
Range (Notes 2, 3)..... –40°C to 125°C
Storage Temperature Range ..... –65°C to 150°C
Reflow Peak Body Temperature (30sec Max)..... 260°C

PIN CONFIGURATION



LQFN PACKAGE
12-LEAD (2mm × 2mm) PLASTIC QFN
$T_{J(MAX)}$ = 125°C, θ_{JA} = 71°C/W (JEDEC BOARD)
EXPOSED PAD (PIN 13) IS GND, MUST BE SOLDERED TO PCB

ORDER INFORMATION

TAPE AND REEL	TAPE AND REEL MINI	PART MARKING*		PACKAGE TYPE	MSL RATING	TEMPERATURE RANGE (SEE NOTE 2)
		DEVICE	FINISH CODE			
LTC3336EV#TRPBF	LTC3336EV#TRMPBF	LHMJ	e4	LQFN (Laminate Package with QFN Footprint)	3	–40°C to 125°C

Contact the factory for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container.

Tape and reel specifications. Some packages are available in 500 unit reels through designated sales channels with #TRMPBF suffix.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at T_A = 25°C (Note 2). V_{IN} = 7.2V unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{IN} Input Voltage Range		●	2.5		15	V
V_{IN} Quiescent Current	Sleeping (in Regulation), V_{OUT} Settings < 2.4V			65	150	nA
	Sleeping (in Regulation), V_{OUT} Settings ≥ 2.4V			10	25	nA
	Dropout (No Load), V_{OUT} Setting = 3.3V			130	220	nA
	Shutdown (EN = 0)			45	70	nA
	Active, Not Sleeping (I_{SW} = 0) (Note 4)			220	320	µA
V_{IN} Peak Current	Active Switching			I_{PEAK}		
V_{OUT} Quiescent Current	Sleeping (in Regulation), V_{OUT} Settings < 2.4V			25	45	nA
	Sleeping (in Regulation), V_{OUT} Settings ≥ 2.4V			90	150	nA

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at T_A = 25°C (Note 2). V_{IN} = 7.2V unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Regulated Output Voltage (V_{OUT})	1.2V Output Setting: Sleep Threshold	●		1.204	1.236	V
	Wake-Up Threshold	●	1.164	1.196		V
	1.5V Output Setting: Sleep Threshold	●		1.505	1.545	V
	Wake-Up Threshold	●	1.455	1.495		V
	1.6V Output Setting: Sleep Threshold	●		1.605	1.648	V
	Wake-Up Threshold	●	1.552	1.595		V
	1.8V Output Setting: Sleep Threshold	●		1.806	1.854	V
	Wake-Up Threshold	●	1.746	1.794		V
	2.0V Output Setting: Sleep Threshold	●		2.007	2.060	V
	Wake-Up Threshold	●	1.940	1.993		V
	2.4V Output Setting: Sleep Threshold	●		2.408	2.472	V
	Wake-Up Threshold	●	2.328	2.392		V
	2.5V Output Setting: Sleep Threshold	●		2.508	2.575	V
	Wake-Up Threshold	●	2.425	2.492		V
	2.8V Output Setting: Sleep Threshold	●		2.809	2.884	V
	Wake-Up Threshold	●	2.716	2.791		V
	3.0V Output Setting: Sleep Threshold	●		3.010	3.090	V
	Wake-Up Threshold	●	2.910	2.990		V
	3.2V Output Setting: Sleep Threshold	●		3.211	3.296	V
	Wake-Up Threshold	●	3.104	3.189		V
	3.3V Output Setting: Sleep Threshold	●		3.311	3.399	V
	Wake-Up Threshold	●	3.201	3.289		V
	3.6V Output Setting: Sleep Threshold	●		3.612	3.708	V
	Wake-Up Threshold	●	3.492	3.588		V
	3.7V Output Setting: Sleep Threshold	●		3.712	3.811	V
	Wake-Up Threshold	●	3.589	3.688		V
	4.1V Output Setting: Sleep Threshold	●		4.114	4.223	V
	Wake-Up Threshold	●	3.977	4.086		V
	4.2V Output Setting: Sleep Threshold	●		4.214	4.326	V
	Wake-Up Threshold	●	4.074	4.186		V
	5.0V Output Setting: Sleep Threshold	●		5.017	5.150	V
	Wake-Up Threshold	●	4.850	4.983		V
Power Good Threshold as Percentage of Output Setting	V_{OUT} Falling (Note 5)	●	90	92.5	95	%
PGOOD Output Low Voltage	10µA Into Pin	●			0.2	V
PGOOD Output High Voltage	10µA Out of Pin	●	V_{OUT} – 0.2			V
V_{OUT} Pull-Down Resistor in Shutdown	EN = 0V			10		kΩ
V_{OUT} Pull-Down Resistor in V_{OUT} Overvoltage Condition				1		MΩ
V_{OUT} Overvoltage Detection Threshold as Percentage of Output Setting				5		%

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at T_A = 25°C (Note 2). V_{IN} = 7.2V unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I_{PEAK} (Inductor Peak Current)	10mA I_{PEAK} Setting, I_{SW} Rising		8.7	10	13	mA
	30mA I_{PEAK} Setting, I_{SW} Rising		26	30	39	mA
	100mA I_{PEAK} Setting, I_{SW} Rising		87	100	130	mA
	300mA I_{PEAK} Setting, I_{SW} Rising		260	300	390	mA
I_{VALLEY} (Inductor Valley Current)	10mA I_{PEAK} Setting, I_{SW} Falling			9		mA
	30mA I_{PEAK} Setting, I_{SW} Falling			27		mA
	100mA I_{PEAK} Setting, I_{SW} Falling			90		mA
	300mA I_{PEAK} Setting, I_{SW} Falling			270		mA
Deliverable Output Current	10mA I_{PEAK} Setting	●	8.3			mA
	30mA I_{PEAK} Setting	●	25			mA
	100mA I_{PEAK} Setting	●	83			mA
	300mA I_{PEAK} Setting	●	250			mA
I_{ZERO}	Inductor Current Going into Sleep, as a Percentage of I_{PEAK}			17		%
P-Channel MOSFET Switch On-Resistance	10mA I_{PEAK} Setting			16		Ω
	30mA I_{PEAK} Setting			5.3		Ω
	100mA I_{PEAK} Setting			1.6		Ω
	300mA I_{PEAK} Setting			0.53		Ω
N-Channel MOSFET Switch On-Resistance	10mA I_{PEAK} Setting, 5V V_{OUT} Setting			9.6		Ω
	30mA I_{PEAK} Setting, 5V V_{OUT} Setting			3.2		Ω
	100mA I_{PEAK} Setting, 5V V_{OUT} Setting			0.96		Ω
	300mA I_{PEAK} Setting, 5V V_{OUT} Setting			0.32		Ω
P-Channel MOSFET Switch Leakage				0	15	nA
N-Channel MOSFET Switch Leakage				0	15	nA
$INTV_{CC}$ Voltage	V_{OUT} Settings < 2.4V, 0 ≤ $I_{(INTVCC)}$ ≤ 10µA		1.9	2	2.2	V
	V_{OUT} Settings ≥ 2.4V, 0 ≤ $I_{(INTVCC)}$ ≤ 10µA			V_{OUT}		V
V_{UVLO} Undervoltage Lockout	V_{IN} Rising			1.95	2.2	V
	V_{IN} Falling		1.5	1.75		V
V_{IH} Digital Input High Voltage	Pins IPK[1:0], OUT[3:0]		$INTV_{CC}$ – 0.15V			V
V_{IL} Digital Input Low Voltage	Pins IPK[1:0], OUT[3:0]				0.15	V

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: The LTC3336 is tested under pulsed load conditions such that $T_J \approx T_A$. The specifications over the –40°C to125°C operating junction temperature range are assured by design, characterization, and correlation with statistical process controls. Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with board layout, the rated package thermal impedance, and other environmental factors.

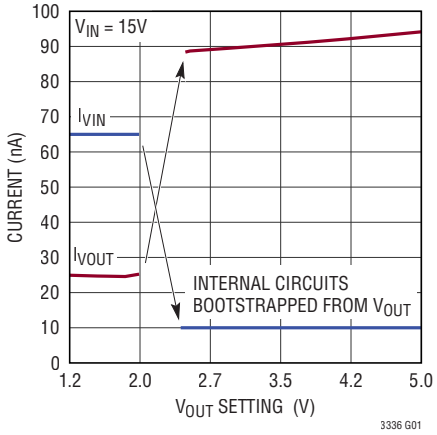
Note 3: T_J is calculated from the ambient T_A and power dissipation P_D according to the following formula: $T_J = T_A + (P_D \bullet \theta_{JA})$.

Note 4: Dynamic supply current is higher due to gate charge being delivered at the switching frequency.

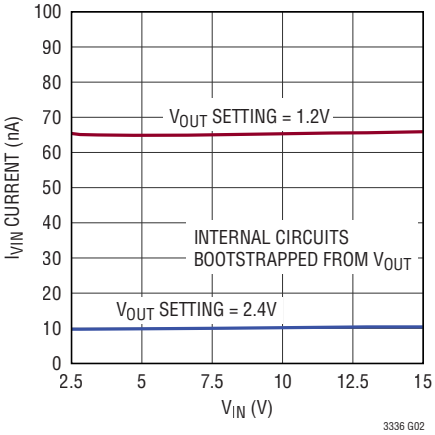
Note 5: The falling threshold is specified as a percentage of the average of the measured sleep and wake-up thresholds for each selected output voltage and the rising threshold is equal to the sleep threshold.

TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

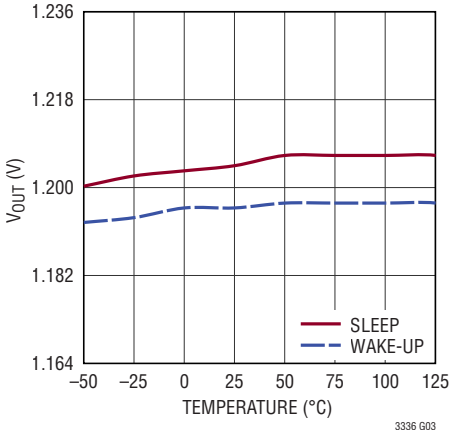
I_{VIN} and I_{VOUT} vs V_{OUT} Setting (Sleeping, In Regulation, No Load)



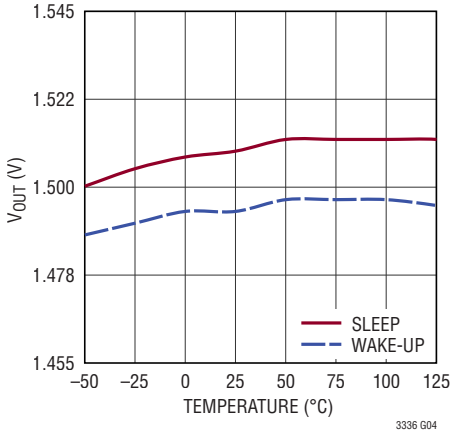
I_{VIN} vs V_{IN} (Sleeping, In Regulation, No Load)



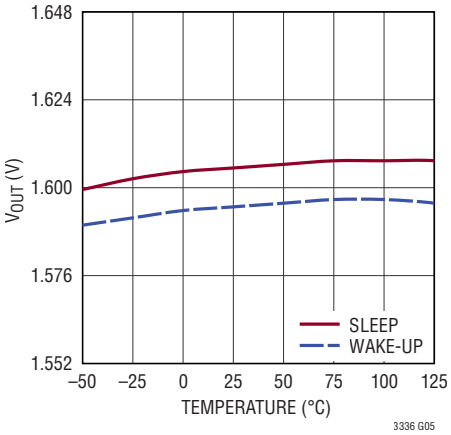
Sleep and Wake-Up Thresholds vs Temperature for 1.2V Setting



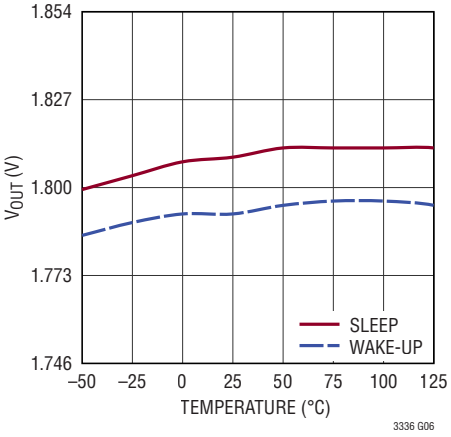
Sleep and Wake-Up Thresholds vs Temperature for 1.5V Setting



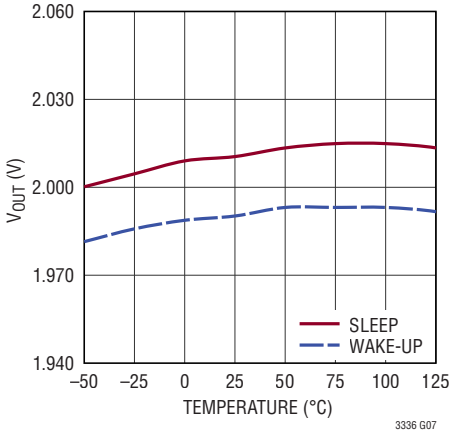
Sleep and Wake-Up Thresholds vs Temperature for 1.6V Setting



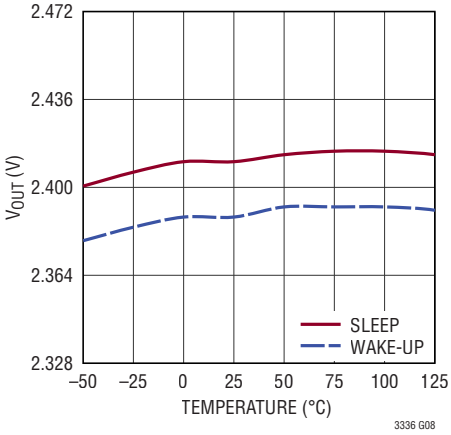
Sleep and Wake-Up Thresholds vs Temperature for 1.8V Setting



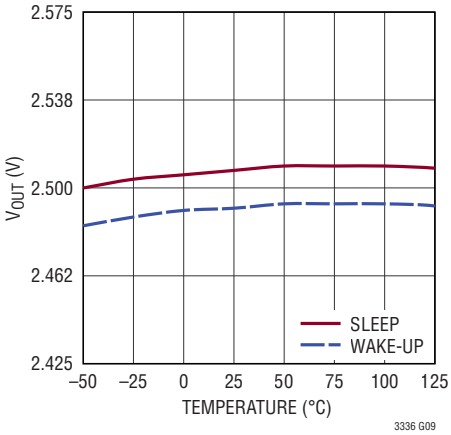
Sleep and Wake-Up Thresholds vs Temperature for 2.0V Setting



Sleep and Wake-Up Thresholds vs Temperature for 2.4V Setting

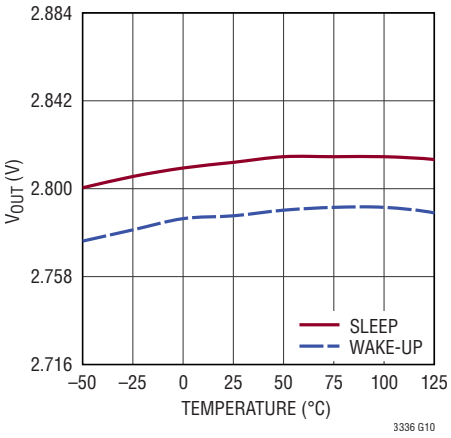


Sleep and Wake-Up Thresholds vs Temperature for 2.5V Setting

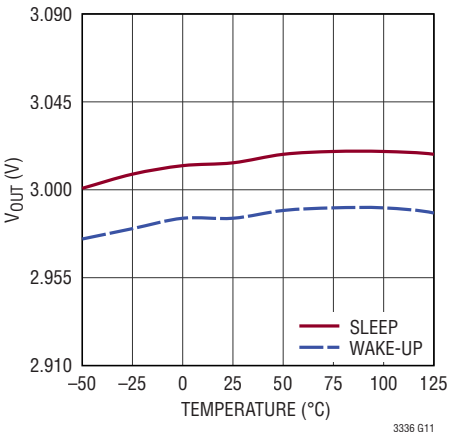


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

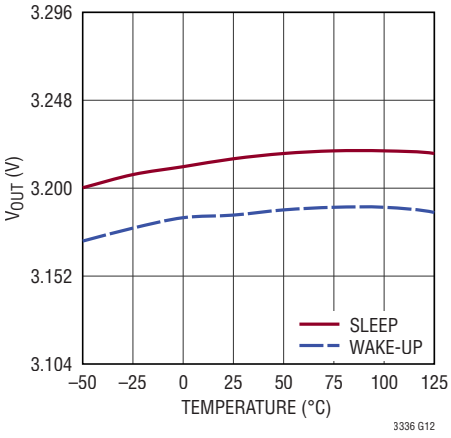
Sleep and Wake-Up Thresholds vs Temperature for 2.8V Setting



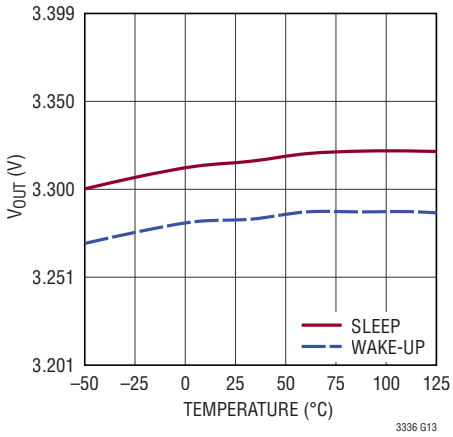
Sleep and Wake-Up Thresholds vs Temperature for 3.0V Setting



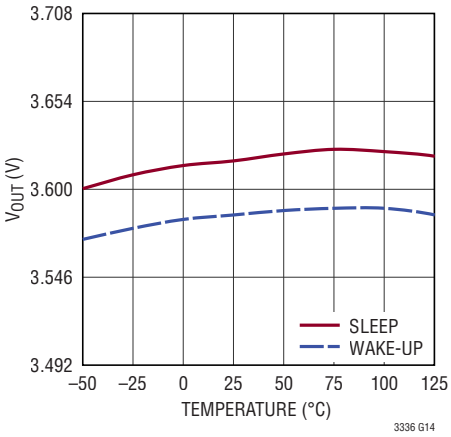
Sleep and Wake-Up Thresholds vs Temperature for 3.2V Setting



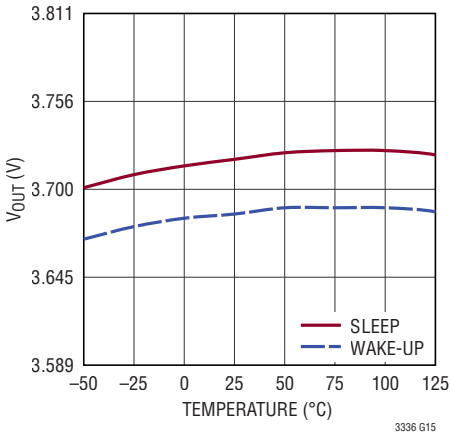
Sleep and Wake-Up Thresholds vs Temperature for 3.3V Setting



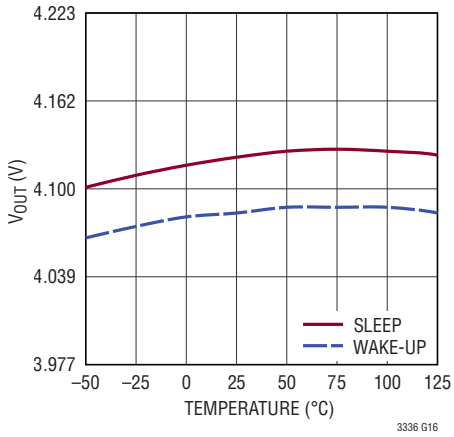
Sleep and Wake-Up Thresholds vs Temperature for 3.6V Setting



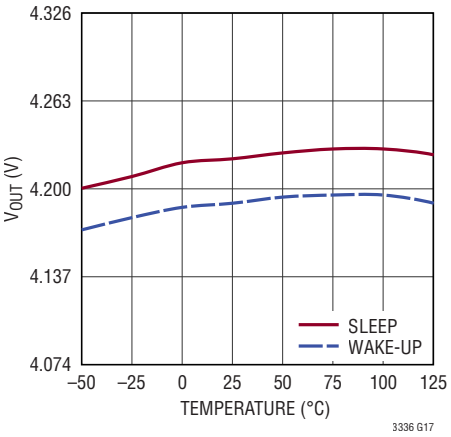
Sleep and Wake-Up Thresholds vs Temperature for 3.7V Setting



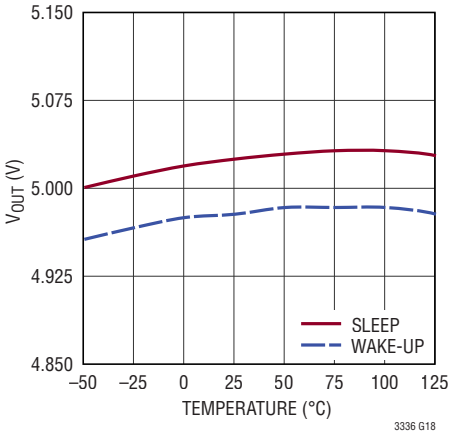
Sleep and Wake-Up Thresholds vs Temperature for 4.1V Setting



Sleep and Wake-Up Thresholds vs Temperature for 4.2V Setting

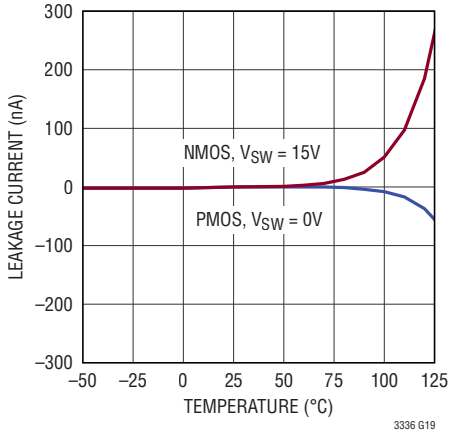


Sleep and Wake-Up Thresholds vs Temperature for 5.0V Setting

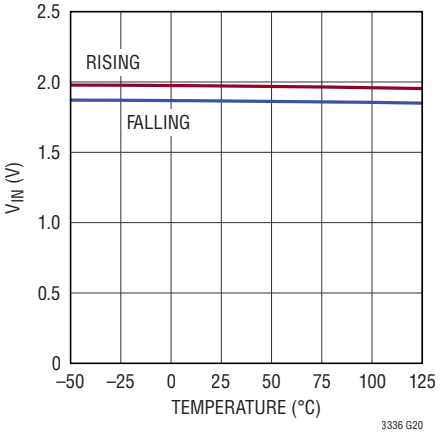


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

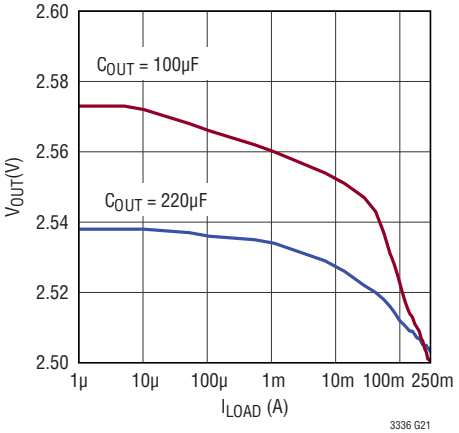
I_{SW} Leakage Current vs Temperature



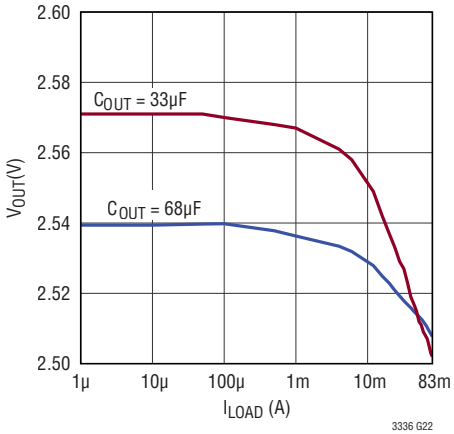
Undervoltage Lockout Thresholds vs Temperature



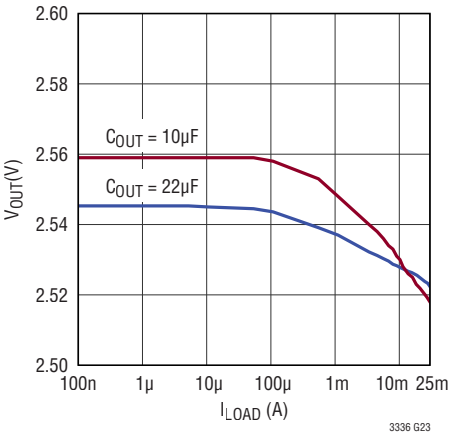
Load Regulation, 300mA I_{PEAK} Setting, V_{IN} = 7.2V, L = 68µH



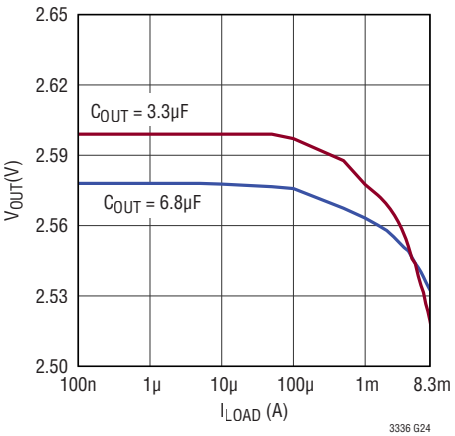
Load Regulation, 100mA I_{PEAK} Setting, V_{IN} = 7.2V, L = 68µH



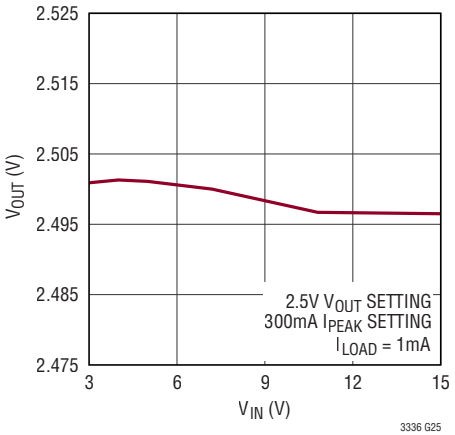
Load Regulation, 30mA I_{PEAK} Setting, V_{IN} = 7.2V, L = 330µH



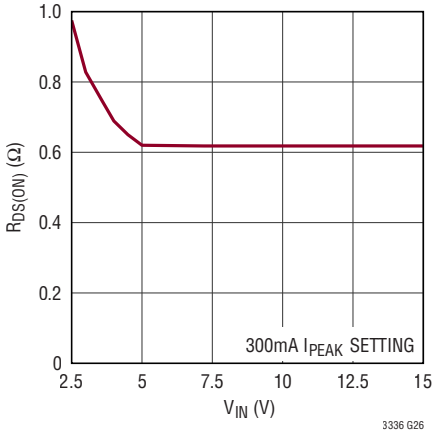
Load Regulation, 10mA I_{PEAK} Setting, V_{IN} = 7.2V, L = 680µH



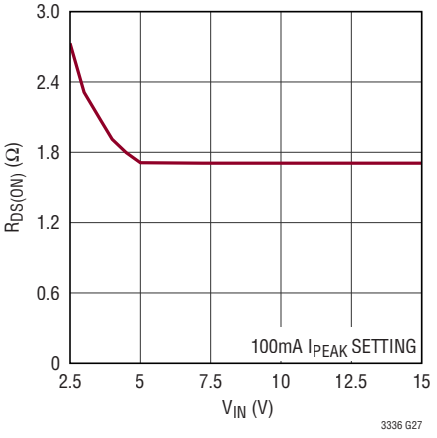
Line Regulation



$R_{DS(ON)}$ of P-Channel MOSFET vs V_{IN}

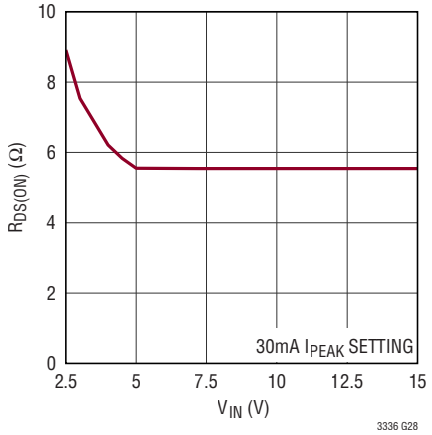


$R_{DS(ON)}$ of P-Channel MOSFET vs V_{IN}

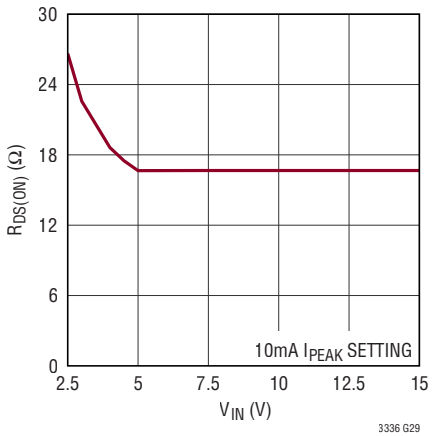


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

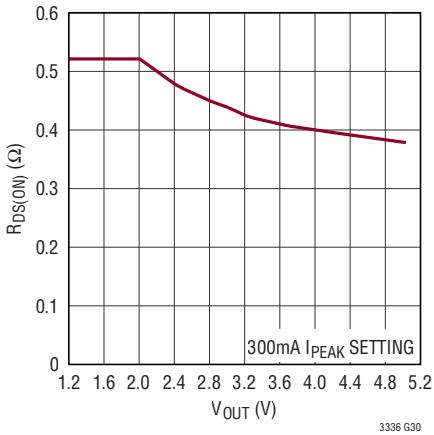
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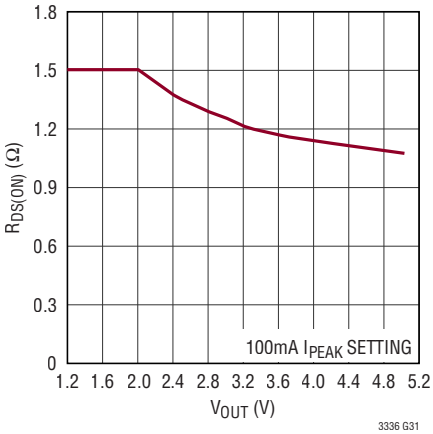
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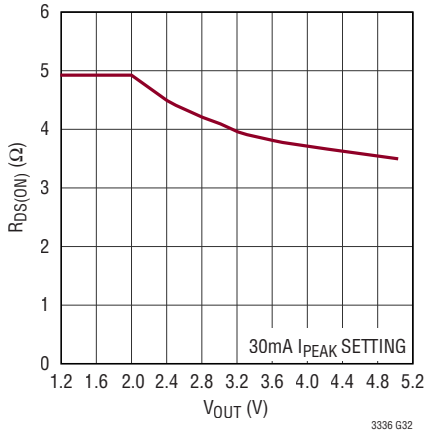
$R_{DS(ON)}$ of N-Channel MOSFET vs V_{OUT}



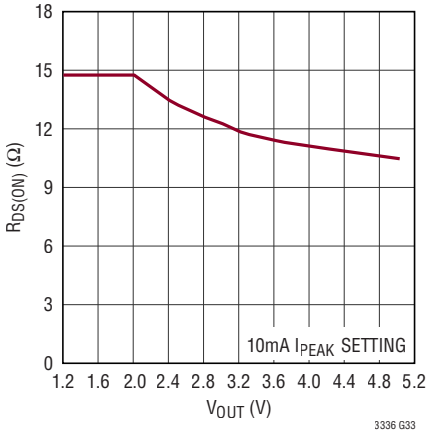
$R_{DS(ON)}$ of N-Channel MOSFET vs V_{OUT}



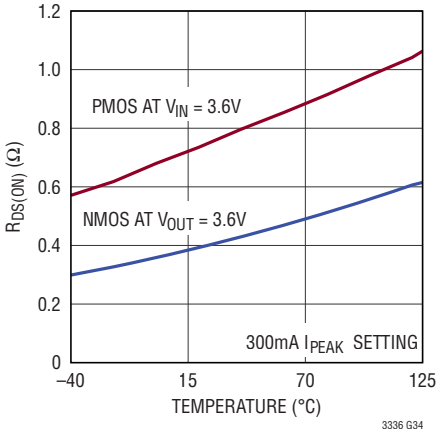
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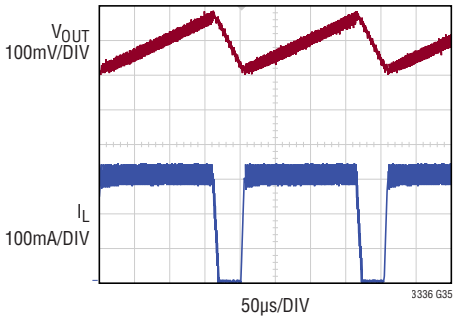
$R_{DS(ON)}$ of N-Channel MOSFET vs V_{OUT}



$R_{DS(ON)}$ vs Temperature



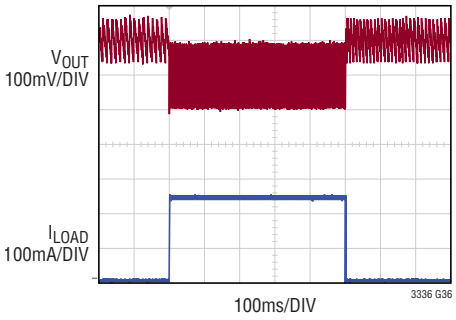
Output Voltage Ripple



L = 68µH, V_{IN} = 7.2V
C_{OUT} = 100µF
300mA I_{PEAK} SETTING
2.5V V_{OUT} SETTING
I_{LOAD} = 250mA

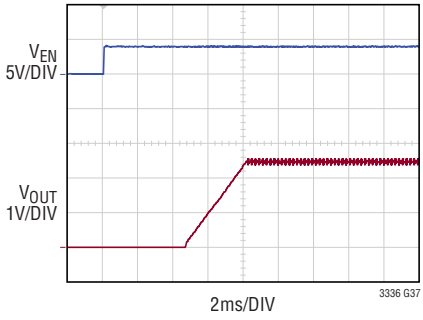
TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

0A to 250mA Load Transient



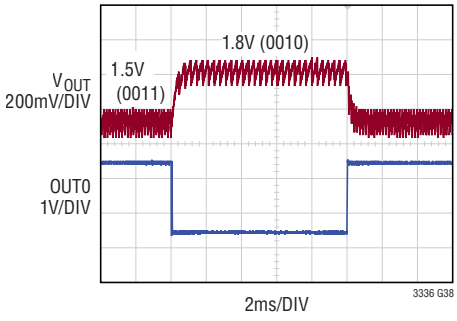
L = 68µH, V_{IN} = 7.2V
C_{OUT} = 100µF
300mA I_{PEAK} SETTING
2.5V V_{OUT} SETTING

Power-Up Transient



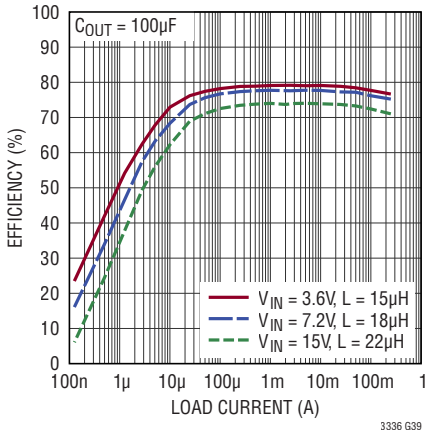
L = 68µH, V_{IN} = 7.2V
C_{OUT} = 100µF
300mA I_{PEAK} SETTING
2.5V V_{OUT} SETTING
I_{LOAD} = 250mA

Dynamic Output Voltage Change Between 1.5V and 1.8V

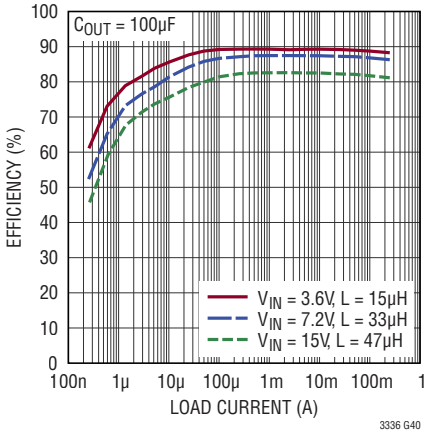


L = 68µH, V_{IN} = 7.2V
C_{OUT} = 100µF
300mA I_{PEAK} SETTING
I_{LOAD} = 250mA

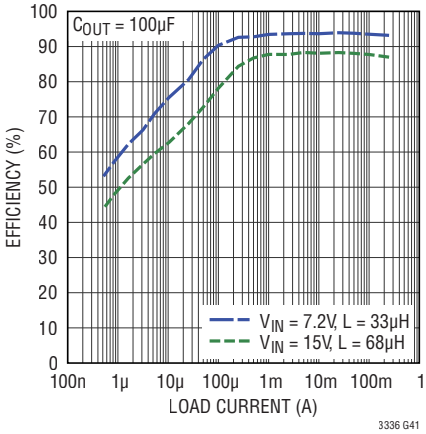
Efficiency vs I_{LOAD}, V_{OUT} = 1.2V, I_{PEAK} = 300mA



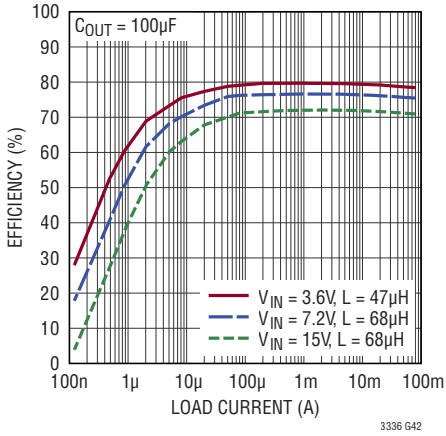
Efficiency vs I_{LOAD}, V_{OUT} = 2.5V, I_{PEAK} = 300mA



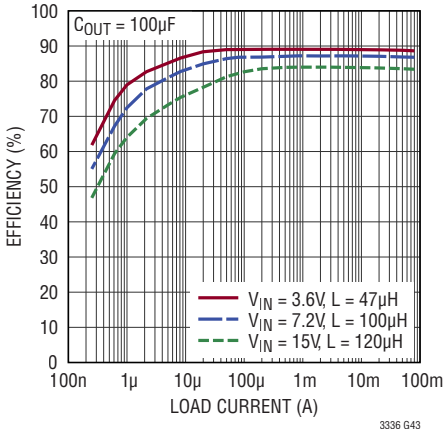
Efficiency vs I_{LOAD}, V_{OUT} = 5V, I_{PEAK} = 300mA



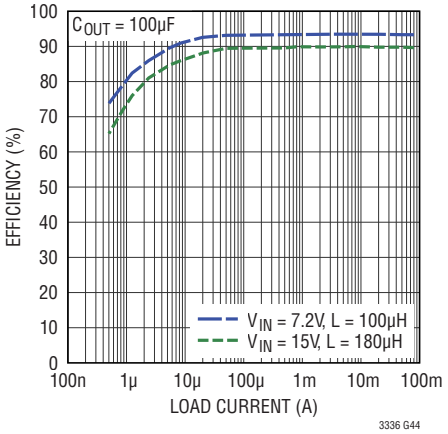
Efficiency vs I_{LOAD}, V_{OUT} = 1.2V, I_{PEAK} = 100mA



Efficiency vs I_{LOAD}, V_{OUT} = 2.5V, I_{PEAK} = 100mA

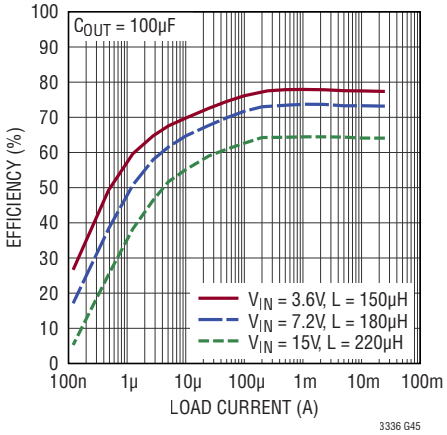


Efficiency vs I_{LOAD}, V_{OUT} = 5V, I_{PEAK} = 100mA

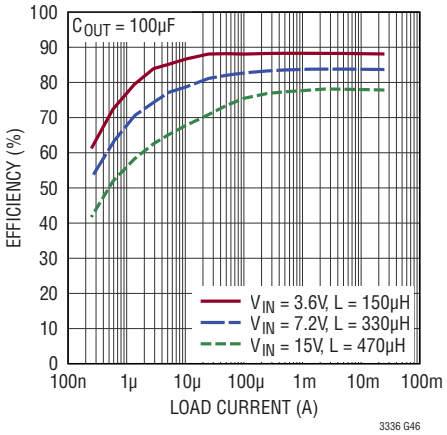


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

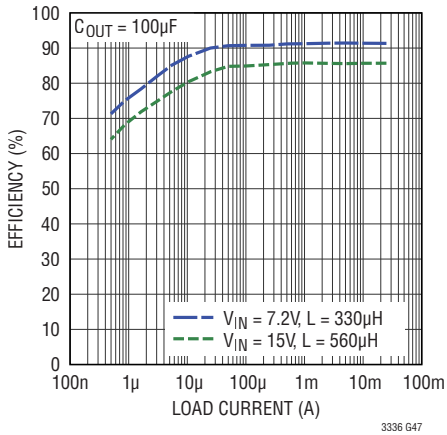
Efficiency vs I_{LOAD}, V_{OUT} = 1.2V, I_{PEAK} = 30mA



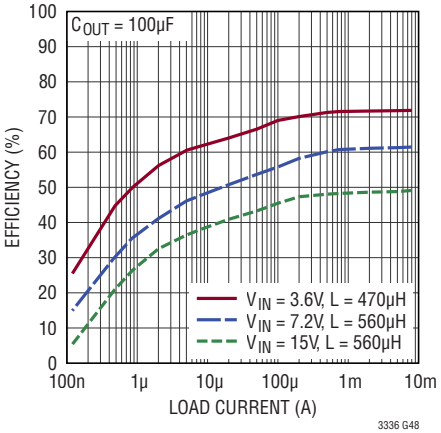
Efficiency vs I_{LOAD}, V_{OUT} = 2.5V, I_{PEAK} = 30mA



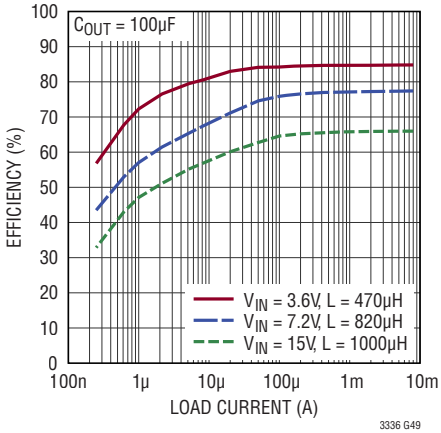
Efficiency vs I_{LOAD}, V_{OUT} = 5V, I_{PEAK} = 30mA



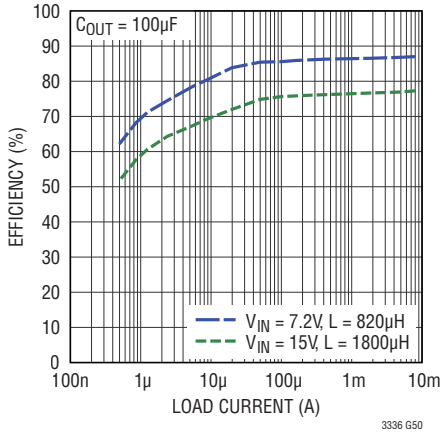
Efficiency vs I_{LOAD}, V_{OUT} = 1.2V, I_{PEAK} = 10mA



Efficiency vs I_{LOAD}, V_{OUT} = 2.5V, I_{PEAK} = 10mA



Efficiency vs I_{LOAD}, V_{OUT} = 5V, I_{PEAK} = 10mA



PIN FUNCTIONS

V_{IN} (Pin 1): Input Voltage. Connect the battery input as close as possible to this pin along with an appropriately-sized bypass capacitor (see the Applications Information section).

EN (Pin 2): Buck Enable Input. Logic level input referenced to $INTV_{CC}$. A logic high on EN enables the buck converter. A logic low prevents the regulator from switching and discharges V_{OUT} with a 10k resistor to ground.

IPK1 (Pin 3): Inductor Peak Current Select Bit (with IPK0). See IPK0.

IPK0 (Pin 4): Inductor Peak Current Select Bit (with IPK1). IPK0 should be tied to $INTV_{CC}$ to select high or to GND to select low to program the desired I_{PEAK} (see Table 1 in the Operation section).

$INTV_{CC}$ (Pin 5): V_{CC} Supply for Internal Circuits. Voltage output used as the logic high reference for input pins EN and IPK[1:0]. The allowed external DC load current at $INTV_{CC}$ is limited to 10µA. The LQFN package has a bypass capacitor integrated inside.

PGOOD (Pin 6): Buck Power Good Output. The PGOOD pin is high (referenced to V_{OUT}) when the buck regulator output V_{OUT} is in regulation. PGOOD is low when EN is low.

OUT3 (Pin 7): Output Voltage Select Bit (with OUT2, OUT1, and OUT0). Tie this pin to $INTV_{CC}$ or V_{OUT} (for logic high) or to GND (for logic low) to statically program V_{OUT} (see Table 2 in the Operation section). For dynamically changing V_{OUT}, refer to the Applications Information section for alternate hookups.

OUT2 (Pin 8): Output Voltage Select Bit (with OUT3, OUT1, and OUT0). See OUT3.

OUT1 (Pin 9): Output Voltage Select Bit (with OUT3, OUT2, and OUT0). See OUT3.

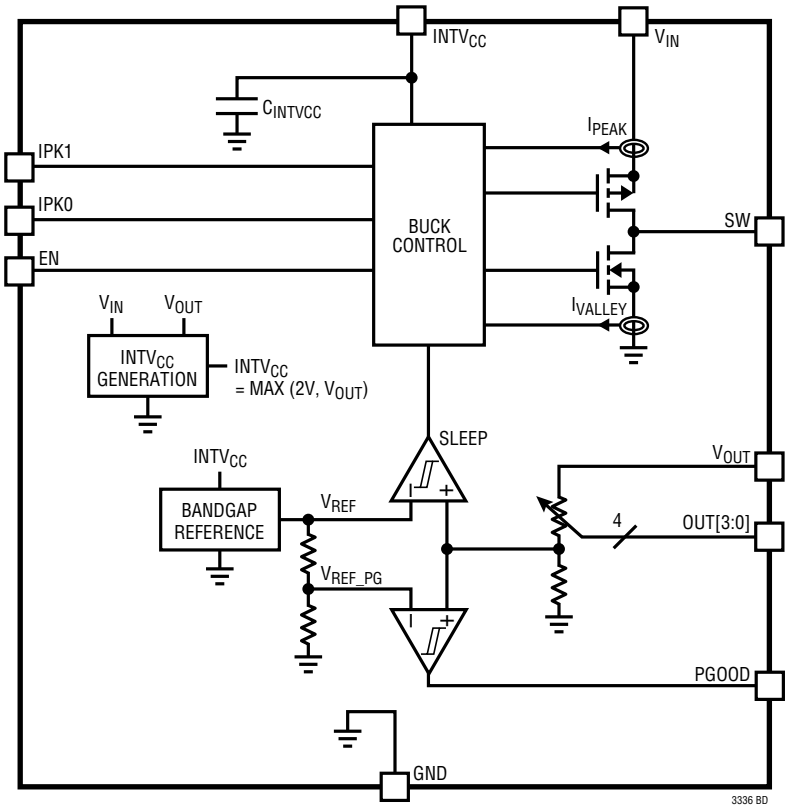
OUT0 (Pin 10): Output Voltage Select Bit (with OUT3, OUT2, and OUT1). See OUT3.

V_{OUT} (Pin 11): Output Voltage Sense Input. The voltage level V_{OUT} is also used as the logic high reference for input pins OUT[3:0] and output pin PGOOD.

SW (Pin 12): Switch Pin of the Buck Regulator. An inductor should be connected from SW to V_{OUT}. The inductor value is dependent on the actual I_{PEAK} setting. See Inductor Selection in the Applications Information section.

GND (Exposed Pad Pin 13): Ground. This pin must be soldered to the PCB. This pin provides both electrical contact to ground and good thermal contact to the printed circuit board.

BLOCK DIAGRAM



OPERATION

BUCK DC/DC REGULATOR

The buck regulator uses hysteretic voltage control to regulate the output through internal feedback from the V_{OUT} sense pin. The output voltage can be programmed to one of sixteen different fixed values. In dropout, the P-channel MOSFET is turned on 100%.

The buck converter charges an output capacitor through an inductor to a value slightly higher than the regulation point. It does this by ramping the inductor current up to the peak current threshold I_{PEAK} (see Table 1) through an internal P-channel MOSFET switch and then ramping it down to the valley current threshold I_{VALLEY} through an internal N-channel MOSFET switch. See waveform in Figure 1. This efficiently delivers energy to the output capacitor. The ramp rates are determined by V_{IN}, V_{OUT}, and the inductor value.

Table 1. I_{PEAK} Selection

IPK1	IPK0	I_{PEAK}
0	0	10mA
0	1	30mA
1	0	100mA
1	1	300mA

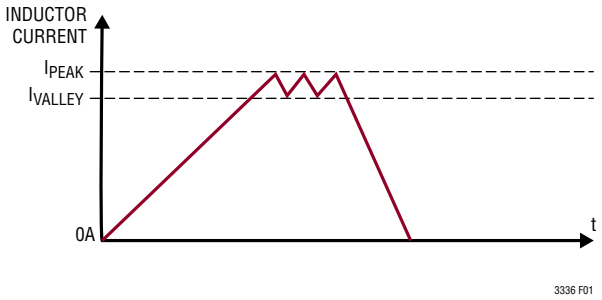


Figure 1.

After the buck brings the output voltage into regulation, the converter enters a low quiescent current sleep state that monitors the output voltage with a sleep comparator. The inductor current is ramped down to zero current in a controlled manner before entering SLEEP.

During SLEEP, load current is provided by the buck output capacitor. When the output voltage falls below the regulation point, the buck regulator wakes up and the cycle repeats. This hysteretic method of providing a regulated output reduces losses associated with MOSFET switching and maintains an output in regulation at light loads.

When the sleep comparator signals that the output has reached the sleep threshold, the buck converter may be in the middle of a cycle with current still flowing through the inductor. Normally both synchronous switches would turn off and the current in the inductor would freewheel to zero through the N-channel MOSFET body diode. The LTC3336 keeps the N-channel MOSFET switched on during this time to prevent the conduction loss that would occur in the diode if the N-channel MOSFET were off. If the P-channel MOSFET is on when the sleep comparator trips, the P-channel immediately turns off and the N-channel MOSFET turns on.

Though the quiescent current when the buck is switching is much greater than the sleep quiescent current, it is still a small percentage of the average inductor current which results in high efficiency over most load conditions.

The buck operates only when the output voltage discharges below the sleep falling threshold. Thus, the buck operating quiescent current is averaged with the low sleep quiescent current. This allows the converter to remain very efficient at loads of 10µA and lower.

Sixteen selectable voltages are available by tying the output select bits (OUT3, OUT2, OUT1, OUT0) to $INTV_{CC}$ or V_{OUT} (for logic high) or to GND (for logic low). Table 2 shows the sixteen codes and their corresponding output voltages.

OPERATION WITH BUCK SUPPLIED FROM OUTPUT

For output voltage settings ≥ 2.4V the quiescent current of the buck regulator is taken from the regulated output V_{OUT}. This mode of operation significantly reduces the V_{IN} quiescent current by about a factor of V_{IN}/V_{OUT}.

OPERATION

Table 2. Buck Regulator Output Voltage Selection via OUT[3:0] Pins

V_{OUT} (V)	OUT3	OUT2	OUT1	OUT0
1.2	0	0	0	1
1.5	0	0	1	1
1.6	0	0	0	0
1.8	0	0	1	0
2.0	0	1	1	0
2.4	0	1	0	1
2.5	0	1	0	0
2.8	0	1	1	1
3.0	1	0	0	0
3.2	1	1	0	0
3.3	1	0	0	1
3.6	1	0	1	0
3.7	1	0	1	1
4.1	1	1	0	1
4.2	1	1	1	0
5.0	1	1	1	1

Note: Underlined voltage values of 1.2V, 1.8V, 2.5V, and 3V can be set as power-up defaults. These voltage values can be "pin-strapped" with a single pin tied high during start-up, while the other pins can be dynamically set after start-up.

BUCK REGULATOR DROPOUT OPERATION

When the input supply voltage decreases towards the output voltage, the rate of change of inductor current during the upslope decreases, reducing the switching frequency of the current bursts. Further reduction in input supply voltage will eventually cause the P-channel MOSFET to be turned on 100%, i.e., DC. The output voltage will then be determined by the input voltage minus the voltage drop across the P-channel MOSFET and the inductor. The LTC3336 senses this state and enters a very low quiescent current state.

BUCK REGULATOR OUTPUT OVERVOLTAGE CONDITION AND INTERNAL CLAMP

An internal 1MΩ resistor pulls down V_{OUT} if V_{OUT} is higher than 5% above its regulation voltage. This should never happen in normal operation.

BUCK REGULATOR OUTPUT DISCHARGE

If EN is low, the buck regulator output is discharged through an internal 10k resistor.

APPLICATIONS INFORMATION

INPUT CAPACITOR SELECTION

The input V_{IN} should be bypassed with at least 0.1µF to GND. In cases where the input voltage is from a battery and the series resistance of the battery is high, a larger capacitor may be required to handle transients. A larger capacitor may also be necessary if the LTC3336 is supplied with an input voltage close to 2.5V (at higher I_{PEAK} settings) to prevent the input voltage from transiently falling below the undervoltage lockout threshold.

OUTPUT CAPACITOR SELECTION

The duration for which the regulator sleeps depends on the load current and the size of the output capacitor. The sleep time decreases as the load current increases and/or as the output capacitor decreases. The DC sleep hysteresis window, Sleep Threshold – Wake-Up Threshold, is ±0.3% around the programmed output voltage. Ideally this means that the sleep time is determined by Equation 1.

$$t_{SLEEP} = C_{OUT} \bullet V_{OUT} \bullet 2 \bullet \left(\frac{0.3\%}{I_{LOAD}}\right) \quad (1)$$

As the output capacitor decreases to much lower values than described in Table 3, delays in the internal sleep comparator along with the load current may result in the V_{OUT} voltage slewing past the ±0.3% thresholds. This will lengthen the sleep time and increase V_{OUT} ripple.

If transient load currents above the I_{PEAK} setting are required, then a larger capacitor can be used at the output. This capacitor will be continuously discharged

APPLICATIONS INFORMATION

during this load condition. The capacitor can be sized using Equation 2 for an acceptable ripple $V_{OUT}^+ - V_{OUT}^-$.

$$C_{OUT} = t_{LOAD} \bullet \left(\frac{I_{LOAD} - 0.95 \bullet I_{PEAK}}{V_{OUT}^+ - V_{OUT}^-} \right) \quad (2)$$

In Equation 2, t_{LOAD} is the duration of the excessive transient load current, I_{PEAK} is the programmed I_{PEAK} setting and $V_{OUT}^+ - V_{OUT}^-$ is the desired V_{OUT} ripple.

At zero or light load conditions V_{OUT} should not exceed the typical 5% overvoltage threshold. Otherwise, it loses some power in the 1MΩ overvoltage pull-down resistor.

A standard surface mount ceramic capacitor can be used for C_{OUT}. These capacitors can be obtained from manufacturers such as Vishay, Murata, TDK, and Taiyo Yuden.

Table 3. Minimum Required Buck Output Capacitor Size for a Sleep Time of 50µs at Max Load

V_{OUT} (V)	I_{PEAK} (mA)	C_{OUT} (µF)
1.2	10	6.8
1.2	30	22
1.2	100	68
1.2	300	220
2.5	10	3.3
2.5	30	10
2.5	100	33
2.5	300	100
5.0	10	2.2
5.0	30	4.7
5.0	100	22
5.0	300	47

INDUCTOR SELECTION

The buck is optimized to work with inductor values calculated with Equation 3 or larger. The calculated values represent a suitable trade-off between size and efficiency for typical applications. A larger inductor will benefit higher input voltage applications by reducing the switching frequency of the P-channel MOSFET switch, thereby improving efficiency by reducing gate charge loss. Choose an inductor with a saturation current rating, I_{SAT}, greater than the programmed I_{PEAK} setting. The DC Resistance (DCR) of the inductor can have an impact on efficiency as it is a source of loss. Trade-offs between price, size, and DCR should be evaluated. Equation 3 can be used to calculate the minimum inductor value that works well with the LTC3336 depending on V_{IN}, V_{OUT}, I_{PEAK} and maximum switching frequency f. A good target for switching frequency is 2MHz.

Examples of inductor series to choose from: LPS4018 (0.56µH to 1000µH), MSS7348 (3.3µH to 1000µH), and MSS1210 (10µH to 10,000µH).

$$L = \frac{1}{f \bullet 10\% \bullet I_{PEAK} \bullet \left(\frac{1}{V_{IN} - V_{OUT}} + \frac{1}{V_{OUT}} \right)} \quad (3)$$

Explanation of symbols used in Equation 3 and how they are derived:

$$T = L \bullet \frac{\Delta_I}{V_L}$$

$$T = \frac{1}{f}$$

$\Delta_I = I_{PEAK} - I_{VALLEY} = 10\% \bullet I_{PEAK}$

V_L = Voltage Across Inductor

f = Switching Frequency

$T = T_{ON} + T_{OFF}$

$T_{ON} = L \bullet \frac{\Delta_I}{V_{IN} - V_{OUT}}$ duration of P-Channel MOSFET On

$T_{OFF} = L \bullet \frac{\Delta_I}{V_{OUT}}$ duration of P-Channel MOSFET Off

DYNAMIC OUTPUT VOLTAGE CHANGE

The selection bits OUT[3:0] can be driven from the outputs of a microcontroller and dynamically changed while the buck is running.

A start-up default voltage, $V_{DEFAULT}$, can be set with one (or more) pins tied high. Refer to Table 4 and the

APPLICATIONS INFORMATION

application: Microcontroller Supply with Dynamic Output Voltage Change in the Typical Applications section.

Table 4. Dynamic Operation Output Voltages with Single Pin Tied High

PIN TIED HIGH (DEFAULT)	$V_{DEFAULT}$ (V)	DYNAMIC OUTPUT VOLTAGES AVAILABLE WITH SINGLE PIN TIED HIGH (V)
OUT0	1.2	1.2, 1.5, 2.4, 2.8, 3.3, 3.7, 4.1, 5.0
OUT1	1.8	1.5, 1.8, 2.0, 2.8, 3.6, 3.7, 4.2, 5.0
OUT2	2.5	2.0, 2.4, 2.5, 2.8, 3.2, 4.1, 4.2, 5.0
OUT3	3.0	3.0, 3.2, 3.3, 3.6, 3.7, 4.1, 4.2, 5.0

PCB LAYOUT CONSIDERATIONS

The LTC3336 switches large currents (relative to the I_Q) at high frequencies. Special care should be given to the PCB layout to ensure stable, noise-free operation. Figure 2 depicts a recommended PCB layout to be utilized for the LTC3336, if a 2-layer PCB is being used. A few key guidelines follow: All circulating high current paths should be kept as short as possible using wide traces. In particular, capacitor ground connections should connect by vias down to the ground plane in the shortest route possible. The bypass capacitors C_{IN} and C_{OUT} should be placed as close to the IC as possible.

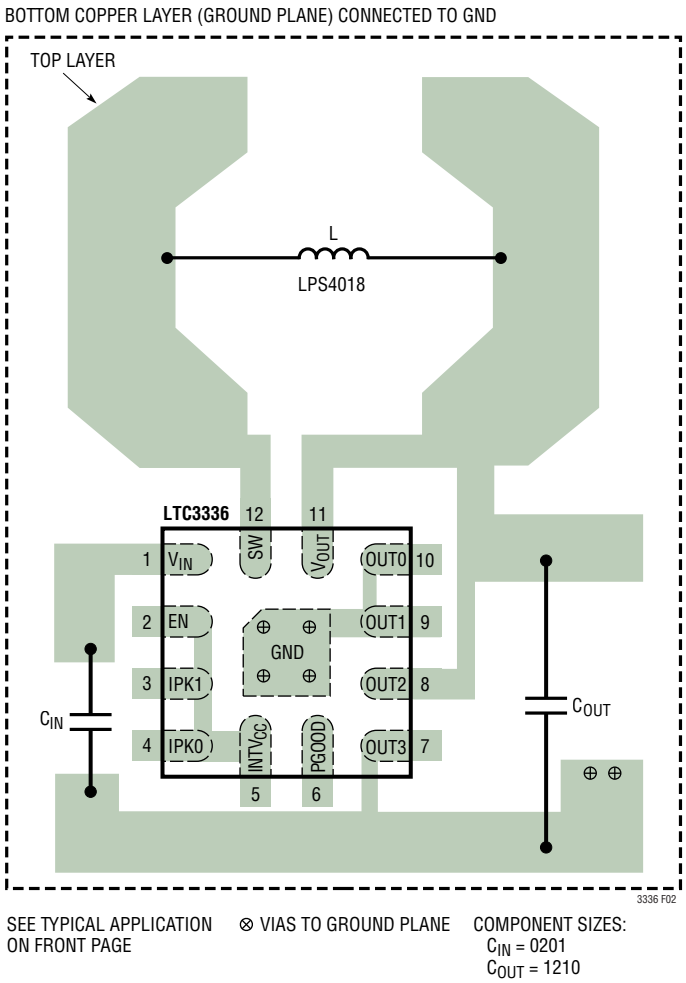
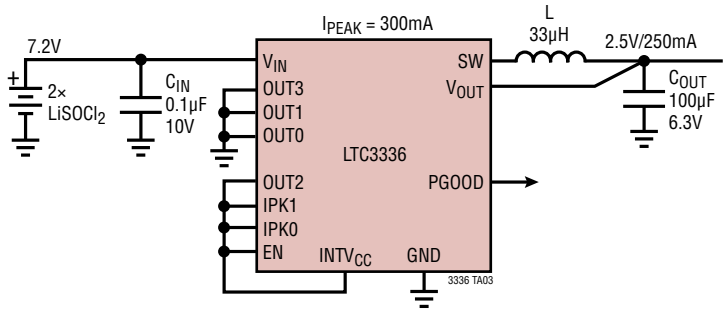


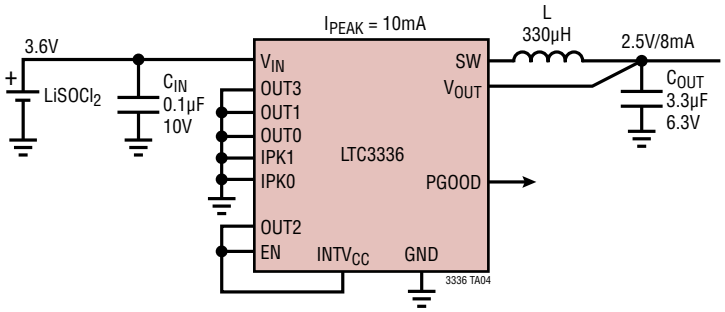
Figure 2. Recommended Component Placement on PCB

TYPICAL APPLICATIONS

2.5V/250mA Buck Powered from 2× Lithium Thionyl Chloride Batteries

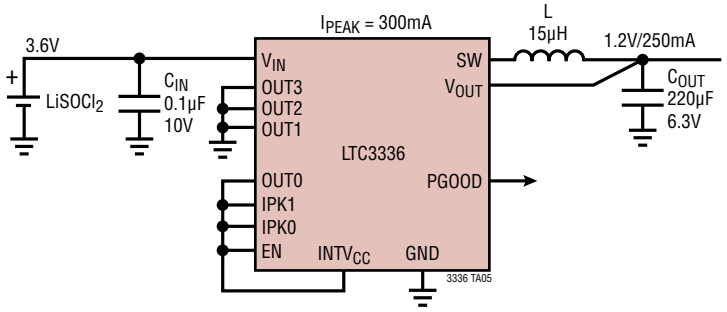


2.5V/8mA Buck Powered from Lithium Thionyl Chloride Battery

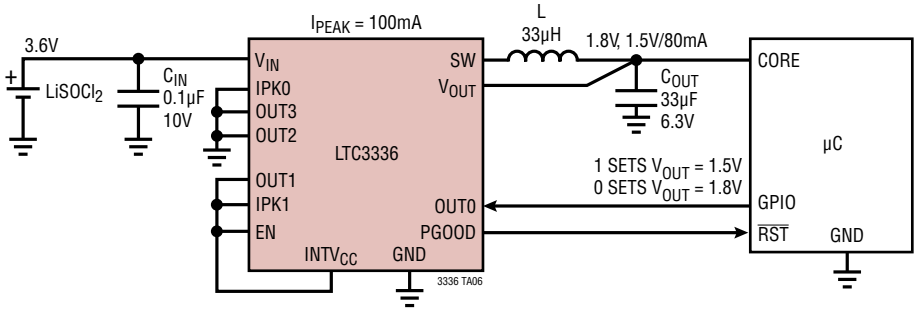


TYPICAL APPLICATIONS

1.2V/250mA Buck Powered from Lithium Thionyl Chloride Battery

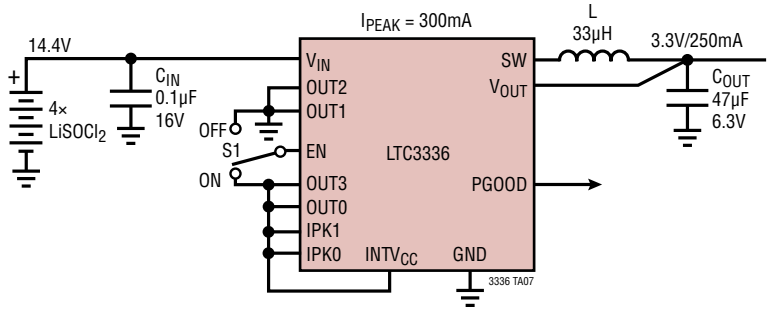


Microcontroller Supply with Dynamic Output Voltage Change 1.8V or 1.5V/80mA

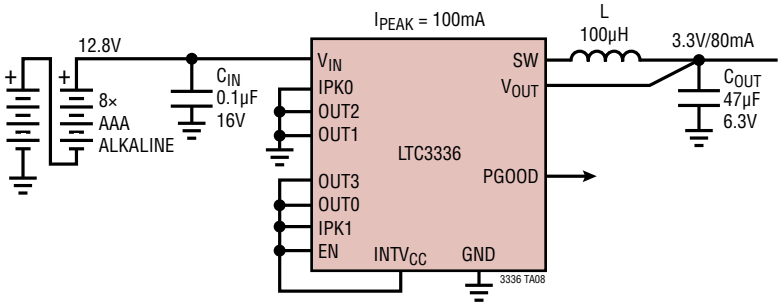


TYPICAL APPLICATIONS

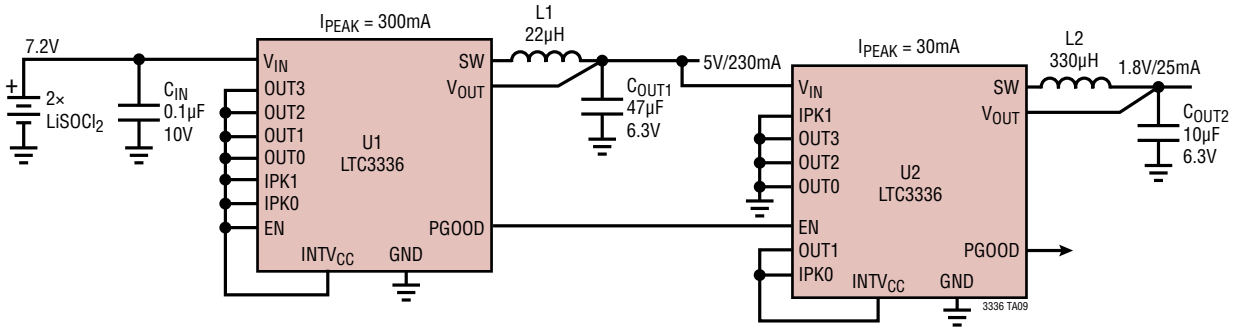
3.3V/250mA Buck Powered from 4× Lithium Thionyl Chloride Batteries



3.3V/80mA Buck Powered from 8× AAA Alkaline Primary Batteries

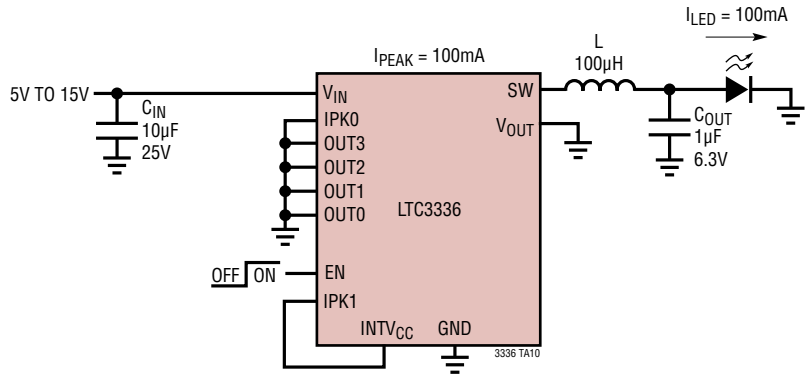


Sequenced Dual Supply 5V/230mA and 1.8V/25mA from 2× Lithium Thionyl Chloride Batteries

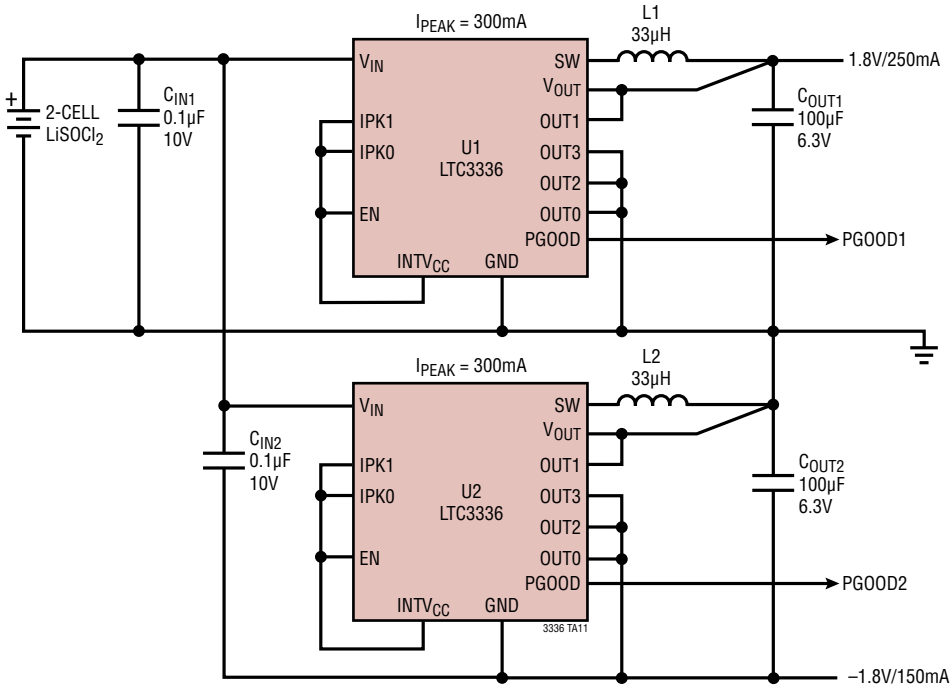


TYPICAL APPLICATIONS

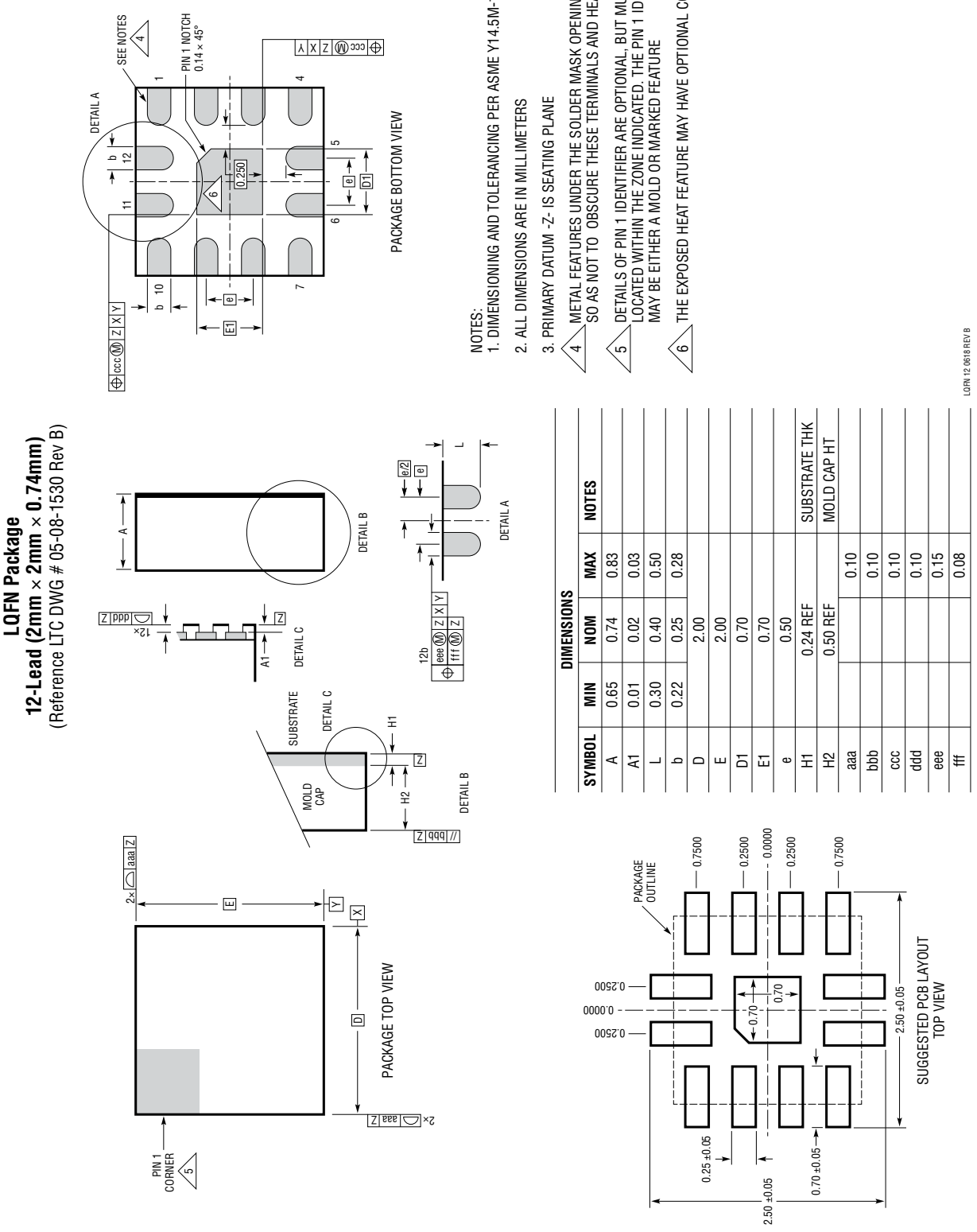
100mA Wide V_{IN} Range Super High Efficiency Current Source White LED Driver



±1.8V from 2× Lithium Thionyl Chloride Batteries



PACKAGE DESCRIPTION

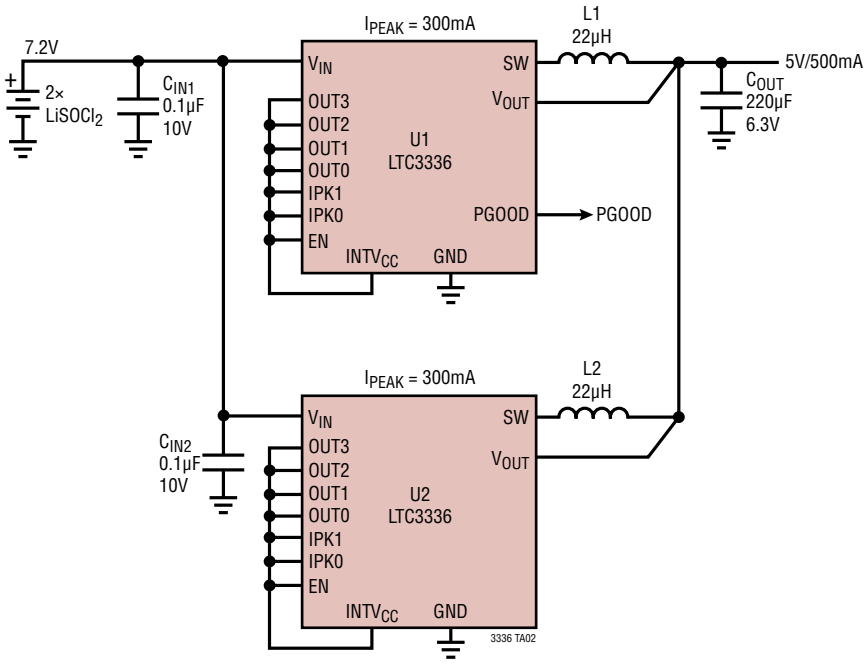


Rev. 0

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TYPICAL APPLICATION

Paralleling Two LTC3336s for Higher Current
5V/500mA Buck Powered from 2× Lithium Thionyl Chloride Batteries, No Load I_{IN} = 160nA



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC3330	Nanopower Buck-Boost DC/DC with Energy Harvesting Battery Life Extender	V_{IN}: 2.7V to 20V, BAT: 1.8V to 5.5V, 750nA I_Q, 5mm x 5mm QFN-32 Package
LTC3331	Nsanopower Buck-Boost DC/DC with Energy Harvesting Battery Charger	V_{IN}: 2.7V to 20V, BAT Float: 3.45V/4V/4.1V/4.2V, 950nA I_Q, 5mm × 5mm QFN-32 Package
LTC3335	Nanopower Buck-Boost DC/DC with Integrated Coulomb Counter	V_{IN}: 1.8V to 5.5V, V_{OUT}: Fixed 1.8V to 5V, I_Q = 680nA, 3mm × 4mm QFN-20 Package
LTC3337	Primary Battery SOH Monitor with Precision Coulomb Counter	V_{IN}: 1.8V to 5.5V, I_{PEAK}: Fixed 5mA/10mA/15mA/20mA/25mA/50mA/75mA/100mA, I_{BAL}: ±10mA, I_Q = 100nA, 12-Lead 2mm × 2mm GQFN Package
LTC3388-1/ LTC3388-3	20V, 50mA High Efficiency Nanopower Step-Down Regulator	V_{IN}: 2.7V to 20V, V_{OUT}: Fixed 1.1V to 5.5V, I_Q = 720nA, MSOP-10, 3mm × 3mm DFN-10 Packages
LTC3588-1/ LTC3588-2	Nanopower Energy Harvesting Power Supply with Up to 100mA of Output Current	V_{IN}: 2.7V to 20V, V_{OUT}: Fixed 1.8V to 5V, I_Q = 950nA, MSOP-10, 3mm × 3mm DFN-10 Packages

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