MAX38650

Tiny 1.8V to 5.5V Input, 390nA I_Q, 100mA nanoPower Buck Converter with 100% Duty Cycle Operation

General Description

The MAX38650 is a nanoPower, ultra-low 390nA quiescent current, buck (step-down) DC-DC converter operating from 1.8V to 5.5V input voltage and supporting load currents of up to 100mA with peak efficiencies of 95%. While in shutdown, there is only 5nA of shutdown current. The device offers ultra-low quiescent current, small total solution size, and high efficiency throughout the load range. The device is ideal for battery applications where long battery life is a must. The MAX38650 supports 100% duty cycle operation allowing seamless transition as battery discharges and falls below the target output voltage. The MAX38650 utilizes a unique control scheme that allows ultra-low quiescent current and high efficiency over a wide output current range. The device is offered in a space-saving, 1.58mm x 0.89mm, 6-pin wafer-level package (WLP) (2 x 3 bumps, 0.4mm pitch). The part is specified over the -40°C to +125°C operating temperature range.

Applications

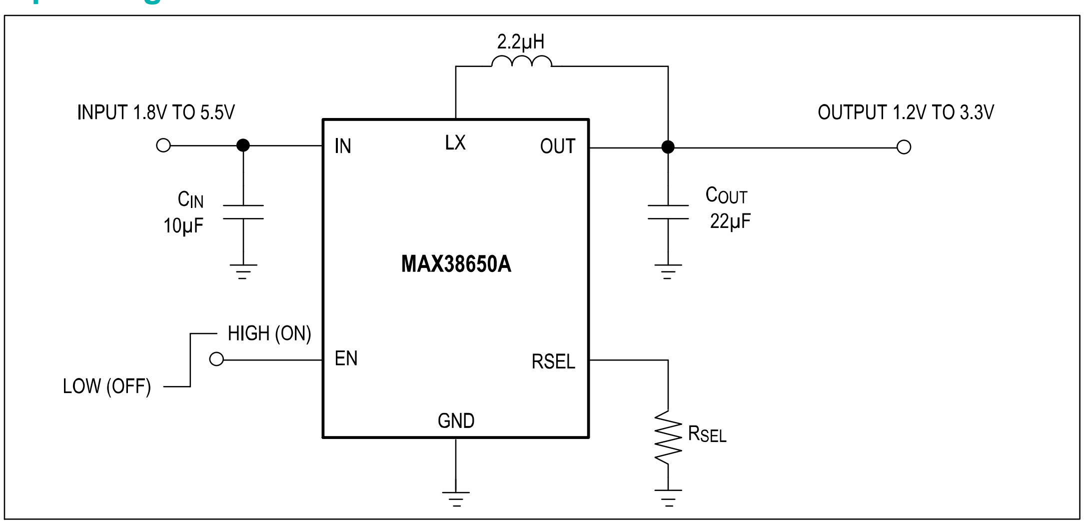
- Portable Space-Constrained Consumer Products
- Wearable Devices, Ultra-Low-Power IoT, NB IoT, and Bluetooth Low Energy (BLE)
- Single Li-Ion and Coin Cell Battery Products
- Wired, Wireless, Industrial Products
- Low-Voltage Industrial Applications

Benefits and Features

- Extends Battery Life
  - 390nA Ultra-Low Quiescent Supply Current
  - 5nA Shutdown Current
  - 95% Peak Efficiency and over 85% at 10µA
- Easy to Use—Addresses Popular Operation
  - 1.8V to 5.5V Input Range
  - Single Resistor-Adjustable V_{OUT} from 1.2V to 3.3V (MAX38650A)
  - Preprogrammed V_{OUT} from 1.2V to 5V (MAX38650B) in steps of 50mV
  - 100% Duty Cycle Mode for Low Dropout Operation
  - ±1.5% Output Voltage Accuracy
  - 100mA Load Current
- Protects System in Multiple Use Cases
  - Reverse-Current Blocking in Shutdown
  - Active Discharge Feature
- Reduces Size and Increases Reliability
  - -40°C to +125°C Operating Temperature Range
  - 1.58mm x 0.89mm, 0.4mm Pitch, 6-Pin (2 x 3) WLP

***Ordering Information* appears at end of data sheet.**

Typical Operating Circuit



Absolute Maximum Ratings

IN, EN, OUT to GND .... -0.3V to +6V

RSEL to GND .... -0.3V to lower of +6V or +IN + 0.3V

LX RMS Current .... $-1.6A_{RMS}$ to $+1.6A_{RMS}$

Continuous Power Dissipation—WLP (T_A = +70°C) (Derate 10.51mW/°C above +70°C) 840mW

Operating Temperature Range....................... -40°C to +125°C

Maximum Junction Temperature ....+150°C

Storage Temperature Range.......................... -65°C to +150°C

Lead Temperature (soldering, 10 seconds) ....+300ºC

Soldering Temperature (reflow)....................................+260°C

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

Package Information

WLP

Package Code	N60R1+1
Outline Number	21-100464
Land Pattern Number	Refer to *Application Note 1891*
THERMAL RESISTANCE, FOUR-LAYER BOARD	
Junction to Ambient (θ_{JA})	95.15°C/W
Junction to Case (θ_{JC})	N/A

For the latest package outline information and land patterns (footprints), go to *www.maximintegrated.com/packages*. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to *www.maximintegrated.com/thermal-tutorial*.

Electrical Characteristics

(V_{IN} = 3.3V, V_{OUT} = 1.8V, T_J = -40°C to +125°C, C_{IN} = 10µF, C_{OUT} = 22µF, unless otherwise specified.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Shutdown Current	I_{IN_SD}	V_{EN} = 0V, T_J = +25°C		0.005	0.1	µA
Input Voltage Range	V_{IN}	Guaranteed by input undervoltage lockout and output accuracy specifications	1.8		5.5	V
Input Undervoltage Lockout	V_{UVLO}	R_{SEL} > 60kΩ, V_{IN} rising		1.75	1.8	V
		R_{SEL} > 60kΩ, V_{IN} falling	1.65	1.7		
		R_{SEL} < 60kΩ, V_{IN} rising		2.6	2.65	
		R_{SEL} < 60kΩ, V_{IN} falling	2.45	2.5		
Output Voltage Range	V_{OUT}	Guaranteed by output accuracy specification (MAX38650A)	1.2		3.3	V
		Guaranteed by output accuracy specification (MAX38650B)	1.2		5	
Output Accuracy	ACC	V_{OUT} falling, when LX begins switching above 300kHz, V_{IN} > V_{OUT} + 0.3V, Note 2	-1.5		+1.5	%
Low-Power Mode Over-Regulation Hysteresis	LPM_HYS	Hysteresis measured as a percent of target output voltage; V_{OUT_TARGET} = 2.5V	+1.3	+2.7	+4	%
DC Load Regulation	ACC_{LD_REG}	I_{LOAD} from 1mA to 80% of I_{PEAK_LX}		±2.5		%
Quiescent Supply Current into IN	I_{Q_IN}	V_{EN} = V_{IN}, not switching V_{OUT} = 104% of target voltage, V_{OUT_TARGET} = 2.5V, T_J = +25°C		390	660	nA
Quiescent Supply Current into IN in 100% Mode	$I_{Q\_IN\_DO}$	V_{EN} = V_{IN} = 2.2V, V_{OUT_TARGET} = 2.5V, I_{LOAD} = 0mA, T_J = +25°C		1050	1680	nA
Quiescent Supply Current into OUT	I_{Q_OUT}	V_{EN} = V_{IN}, not switching V_{OUT} = 104% of target voltage, V_{OUT_TARGET} = 2.5V, T_J = +25°C		15		nA
Soft-Start Time	t_{SS}	V_{OUT} = 1.8V, I_{OUT} = 0mA		1		ms
LX Leakage Current	I_{LEAK_LX}	V_{LX} = V_{OUT} = 5.5V, V_{EN} = 0V, T_J = +25°C		4.5	100	nA
Inductor Peak Current Limit	I_{PEAK_LX}	Note 3	0.21	0.26	0.31	A
High-Side Channel Resistance	R_{DS_H}			325	525	mΩ
Low-Side Channel Resistance	R_{DS_L}			150	250	mΩ
Zero-Crossing Threshold	I_{ZX_LX}	V_{OUT} = 1.2V, Note 3		12.5		mA
Minimum Off-Time	t_{OFF_MIN}			50		ns
Enable Input Leakage Current	I_{LEAK_EN}	V_{EN} = 5.5V, T_J = +25°C		1	100	nA
Enable Voltage Threshold	V_{IH}	V_{EN} rising		0.8	1.2	V
	V_{IL}	V_{EN} falling	0.4	0.7		

(V_{IN} = 3.3V, V_{OUT} = 1.8V, T_J = -40°C to +125°C, C_{IN} = 10μF, C_{OUT} = 22μF, unless otherwise specified.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Active Discharge Resistance	R_{OUT_DIS}	V_{EN} = 0V (MAX38650A, MAX38650B)		50	85	200	Ω
Required Select Resistor Accuracy	ACC_{RSEL}	Guaranteed by output accuracy testing over R_{SEL} range; use ±1% resistor from *Table 1*	MAX38650A	-1		+1	%
Select Resistor Detection Time	t_{RSEL}	C_{RSEL} < 2pF	MAX38650A	240	600	1320	μs
Thermal Shutdown Threshold	T_{SHUT}	T_J rising when output turns off			165		°C
		T_J falling when output turns on			150		

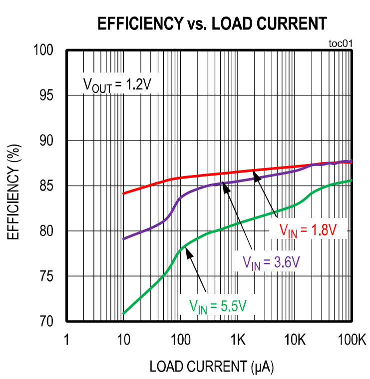
Note 1: Limits over the specified operating temperature and supply voltage range are guaranteed by design and characterization, and production tested at room temperature only.

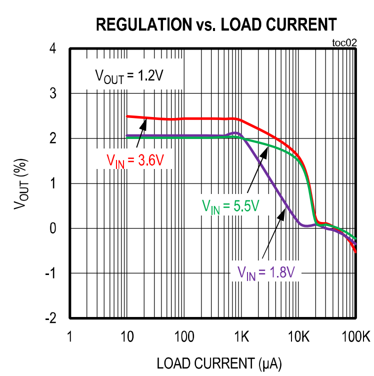
Note 2: Output accuracy in low-power mode (LPM) and does not include load, line, or ripple.

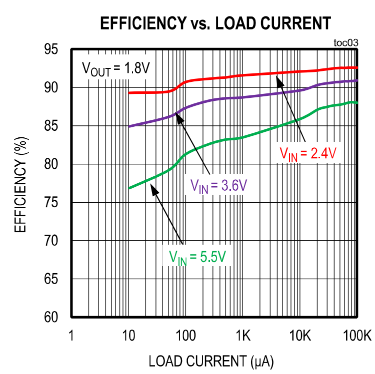
Note 3: This is a static measurement. The actual peak current limit depends upon V_{IN}, V_{OUT}, and the inductor due to propagation delays.

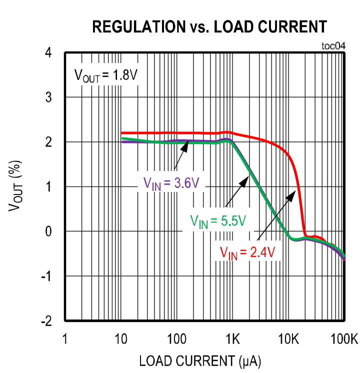
Typical Operating Characteristics

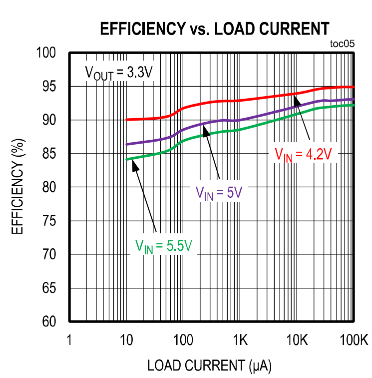
V_{IN} = 3.6V, V_{OUT} = 1.8V, C_{IN} =10μF, C_{OUT} = 22μF, L = 2.2μH unless otherwise noted.

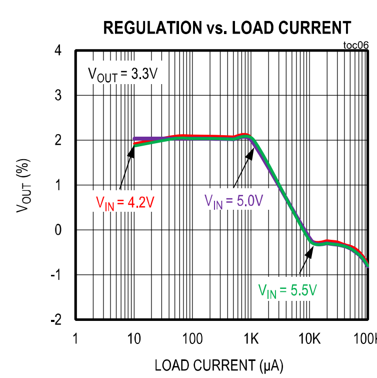




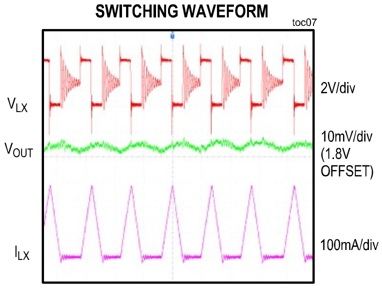






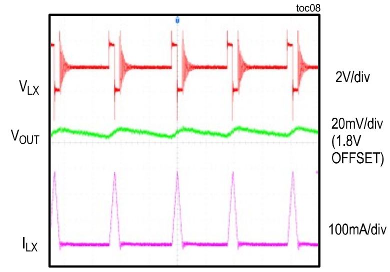


HEAVY-LOAD SWITCHING WAVEFORM



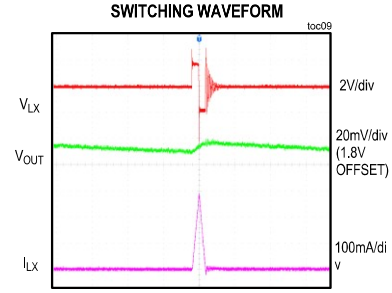
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{OUT} = 75mA
1µs/div

LIGHT-LOAD SWITCHING WAVEFORM



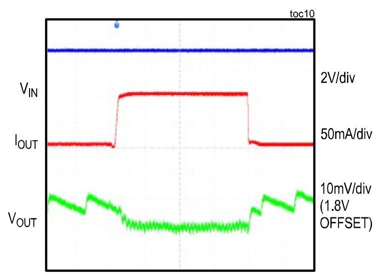
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{OUT} = 25mA
2µs/div

ULTRA-LIGHT-LOAD SWITCHING WAVEFORM



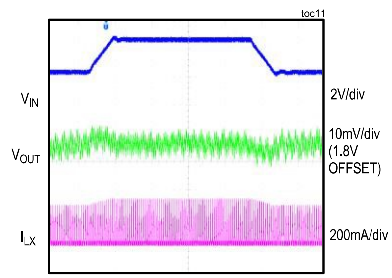
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{OUT} = 8mA
2µs/div

LOAD TRANSIENT



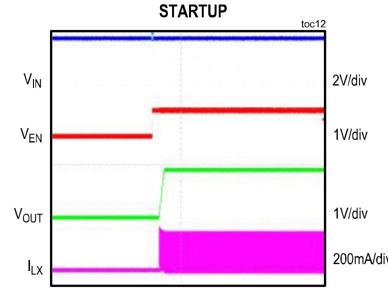
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{OUT} = 10mA TO 100mA
T_{RISE} = T_{FALL} = 2µs
10µs/div

LINE TRANSIENT



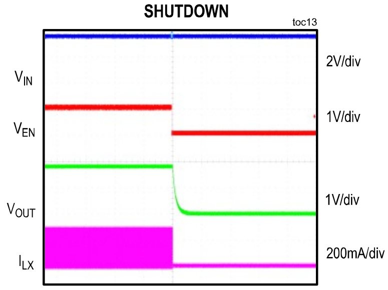
V_{IN} = 2.5V TO 5V, V_{OUT} = 1.2V, I_{OUT} = 70mA
T_{RISE} = T_{FALL} = 20µs
40µs/div

STARTUP



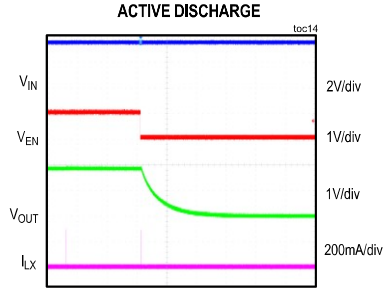
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{LOAD} = 100mA
4ms/div

SHUTDOWN



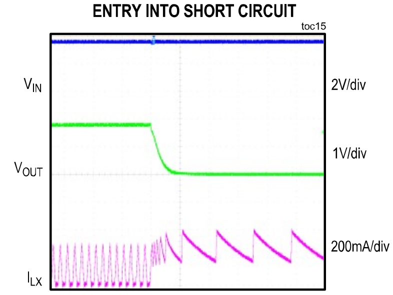
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{LOAD} = 100mA
4ms/div

ACTIVE DISCHARGE



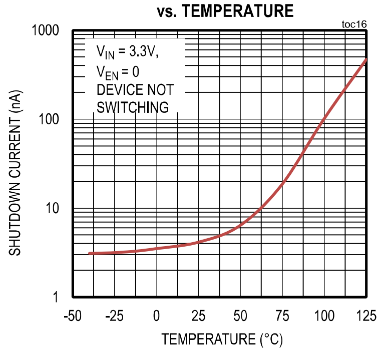
V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{LOAD} = 0mA
4ms/div

ENTRY INTO SHORT CIRCUIT

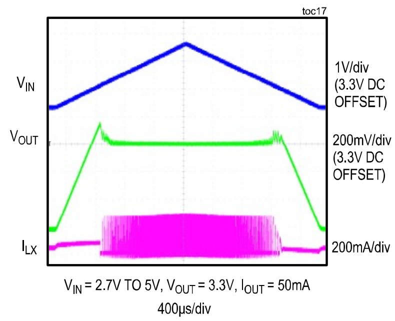


V_{IN} = 3.6V, V_{OUT} = 1.8V, I_{LOAD} = 100mA
4µs/div

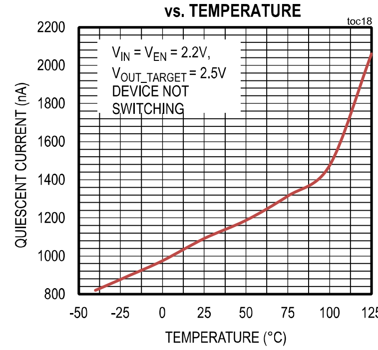
SHUTDOWN CURRENT vs. TEMPERATURE



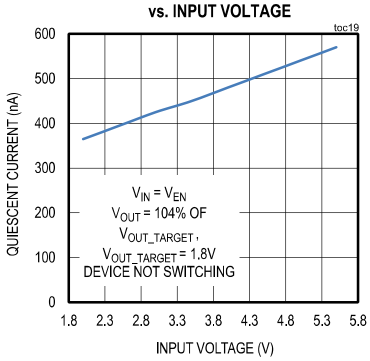
100% DUTY ENTRY/EXIT OPERATION



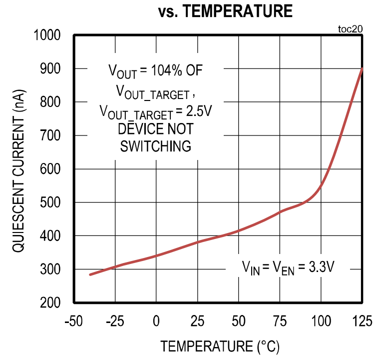
100% DUTY QUIESCENT CURRENT vs. TEMPERATURE



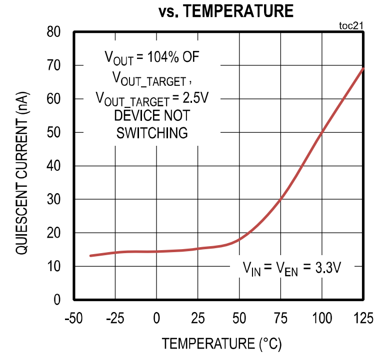
QUIESCENT CURRENT INTO INPUT vs. INPUT VOLTAGE



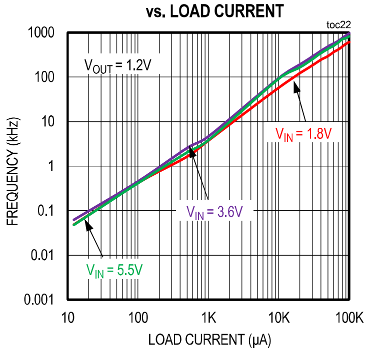
QUIESCENT CURRENT INTO INPUT vs. TEMPERATURE



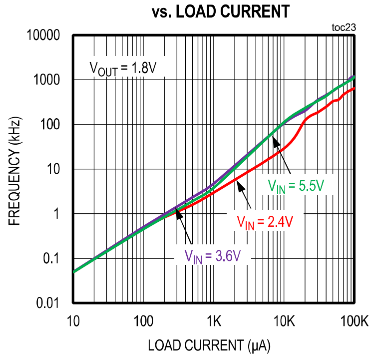
QUIESCENT CURRENT INTO OUTPUT vs. TEMPERATURE



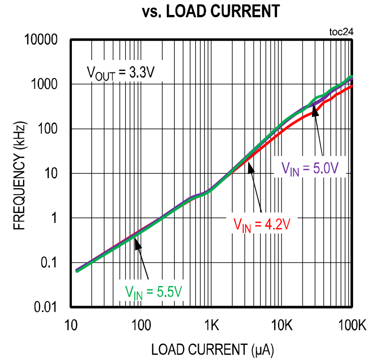
SWITCHING FREQUENCY vs. LOAD CURRENT



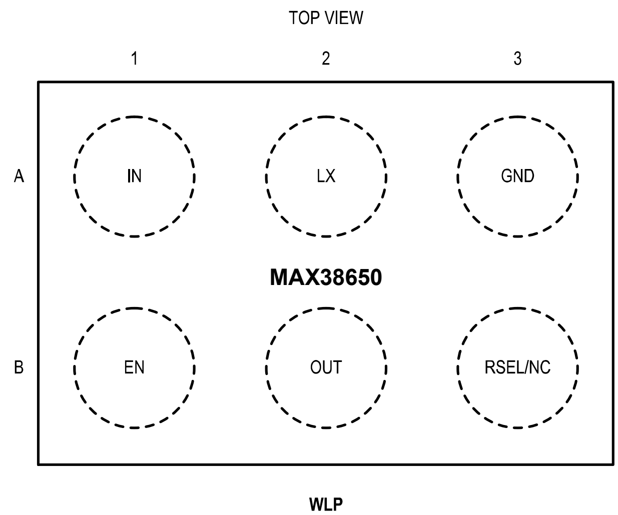
SWITCHING FREQUENCY vs. LOAD CURRENT



SWITCHING FREQUENCY vs. LOAD CURRENT



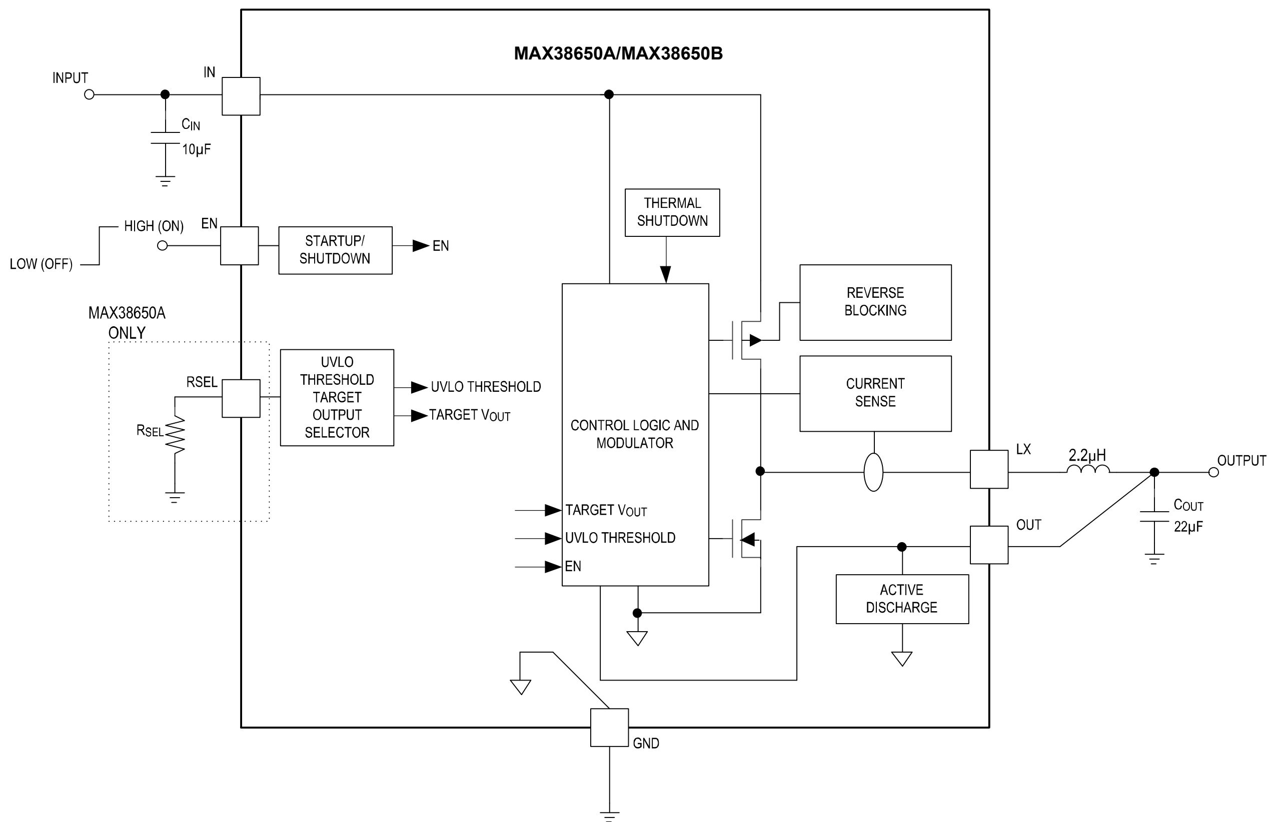
Pin Configurations



Pin Descriptions

PIN	NAME	FUNCTION
A1	IN	Regulator Supply Input Pin. Connect to a voltage between 1.8V and 5.5V and bypass with a 10µF capacitor from IN to GND.
A2	LX	Switching Node Pin. Connect recommended inductor between LX and OUT.
A3	GND	Ground Pin. Connect to application board GND.
B3	RSEL/NC	**MAX38650A**: Connect a resistor from RSEL to GND to program the output voltage and IN undervoltage threshold based on *Table 1*. **MAX38650B**: The pin is no connect since the device is preprogrammed and should be left floating.
B2	OUT	Output Voltage Pin. Connect to the load at a point where accurate regulation (output capacitor) is required to eliminate voltage drops.
B1	EN	Enable Input Pin. Force this pin high to enable the buck converter. Force this pin low to disable the part and enter shutdown.

Functional Diagram



Detailed Description

The MAX38650 is an ultra-low I_Q (390nA) buck converter that steps-down from an input voltage range of 1.8V to 5.5V to a wide range of output voltages between 1.2V to 5V. The output voltage is either programmable (the MAX38650A) using a single external resistor or fixed from the factory (the MAX38650B). The external R_{SEL} resistor on the RSEL pin programs the output voltage upon startup in the MAX38650A.

The buck converter automatically switches between low-power mode (LPM) and high-power mode (HPM) to better service the load, depending on the load current. The buck converter overregulates in LPM to allow the output capacitor to handle the transient load currents. The device supports 100% duty cycle operation.

The active discharge resistor in the MAX38650A/MAX38650B pulls OUT to ground when the part is in shutdown.

Enable Mode

When V_{IN} is above the UVLO rising threshold and the EN pin is pulled high ($V_{EN} > V_{IH}$), the MAX38650 is enabled. For the MAX38650A, there is a delay in reading the RSEL pin after which the soft-start mechanism begins.

Disable Mode

When the EN pin is pulled low ($V_{EN} < V_{IL}$), the MAX38650 goes into disable (shutdown) mode. While in shutdown, 5nA of current is consumed from V_{IN}. Reverse-current blocking from the output is active only when the part is disabled.

Voltage Configuration

Select the R_{SEL} resistor value by choosing the desired output voltage in *Table 1*.

The MAX38650A includes an RSEL pin to configure the output voltage and input UVLO threshold on startup. Resistors with a tolerance of 1% (or better) should be chosen, with nominal values specified in *Table 1*.

At startup, the MAX38650 sources up to 200μA during the select resistor detection time, typically for 600μs (t_{RSEL}), to read the R_{SEL} value.

Care must be taken that the total capacitance on this pin is less than 2pF. See the *PCB Layout Guidelines* for more information.

The R_{SEL} output voltage selection method has many benefits:

- In conventional converters, current will be drawn from the output continuously through a feedback resistor-divider. In the MAX38650, 200μA of current will be drawn only during startup, which helps to increase efficiency at light loads.
- It provides lower cost and smaller size, since only one resistor is needed versus the two resistors in typical feedback connections.
- R_{SEL} allows customers to stock just one part in their inventory system and use it in multiple projects with different output voltages just by changing a single standard 1% resistor.
- R_{SEL} allows much higher internal feedback resistors instead of lower impedance external feedback resistors, thus enabling ultra-low power applications.

Table 1. MAX38650A R_{SEL} Selection Table

TARGET OUTPUT VOLTAGE (V)	R_{SEL} (kΩ)	INPUT UVLO THRESHOLD, RISING (V)
2.5	OPEN	1.75
2	909	1.75
1.8	768	1.75
1.5	634	1.75
1.3	536	1.75
1.25	452	1.75
1.2	383	1.75
3.3	56.2	2.6
3	47.5	2.6
2.8	40.2	2.6
2.75	34	2.6
2.5	28	2.6
2	23.7	2.6
1.8	20	2.6
1.5	16.9	2.6
1.25	14	2.6
1.2	11.8	2.6

Note: The MAX38650B has an output voltage that is preprogrammed (no RSEL programming). Contact your Maxim Integrated representative to order a part with an output voltage preprogrammed in the output voltage range from 1.2V to 5.0V in 50mV steps. The input UVLO threshold for a preprogrammed device is 1.75V (V_{IN} rising) with 50mV hysteresis.

100% Duty Cycle Operation

The MAX38650 features 100% duty cycle operation. When the input voltage approaches the output voltage, the MAX38650 stops switching and enters 100% duty cycle operation. It connects the output to input through the high side power switch and the inductor. Entry into 100% duty cycle mode depends on the voltage ripple at the IN and OUT pins; refer to the Input and Output Capacitor Selection sections for recommended C_{IN} and C_{OUT} capacitors. When the input voltage is increased again where it pulls V_{OUT} to the level 5% above its target level, the converter restarts regulation. When the load is light, the device consumes only 1.05µA of current in 100% duty cycle mode while still protecting the inductor current from exceeding current limit.

Active Discharge

The MAX38650 integrates a discharge resistor from the OUT pin to GND. This discharge resistor gets activated when converter is disabled, which helps discharge the output capacitor quickly. The typical value of the discharge resistance is 85Ω.

Applications Information

Typical Application

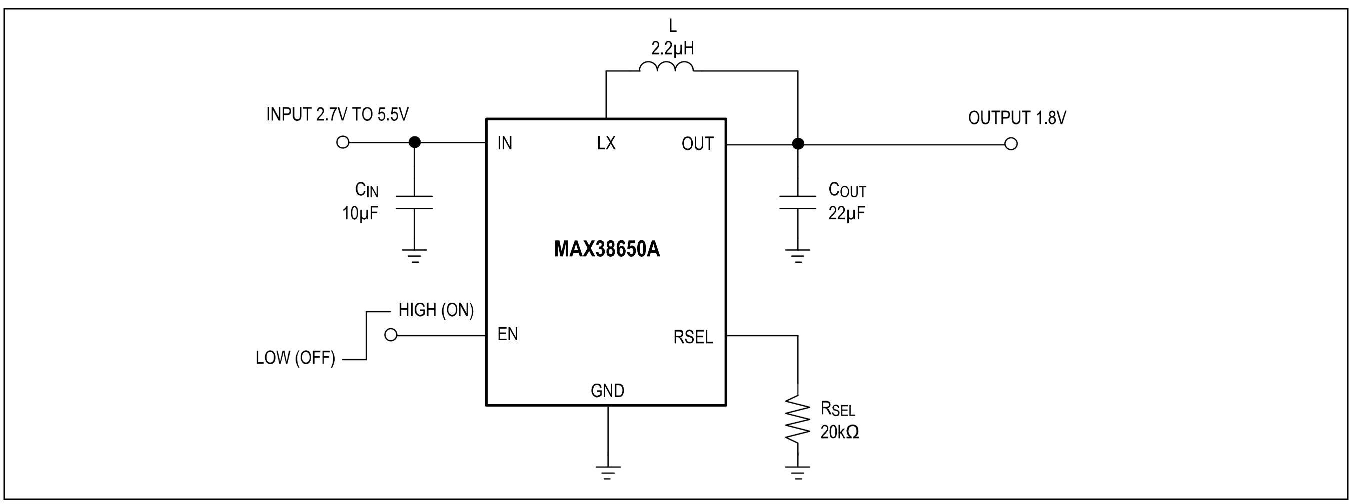


Figure 1. 1.8V Buck Converter Using the MAX38650A

Inductor Selection

The inductor value for the MAX38650 affects the ripple current, the transition point from LPM to HPM and overall efficiency performance. It is recommended to use an inductor value of 2.2µH.

Input Capacitor Selection

The input capacitor (C_{IN}) reduces the peak current drawn from battery or input power source and reduces the switching noise in the IC. The impedance of C_{IN} at the switching frequency should be very low. Ceramic capacitors are recommended with their small size and low ESR. For most applications, it is recommended to use a 10µF ceramic capacitor with X7R temperature characteristics. For operations where ambient temperature is less than +85°C, X5R can be used. In applications where the device will approach or go into 100% duty cycle operation, more capacitance at the input pin is required; therefore, 10μF (5μF effective capacitance) at C_{IN} is recommended.

Output Capacitor Selection

The output capacitor (C_{OUT}) is required to keep the output voltage ripple small and to ensure loop stability. C_{OUT} must have low impedance at the switching frequency. Ceramic capacitors are recommended due to their small size and low ESR. Make sure the capacitor does not degrade its capacitance significantly over temperature and DC bias. For most applications, it is recommended to use 22μF ceramic capacitor with X7R temperature characteristics. For operations where ambient is less than +85°C, X5R can be used. A 22μF ceramic capacitor (10μF effective capacitance) is recommended for applications.

PCB Layout and Routing

Careful PCB layout is especially important in nanoPower DC-DC converters. Poor layout can affect the IC performance causing electromagnetic interference (EMI), electromagnetic compatibility (EMC) issues, ground bounce, voltage drops, etc. Poor layout can also affect regulation and stability.

A good layout is implemented using the following rules:

- Place the inductor, input capacitor, and output capacitor close to the IC using short traces and/or copper pours. These components carry high switching currents and long traces act like antennas. The input capacitor placement is the most important in the PCB layout and should be placed directly next to the IC. The inductor and output capacitor placement are secondary to the input capacitor's placement but should remain close to the IC.
- The connection from the bottom plate of the input capacitor and the ground pin of the device must be extremely short, as should be that of the output capacitor.
- Similarly, the top plate of input capacitor connection to the IN pin of the device must be short as well.
- Minimize the surface area used for LX since this is the noisiest node.
- Keep the main power path from IN, LX, OUT, and GND as tight and short as possible.
- Route the output voltage sense away from the inductor and LX switching node to minimize noise and magnetic interference.
- Maximize the size of the ground metal on the component side to help with thermal dissipation. Use a ground plane with several vias connecting to the component-side ground to further reduce noise interference on sensitive circuit nodes.
- The trace used for the RSEL signal should neither be too long nor should produce a capacitance of more than 2pF.

It is also recommended to consult the MAX38650 EV kit layout.

Ordering Information

PART NUMBER	ACTIVE DISCHARGE	FEATURES	PACKAGE
MAX38650AANT+	Yes	1.2V to 3.3V output voltage selectable using RSEL	WLP
MAX38650BANT+*	Yes	Preprogrammed output voltage from 1.2V to 5V	WLP

*Future product—contact factory for availability.
+ Denotes a lead(Pb)-free/RoHS-compliant package.
T = Tape-and-reel.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	1/21	Initial release	—