Click here to ask an associate for production status of specific part numbers.

Tiny 1.8V to 5.5V Input, 420nA I_Q, 1.5A nanoPower Buck Converter with 100% Duty-Cycle Operation

MAX38656

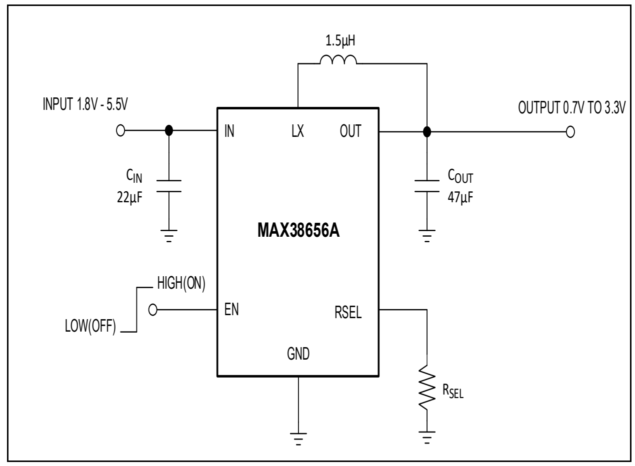
Product Highlights

- Extends Battery Life
  - 420nA 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 0.7V to 3.3V (MAX38656A)
  - Preprogrammed V_{OUT} from 0.7V to 5V (MAX38656B) in Steps of 50mV
  - 100% Duty-Cycle Mode for Low-Dropout Operation
  - ±1.5% Output Voltage Accuracy
  - Up to 1.5A 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
  - 2mm x 2mm 8-pin TDFN Package

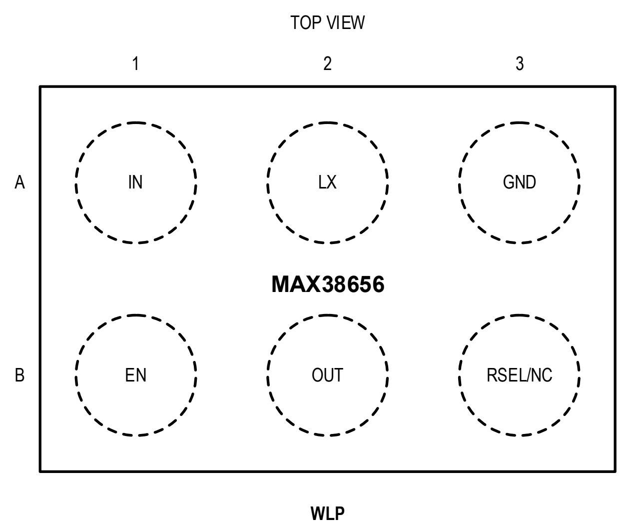
Key Applications

- Portable Space-Constrained Consumer Products
- Wearable Devices, Ultra-Low-Power Internet of Things (IoT), Narrowband IoT, and Bluetooth Low Energy
- Single Li-Ion and Coin Cell Battery Products
- Wired, Wireless Industrial Products

Simplified Application Diagram



Pin Configuration



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

19-101555; Rev 0; 11/22

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 $+1.6A_{RMS}$
LX to GND (Note 1) .... -0.3V to V_{IN} + 0.3V
Continuous Power Dissipation ((T_A = +70°C) WLP Derate 10.51mW/°C above +70°C) 840mW
TDFN (Derate 9.8mW/°C above 70°C) 784mW
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

Note 1: The LX pin has internal clamps to GND and IN. These diodes may be forward biased during switching transitions. During these transitions, the max LX current should be within the maximum root mean square (RMS) current rating for safe operation.

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} = 22µF, C_{OUT} = 47µF, unless otherwise specified.) (*Note 2*)

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 (UVLO)	V_{UVLO}	R_{SEL} > 60kΩ	V_{IN} rising		1.75	1.8	V
Input Undervoltage Lockout	V_{UVLO}	R_{SEL} > 60kΩ	V_{IN} falling	1.65	1.7		V
		R_{SEL} < 60kΩ	V_{IN} rising		2.6	2.65	
			V_{IN} falling	2.45	2.5		
Output Voltage Range	V_{OUT}	Guaranteed by output accuracy specification (MAX38656A)		0.7		3.3	V
		Guaranteed by output accuracy specification (MAX38656B)		0.7		5	

(V_{IN} = 3.3V, V_{OUT} = 1.8V, T_J = -40°C to +125°C, C_{IN} = 22µF, C_{OUT} = 47µF, unless otherwise specified.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Output Accuracy	ACC	V_{OUT} falling when LX begins switching above 300kHz, V_{IN} > V_{OUT} + 0.3V, (Note 3)		-1.5		+1.5	%
Ultra-Low-Power Mode Overregulation Hysteresis	ULPM_HYS	Hysteresis measured as a percent of target output voltage; V_{OUT_TARGET} = 2.5V		+1.3	+2.7	+4	%
		Hysteresis measured as a percent of target output voltage; V_{OUT_TARGET} = 1.2V		+2	+3.3	+5.2	
		Hysteresis measured as a percent of target output voltage; V_{OUT_TARGET} = 0.7V		+2.8	+4.3	+5.5	
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			420	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			850	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_{IN} = 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 4)		1.71	1.8	1.98	A
High-Side Channel Resistance	R_{DS_H}				100	170	mΩ
Low-Side Channel Resistance	R_{DS_L}				50	100	mΩ
Zero-Crossing Threshold	I_{ZX_LX}	V_{OUT} = 1.2V	(Note 4)	15	50	85	mA
Minimum Off-Time	t_{OFF_MIN}				50		ns
Enable Input Leakage Current	I_{LEAK_EN}	V_{IN} = 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		
Active Discharge Resistance	R_{OUT_DIS}	V_{EN} = 0V (MAX38656A, MAX38656B)		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	MAX38656A	-1		+1	%
Select Resistor Detection Time	t_{RSEL}	C_{RSEL} < 2pF	MAX38656A	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 2: Limits over the specified operating temperature and supply voltage range are guaranteed by design and characterization, and production tested at room temperature only.

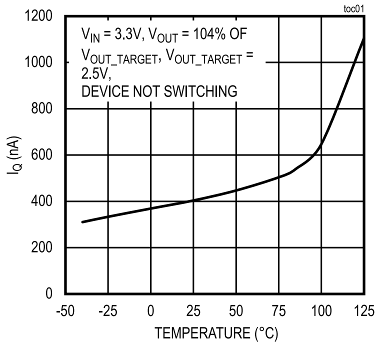
Note 3: Output accuracy in low-power mode (LPM) and does not include load, line, or ripple.

Note 4: This is a static measurement. The actual peak current limit depends upon V_{IN}, V_{OUT}, and the inductor due to propagation delays.

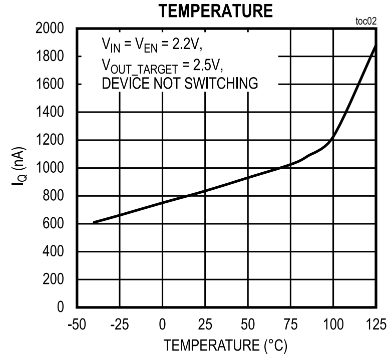
Typical Operating Characteristics

V_{IN} = 3.3V, V_{OUT} = 1.8V, C_{IN} = 22µF, C_{OUT} = 47µF, L = 1.5µH unless otherwise noted.

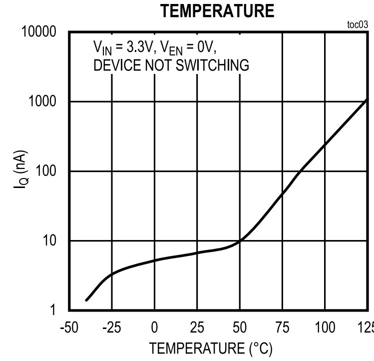
QUIESCENT CURRENT INTO INPUT vs. TEMPERATURE



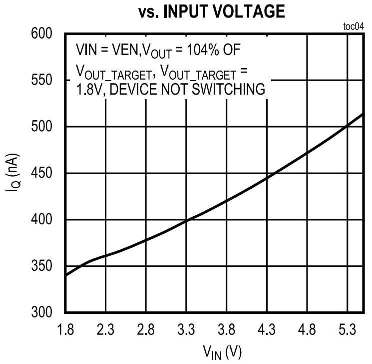
100% DUTY QUIESCENT vs. TEMPERATURE



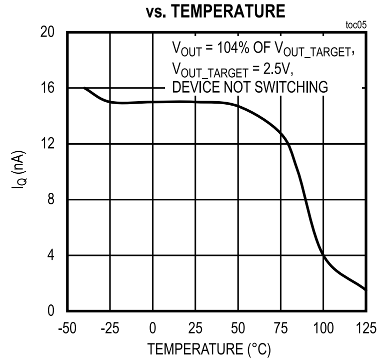
SHUTDOWN CURRENT vs. TEMPERATURE



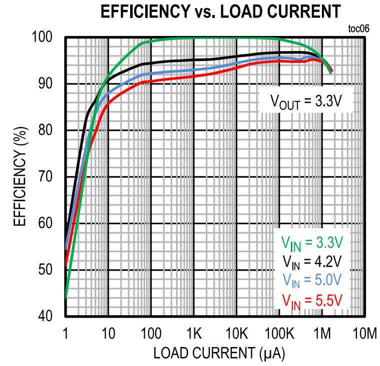
QUIESCENT CURRENT INTO INPUT vs. INPUT VOLTAGE



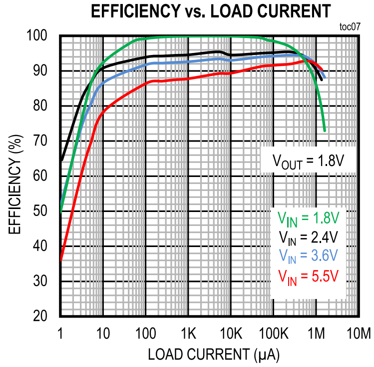
QUIESCENT CURRENT INTO OUTPUT vs. TEMPERATURE



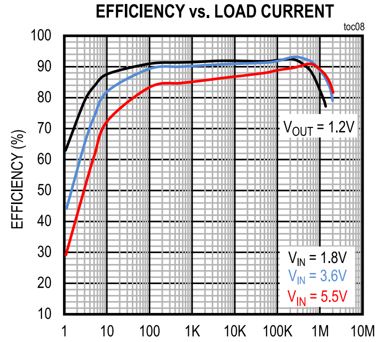
EFFICIENCY vs. LOAD CURRENT



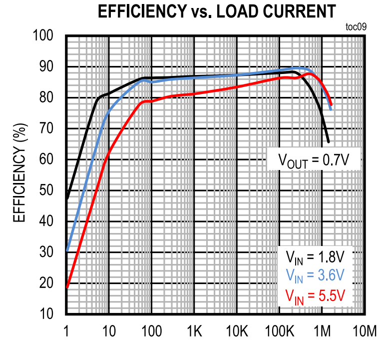
EFFICIENCY vs. LOAD CURRENT



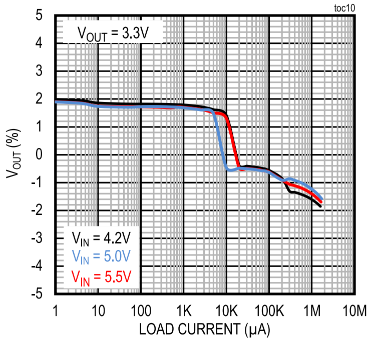
EFFICIENCY vs. LOAD CURRENT



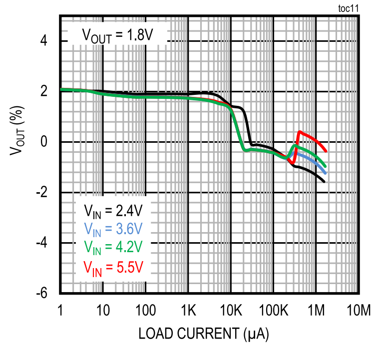
EFFICIENCY vs. LOAD CURRENT



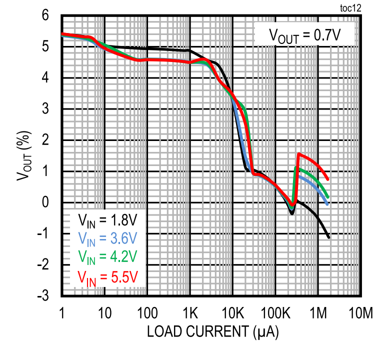
REGULATION vs. LOAD CURRENT



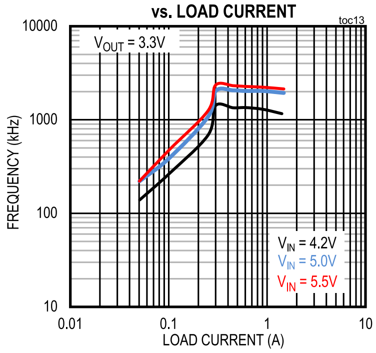
REGULATION vs. LOAD CURRENT



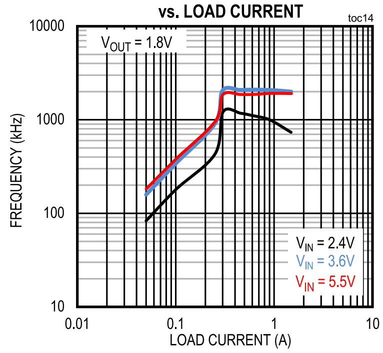
REGULATION vs. LOAD CURRENT



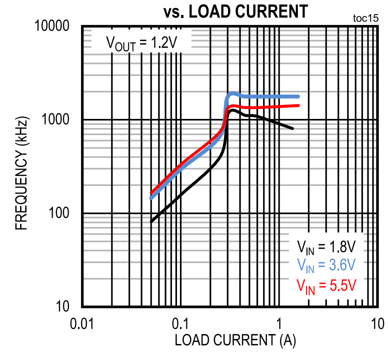
SWITCHING FREQUENCY vs. LOAD CURRENT



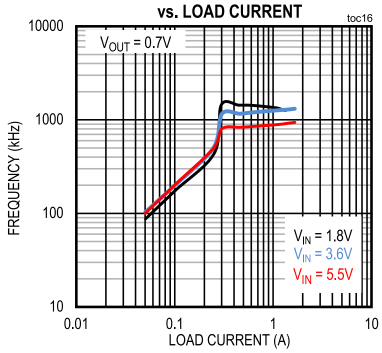
SWITCHING FREQUENCY vs. LOAD CURRENT



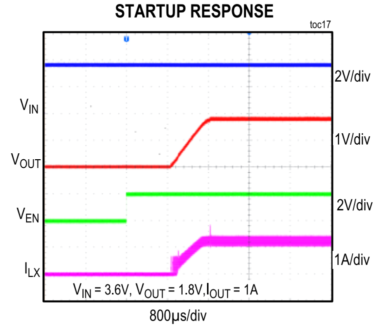
SWITCHING FREQUENCY vs. LOAD CURRENT



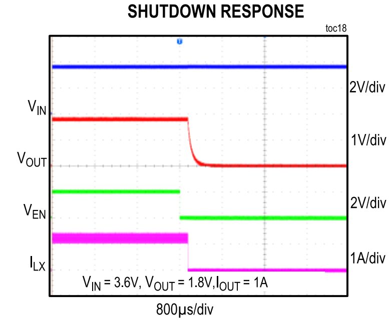
SWITCHING FREQUENCY vs. LOAD CURRENT



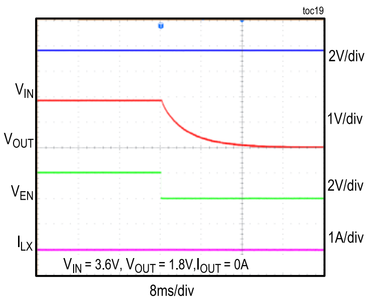
STARTUP RESPONSE



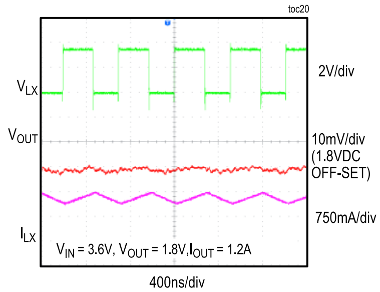
SHUTDOWN RESPONSE



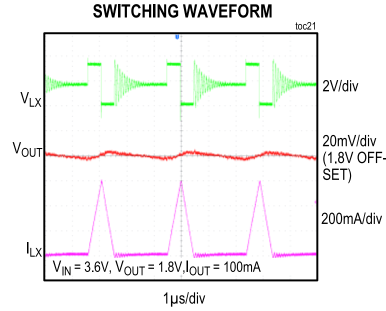
ACTIVE DISCHARGE



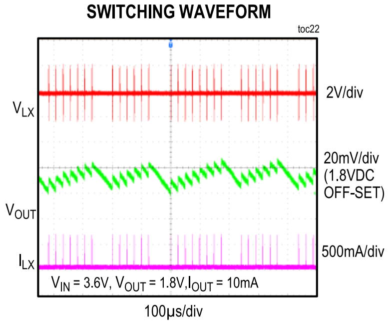
HEAVY-LOAD SWITCHING WAVEFORM



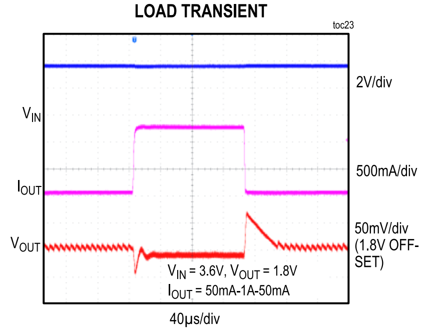
LIGHT-LOAD SWITCHING WAVEFORM



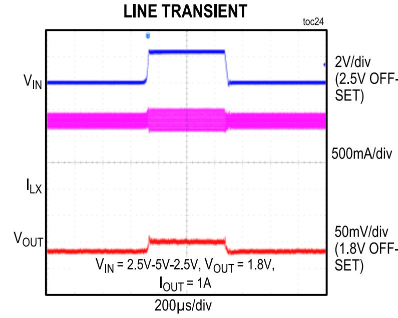
ULTRA LIGHT-LOAD SWITCHING WAVEFORM



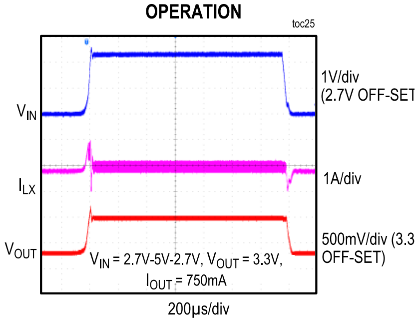
LOAD TRANSIENT



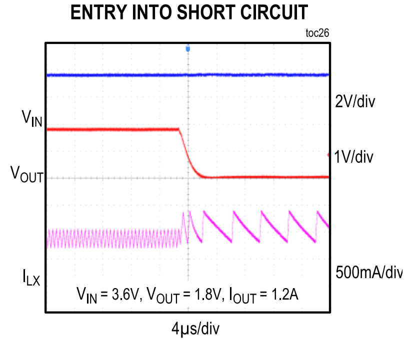
LINE TRANSIENT



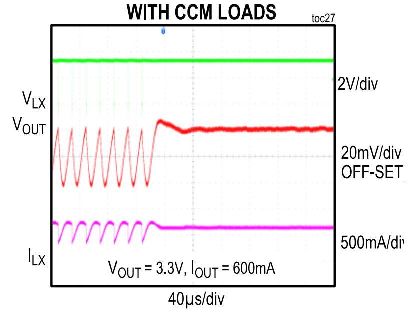
100% DUTY ENTRY/EXIT OPERATION

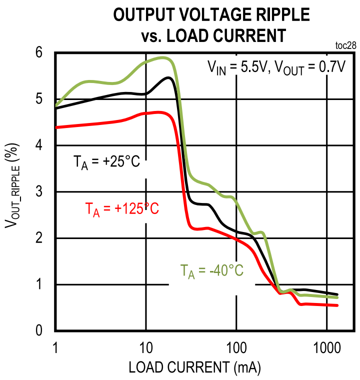


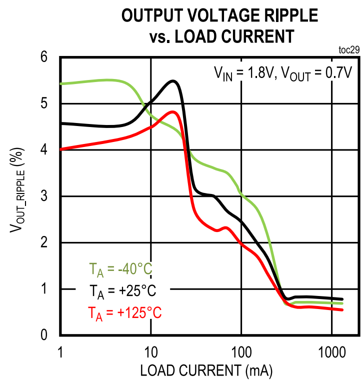
ENTRY INTO SHORT CIRCUIT

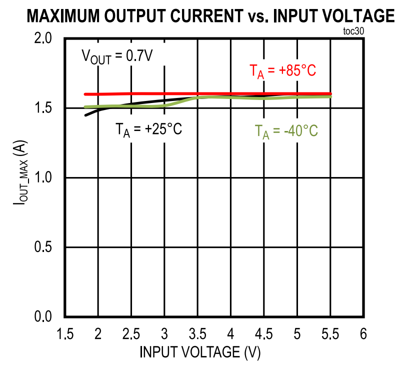


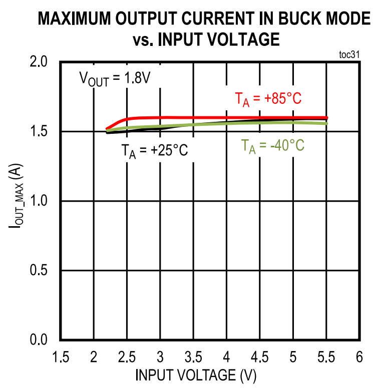
100% DUTY ENTRY OPERATION WITH CCM LOADS




OUTPUT VOLTAGE RIPPLE
vs. LOAD CURRENT
toc28
VIN = 5.5V, VOUT = 0.7V
TA = +25°C
TA = +125°C
TA = -40°C
VOUT_RIPPLE (%)
LOAD CURRENT (mA)
0
1
2
3
4
5
6
1
10
100
1000

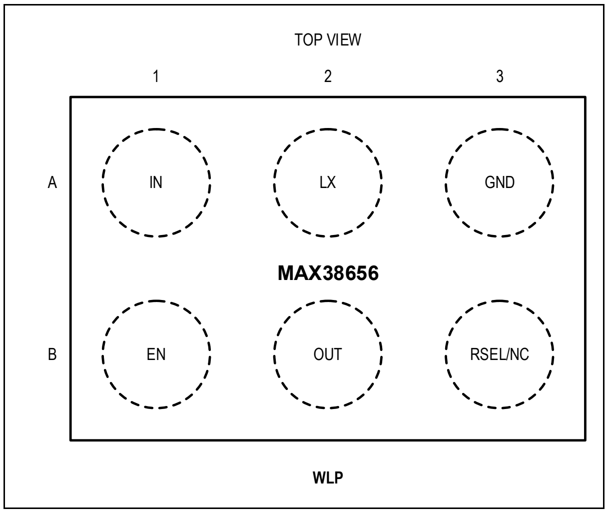

OUTPUT VOLTAGE RIPPLE
vs. LOAD CURRENT
toc29
VIN = 1.8V, VOUT = 0.7V
TA = -40°C
TA = +25°C
TA = +125°C
VOUT_RIPPLE (%)
LOAD CURRENT (mA)
0
1
2
3
4
5
6
1
10
100
1000


MAXIMUM OUTPUT CURRENT vs. INPUT VOLTAGE
toc30
VOUT = 0.7V
TA = +85°C
TA = +25°C
TA = -40°C
IOUT_MAX (A)
INPUT VOLTAGE (V)
0.0
0.5
1.0
1.5
2.0
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


MAXIMUM OUTPUT CURRENT IN BUCK MODE
vs. INPUT VOLTAGE
toc31
VOUT = 1.8V
TA = +85°C
TA = +25°C
TA = -40°C
IOUT_MAX (A)
INPUT VOLTAGE (V)
0.0
0.5
1.0
1.5
2.0
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6

Pin Configuration

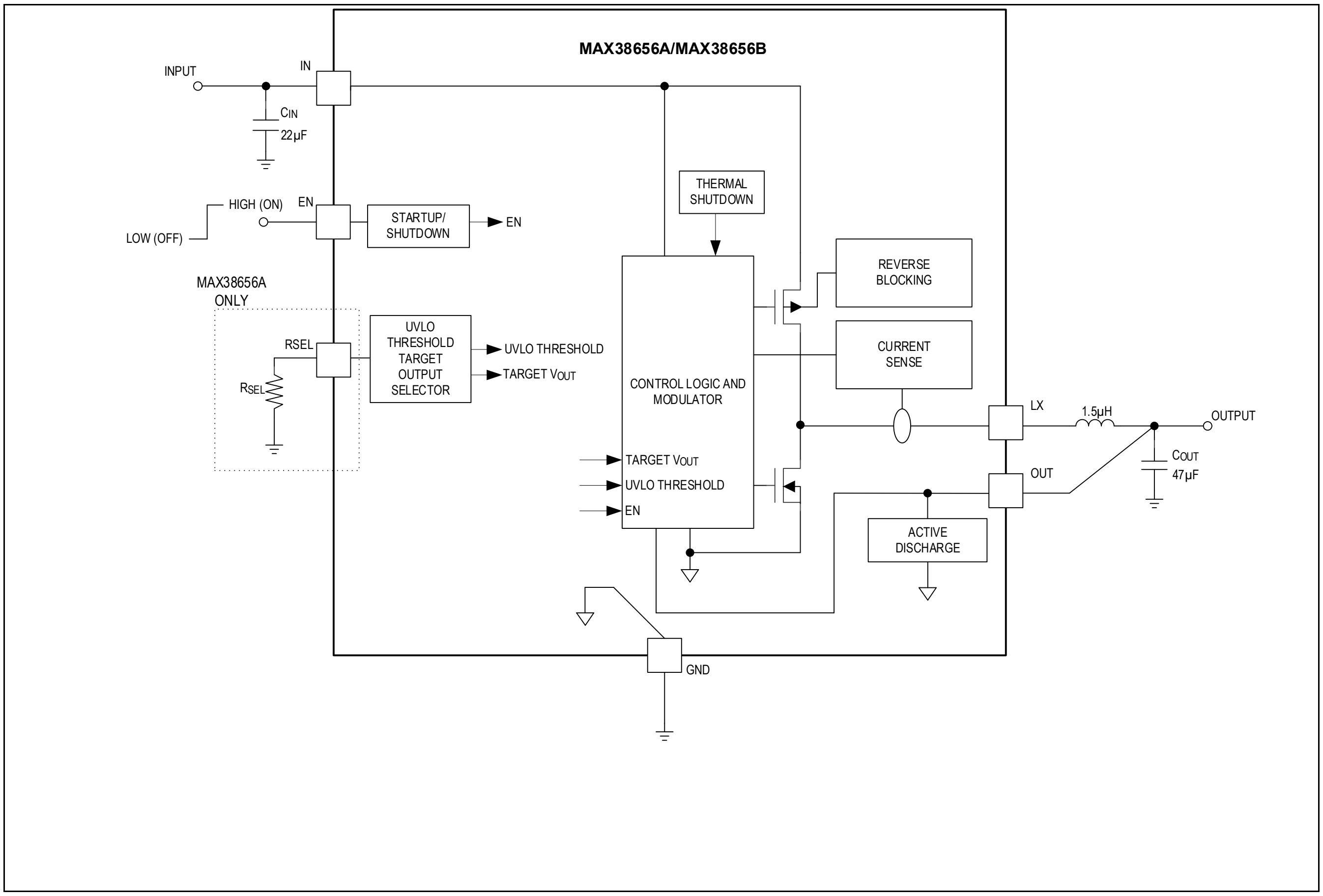
WLP



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 22μF capacitor from IN to GND.
A2	LX	Switching Node Pin. Connect recommended inductor between LX and OUT.
A3	GND	Ground Pin.
B3	RSEL/NC	**MAX38656A**: Connect a resistor from RSEL to GND to program the output voltage and IN undervoltage threshold based on *Table 1*. **MAX38656B**: 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 (47μF 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 MAX38656 is an ultra-low I_Q (420nA) buck converter that steps down from an input voltage range of 1.8V to 5.5V to a wide range of output voltages between 0.7V to 3.3V using a single resistor at the RSEL pin for the MAX38656A or factory-preprogrammed fixed output voltage versions from 0.7V to 5V for the MAX38656B. For the MAX38656B, the RSEL pin can be left floating.

The MAX38656 buck converter offers robust performance features. To optimize efficiency and transient response across the load range, the buck converter automatically switches between ultra-low-power mode (ULPM), low-power mode (LPM) and high-power mode (HPM) to service the load better, depending on the load current. The buck converter overregulates in ULPM to allow the output capacitor to handle the transient load currents. See *Figure 1* for the MAX38656 mode transitions. The device supports 100% duty-cycle operation. In applications where the ambient temperature is more than +85°C, make sure that the load current is always more than 10µA at the output of buck converter.
The active discharge resistor in the MAX38656A/MAX38656B pulls OUT to ground when the part is in shutdown.

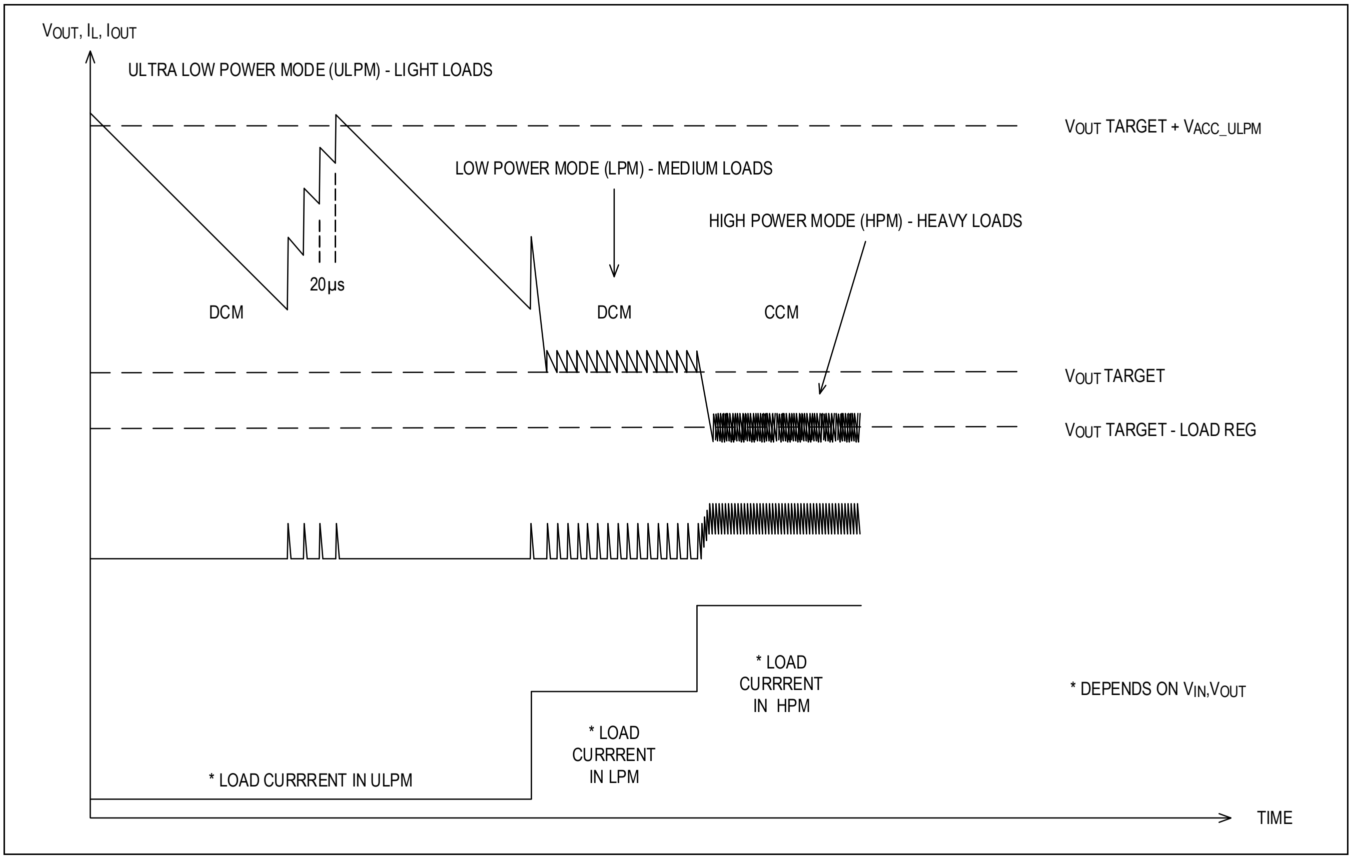


Figure 1. Mode Transitions

Enable Mode

When V_{IN} is above the UVLO rising threshold and the EN pin is pulled high ($V_{EN} > V_{IH}$), the MAX38656 is enabled. For the MAX38656A, 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 MAX38656 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 MAX38656A includes a 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 MAX38656 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 so that the total capacitance on this pin is less than 2pF. See the *PCB Layout and Guidelines* section for more information.

The R_{SEL} output voltage selection method has many benefits, which are as follows:

- In conventional converters, current is drawn from the output continuously through a feedback resistor-divider. In the MAX38656, 200µA of current is 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.
- The 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.

- The R_{SEL} allows much higher internal feedback resistors instead of lower impedance external feedback resistors, thus enabling ultra-low-power applications.

Table 1. MAX38656A R_{SEL} Selection Table

TARGET OUTPUT VOLTAGE (V)	R_{SEL} (kΩ)	INPUT UVLO THRESHOLD, RISING (V)
2.5	OPEN	1.75
2	909	
1.8	768	
1.5	634	
1.3	536	
1.25	452	
1.2	383	
1.15	324	
1.1	267	
1.05	226	
1	191	
0.95	162	
0.9	133	
0.85	113	
0.8	95.3	
0.75	80.6	
0.7	66.5	
3.3	56.2	2.6
3	47.5	
2.8	40.2	
2.75	34	
2.5	28	
2	23.7	
1.8	20	
1.5	16.9	
1.25	14	
1.2	11.8	
1.15	10	
1.1	8.45	
1.0	7.15	
0.95	5.9	
0.9	4.99	

Note: The MAX38656B has an output voltage that is preprogrammed (no RSEL programming). Contact your Analog Devices, Inc., representative to order a part with an output voltage preprogrammed in the output voltage range from 0.7V 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 MAX38656 features 100% duty cycle operation. When the input voltage approaches the output voltage, the MAX38656 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; see the *Input Capacitor Selection* 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 850nA of current in 100% duty cycle mode while still protecting the inductor current from exceeding the current limit.

Active Discharge

The MAX38656 integrates a discharge resistor from the OUT pin to GND. This discharge resistor gets activated when the converter is disabled, which helps to discharge the output capacitor quickly. The typical value of the discharge resistance is 85Ω.

Applications Information

Typical Application

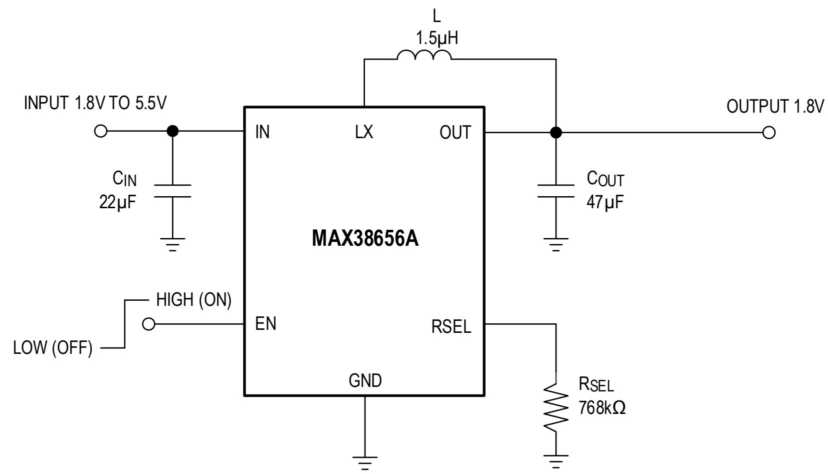


Figure 2. 1.8V Buck Converter Using the MAX38656A

Inductor Selection

The inductor value for the MAX38656 affects the ripple current, the transition point from LPM to HPM, and overall efficiency performance. It is recommended to use an inductor value of 1.5µH.

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 due to their small size and low ESR. For most applications, it is recommended to use a 22µF 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 approaches or go into 100% duty-cycle operation, additional 10µF 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 that the capacitor does not degrade its capacitance significantly over temperature and DC bias. For operations where ambient is less than +85°C, ceramic capacitor with X5R temperature characteristics can be used else X7R capacitors are recommended. Use a minimum effective capacitance of 27µF for output voltage below 1.5V and 20µF for output voltage more than 1.5V. In applications where the device approaches or go into 100% duty-cycle operation, it is recommended to double the effective output capacitance.

PCB Layout and Guidelines

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 the 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.

Ordering Information

PART NUMBER	OUTPUT CURRENT (A)	ACTIVE DISCHARGE	FEATURES	PIN-PACKAGE
MAX38656AANT+	1.5	Yes	0.7V to 3.3V Resistor Selectable Output Voltage Using RSEL Pin	6 WLP
MAX38656BANT_ _ +*	1.5	Yes	0.7V to 5V Preprogrammed Output Voltage	6 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	11/22	Release for Market Intro	—