Current Mode Buck-Boost Converter

General Description

The RT6150A/B is a high efficiency, fixed frequency, Buck-Boost DC/DC converter that operates from input voltages above, below or equal to the output voltage. The topology incorporated in the IC provides a continuous transfer function through all operating modes, making the product ideal for single lithium-ion, multi-cell alkaline or Ni-MH battery applications where the output voltage is within the battery voltage range.

The device includes two N-MOSFET switches and two P-MOSFET switches for high efficiency operation. Switching frequency is set at 1MHz to reduce the external component size. Quiescent current is only 60μA in Power Save Mode (PSM), maximizing battery life in portable applications. PSM operation is user controlled and can be enabled by driving the PS pin low. If the PS pin is driven high, then fixed frequency switching is enabled.

Other features include low shutdown current, internal soft-start control, thermal shutdown protection and current limit. The RT6150A is available in the WDFN-10L 3x3 package and the RT6150B is available in the WDFN-10L 2.5x2.5 package.

Applications

- Portable Products
- Handheld Instrumentation

Features

- **Single Inductor**
- **Fixed Frequency Operation with Battery Voltages**
- **Synchronous Rectification : Up to 90% Efficiency**
- **Up to 800mA Continuous Output Current**
- **VOUT Disconnected from VIN during Shutdown**
- **Power Save Mode (PSM) Enable Control**
- **<1μA Shutdown Current**
- **Input Voltage Range: 1.8V to 5.5V**
- **Fixed 3.3V and Adjustable Output Voltage Options from 1.8V to 5.5V**
- **10-Lead WDFN Packages**
- **RoHS Compliant and Halogen Free**

Ordering Information

RT6150A/B-□□□

Package Type
QW : WDFN-10L 3x3 (W-Type)
QW : WDFN-10L 2.5x2.5 (W-Type)

Lead Plating System
G : Green (Halogen Free and Pb Free)

Output Voltage
33 : 3.3V (Only for RT6150B)

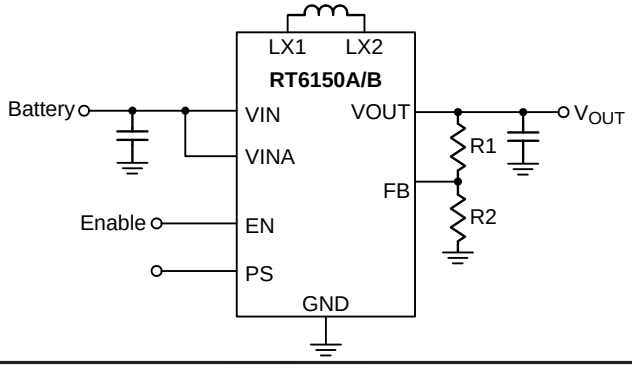
A : WDFN-10L 3x3
B : WDFN-10L 2.5x2.5

Note :

Richtek products are :

- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

Simplified Application Circuit



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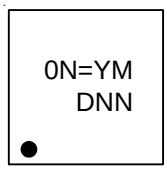
Marking Information

RT6150AGQW



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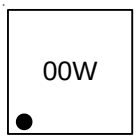
YMDNN : Date Code

RT6150BGQW



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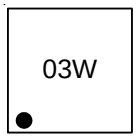
RT6150B-33GQW

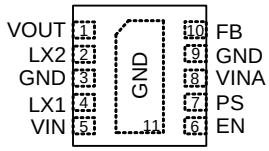


03 : Product Code

W : Date Code

Pin Configurations

(TOP VIEW)



WDFN-10L 3x3 / WDFN-10L 2.5x2.5

Functional Pin Description

Pin No.	Pin Name	Pin Function
1	VOUT	Output of the Buck-Boost Converter. Connect a capacitor between the VOUT and GND.
2	LX2	Second Switch Node. Connect this pin to the inductor.
3, 9, 11 (Exposed Pad)	GND	Power Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation.
4	LX1	First Switch Node. Connect this pin to the inductor.
5	VIN	Power Input. Connect an at least 10μF capacitor between the VIN pin and GND.
6	EN	Enable Control Input for the Buck-Boost Converter.
7	PS	PSM Control Input. Pull low for PSM operation and pull high for fixed switching frequency operation.
8	VINA	Supply Voltage Input for Control Circuit.
10	FB	Feedback Input. For adjustable versions, connect a resistive divider to set the output voltage and it can be adjusted from 1.8V to 5.5V; For fixed version, must be connected to VOUT.

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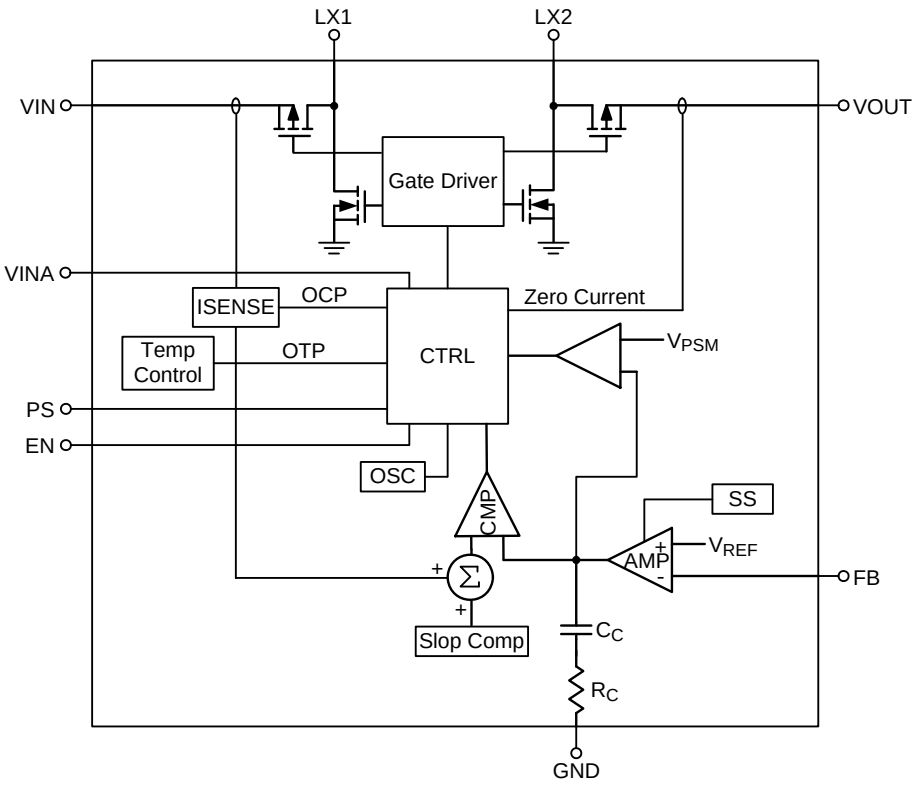
Function Block Diagram



Operation

The RT6150A/B is a synchronous average current mode switching Buck-Boost converter designed to maintain a fixed output voltage from an input supply that can be above, equal, or below the output voltage. The average inductor current is regulated by a fast current regulator which is controlled by a voltage control loop. The voltage error amplifier gets its feedback input from the FB pin. For adjustable output voltage, a resistive voltage divider must be connected to the FB pin. When VIN is greater than VOUT, the device operates in Buck mode. When VIN is lower than VOUT, the device operates in Boost mode. When VIN is close to VOUT, the RT6150A/B automatically enters Buck-Boost mode. In Buck-Boost mode, the converter will maintain the regulation for output voltage and keep a minimum current ripple in the inductor to guarantee good performance.

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Absolute Maximum Ratings (Note 1)

- VOUT, VIN, EN, PS, VINA, FB Pin ---------- –0.3V to 6V
- Switch Output Voltage, LX1, LX2 Pin ---------- –0.3V to 6V
  < 10ns ---------- –2V to 7.5V
- Power Dissipation, P_D @ T_A = 25°C
  WDFN-10 3x3 ---------- 3.28W
  WDFN-10 2.5x2.5 ---------- 2.44W
- Package Thermal Resistance (Note 2)
  WDFN-10 3x3, θ_{JA} ---------- 30.5°C/W
  WDFN-10 3x3, θ_{JC} ---------- 7.5°C/W
  WDFN-10 2.5x2.5, θ_{JA} ---------- 40.9°C/W
  WDFN-10 2.5x2.5, θ_{JC} ---------- 18.6°C/W
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature ---------- 150°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 3)
  HBM (Human Body Model) ---------- 2kV
  MM (Machine Model) ---------- 200V

Recommended Operating Conditions (Note 4)

- Supply Input Voltage, VIN ---------- 1.8V to 5.5V
- Junction Temperature Range ---------- –40°C to 125°C
- Ambient Temperature Range ---------- –40°C to 85°C

Electrical Characteristics

(V_{IN} = V_{OUT} = 3.6V, T_A = 25°C, unless otherwise specified.)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Input Voltage UVLO	High-Level			--	1.65	1.8	V
	Low-Level			1.4	1.55	--	
Feedback Voltage		V_{FB}	V_{PS} = V_{IN}	0.495	0.5	0.505	V
Feedback Input Current			V_{FB} = 0.5V	--	1	50	nA
Quiescent Current			I_{OUT} = 0mA, PS = 0V (Note 5) Power Save Mode	--	60	--	µA
			EN = 0V, Not Including Switch Leakage Shutdown	--	0.1	1	
N-MOSFET Switch Leakage				--	0.1	5	µA
P-MOSFET Switch Leakage				--	0.1	10	µA
N-MOSFET Switch On Resistance		$R_{DS(ON)_N}$		--	0.15	--	Ω
P-MOSFET Switch On Resistance		$R_{DS(ON)_P}$		--	0.15	--	Ω
Switch Current Limit		I_{LIM}	V_{IN} = 3.6V	1.6	--	--	A
Oscillator Frequency		f_{OSC}		0.8	1	1.2	MHz
Soft-Start Time		t_{SS}	Time from when EN signal asserts to output voltage I_{OUT} = 0mA	--	0.65	1	ms

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Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
EN and PS Input Voltage	Logic-High			1.2	--	--	V
	Logic-Low			--	--	0.4	
EN and PS Input Current			V_{EN} = V_{PS} = V_{IN}	--	0.01	1	μA
Thermal Shutdown		T_{SD}		--	140	--	°C

Note 1. Stresses beyond those listed "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 may affect device reliability.

Note 2. θ_{JA} is measured at T_A = 25°C on a high effective thermal conductivity four-layer test board per JEDEC 51-7. θ_{JC} is measured at the exposed pad of the package.

Note 3. Devices are ESD sensitive. Handling precaution is recommended.

Note 4. The device is not guaranteed to function outside its operating conditions.

Note 5. Current measurements are performed when the output are not switching.

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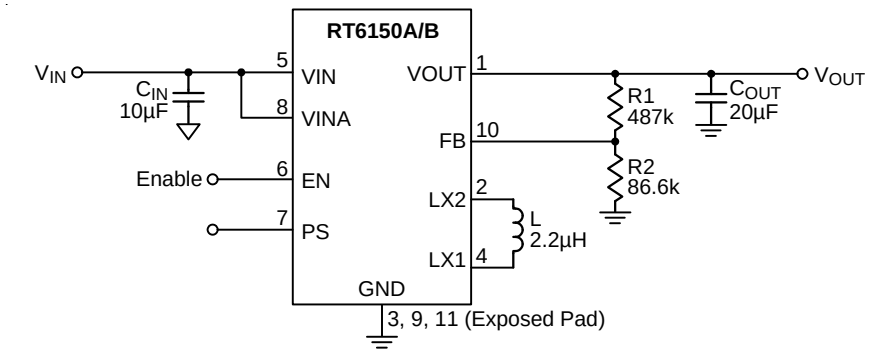
Typical Application Circuit



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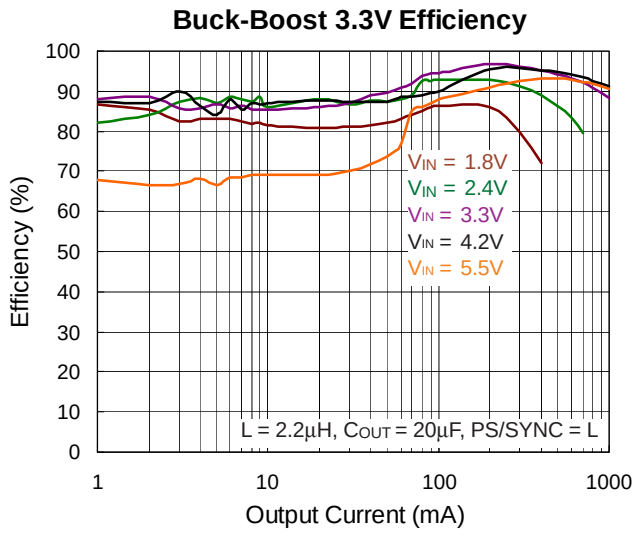
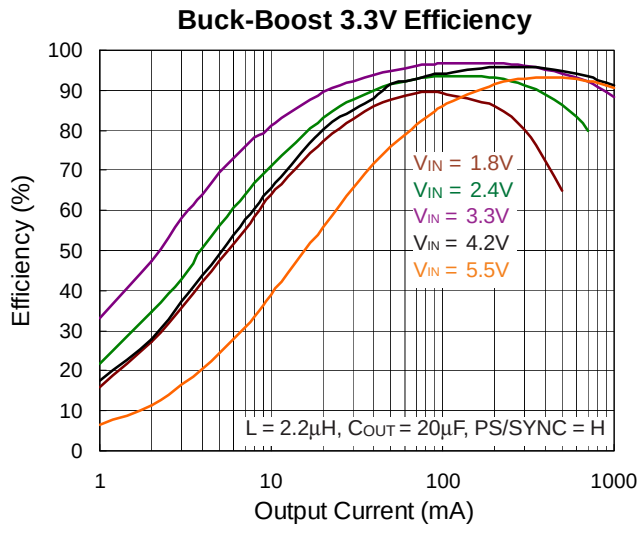
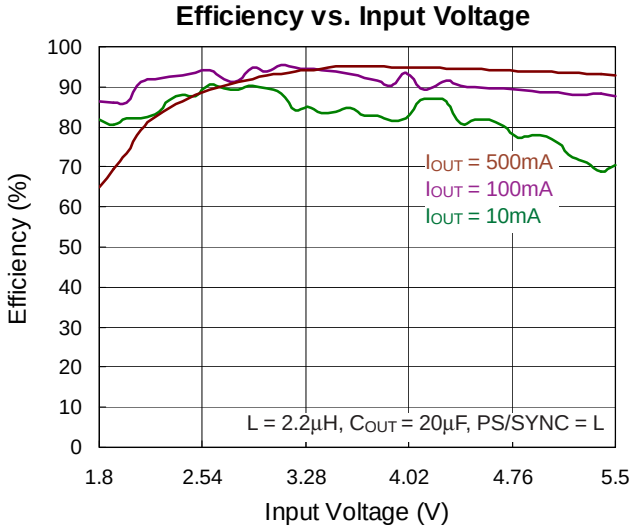
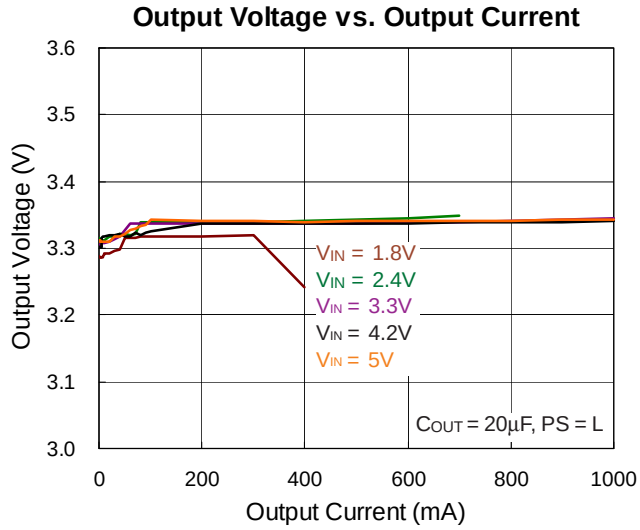
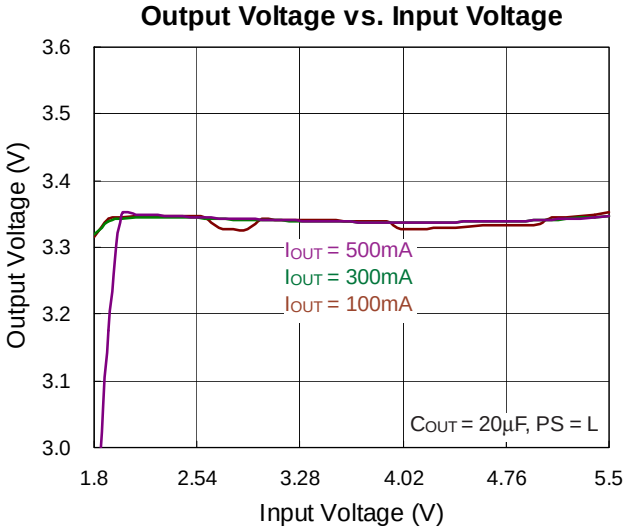
Typical Operating Characteristics

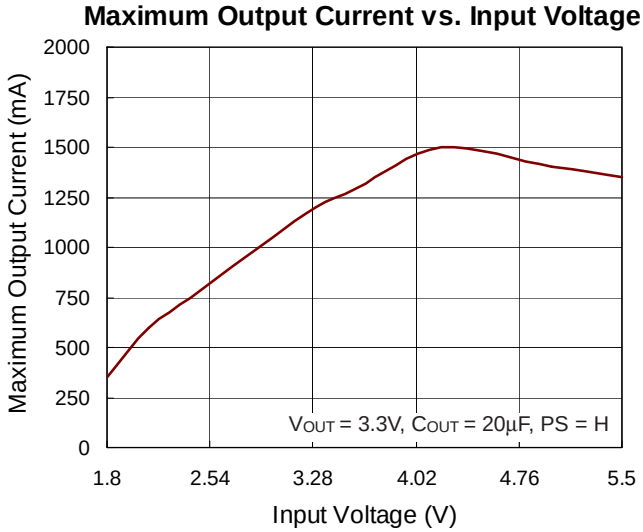












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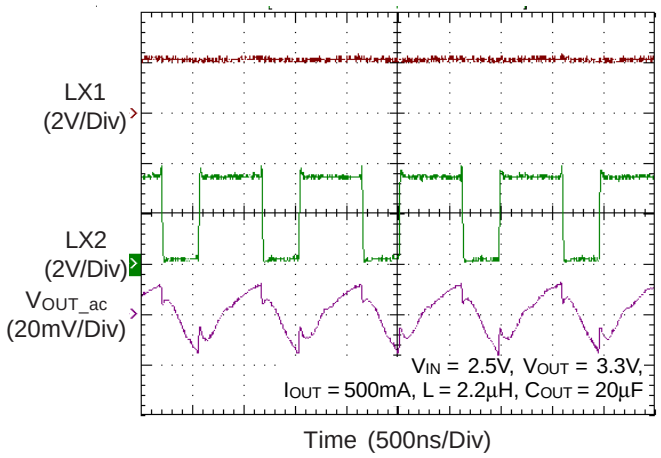
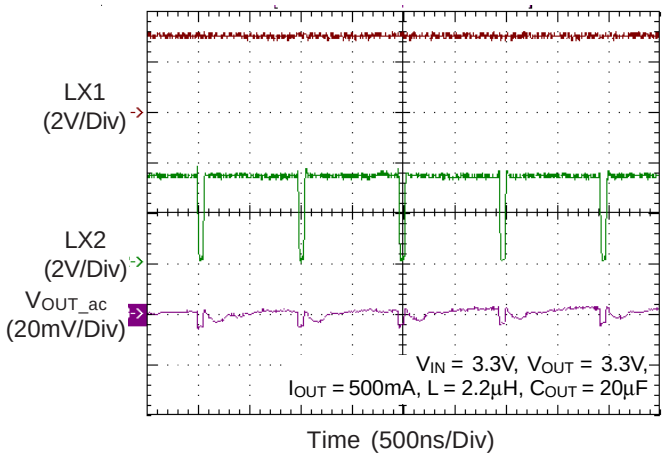
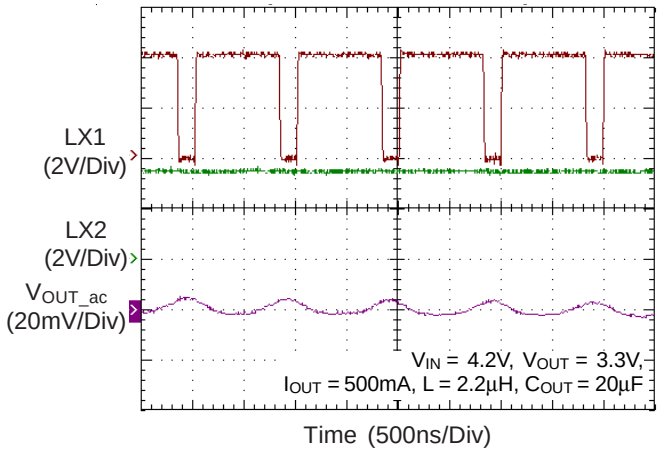
Output Voltage Ripple



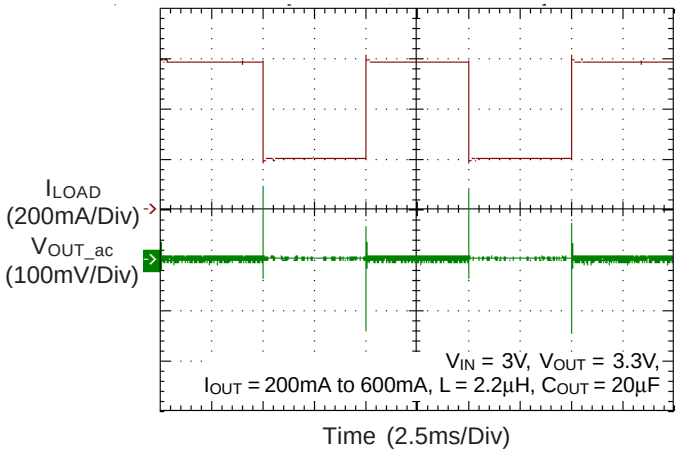
Output Voltage Ripple



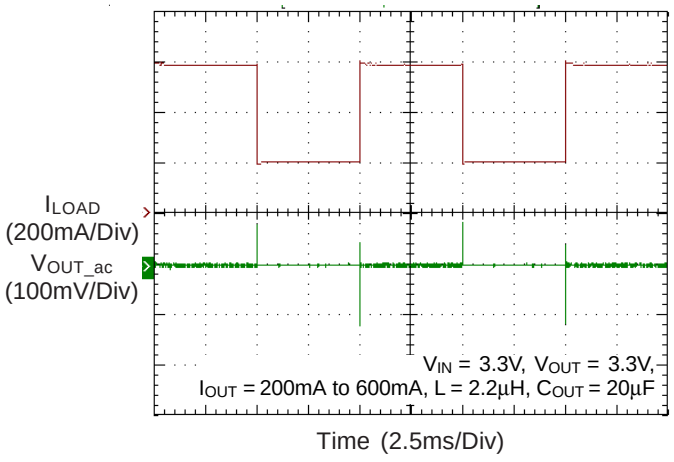
Output Voltage Ripple



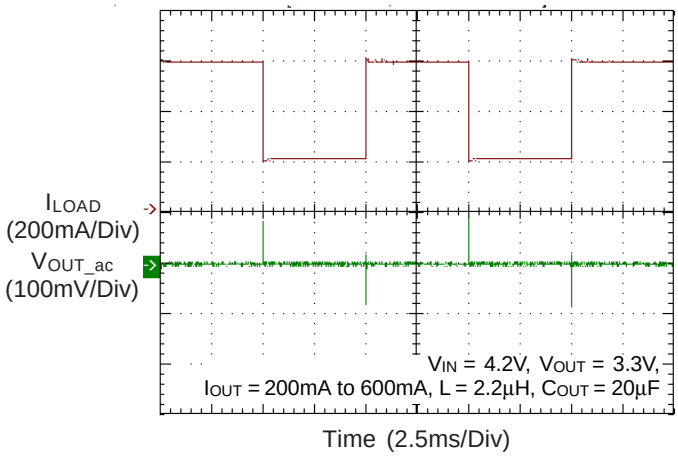
Load Transient Response



Load Transient Response



Load Transient Response



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Application Information

The RT6150A/B Buck-Boost DC/DC converter is designed for systems powered by one-cell Li-Ion or Li-Polymer battery with a typical voltage between 2.5V and 4.2V. They can also be used in systems powered by a double or triple cell Alkaline, NiCd, or NiMH battery with a typical terminal voltage between 1.8V and 5.5V. Additionally, the output voltage can be set between 1.8V and 5.5V.

The controller monitors the average input current as well as the peak input current. With this, maximum input power can be controlled to achieve a safe and stable operation. To protect the device from overheating, an internal temperature sensor is implemented.

Enable

The device can be enabled or disenabled by the EN pin. When the EN pin is higher than the threshold of logic-high, the device starts operation with soft-start. Once the EN pin is set at low, the device will be shut down. In shutdown mode, the converter stops switching, internal control circuitry is turned off, and the load is disconnected from the input. This also means that the output voltage can drop below the input voltage during shutdown.

Soft-Start

When the RT6150A/B is enabled, the output voltage will increase to its setting value within 1ms. During start-up period, the duty cycle and the peak current are limited to reduce high peak current flowing from the input.

Output Voltage Setting

There are fixed and adjustable output voltage versions available. To properly configure the fixed output voltage devices, the FB pin is used to sense the output voltage and must be connected directly to VOUT. At the adjustable versions, the output voltage is setting by an external resistive divider. The resistive divider must be connected between VOUT, FB and GND. When the output voltage is regulated properly, the typical value of the voltage at the FB pin is 500mV, and the current into FB pin is about 10nA generally. The current through divider resistor should be about 100 times larger than the current into FB pin in order to neglect the FB input current. The suggested value for R2 is 80kΩ to 500kΩ, and the value of R1 is depended on the needed output voltage. Output voltage can be calculated by equation as below :

$$R1 = R2 \times \left(\frac{V_{OUT}}{V_{FB}} - 1 \right)$$

For example, an output voltage of 3.3V is needed. It is recommended to use a 487kΩ resistor for R1. For better transient response performance, adding a feedforward capacitor in parallel with R1 is recommended. The value for the feedforward capacitor can be calculated using equation as below :

Cff = [(487k/R1) x 20] –20 (pF)

Power Save Mode

The PS pin can be used to select different operation modes. To enable Power Save Mode (PSM), the PS pin must be set at low. The PSM is used to improve the efficiency at light load. If the power save mode is disabled by pulling high the PS pin, the converter will operate in PWM mode with fixed switching frequency.

Under-Voltage Lockout

The under-voltage lockout circuit prevents the device from operating incorrectly at low input voltages. It prevents the converter from turning on the power switches under undefined conditions and prevents the battery from deep discharge. VINA voltage must be greater than 1.65V to enable the converter. During operation, if VINA voltage drops below 1.55V, the converter is disabled until the supply exceeds the UVLO rising threshold. The RT6150A/B automatically restarts if the input voltage recovers to the input voltage UVLO high level.

Thermal Shutdown

The device has a built-in temperature sensor which monitors the internal junction temperature. If the temperature exceeds the threshold, the device stops operating. As soon as the IC temperature has decreased below the threshold with a hysteresis, it starts operating again. The built-in hysteresis is designed to avoid unstable operation at IC temperatures near the over temperature threshold.

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Inductor Selection

To properly configure the Buck-Boost converter, an inductor must be connected between the LX1 and LX2 pins. To estimate the inductance value, two equations are listed as below :

$$L1 > \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{f \times \Delta I_L \times V_{IN(MAX)}} \quad (H)$$

$$L2 > \frac{V_{IN(MIN)} \times (V_{OUT} - V_{IN(MIN)})}{f \times \Delta I_L \times V_{OUT}} \quad (H)$$

where f is the minimum switching frequency. L1 is the minimum inductor value for Buck mode operation. $V_{IN(MAX)}$ is the maximum input voltage. L2 is the minimum inductance, for Boost mode operation. $V_{IN(MIN)}$ is the minimum input voltage. The recommended minimum inductor value is either L1 or L2 whichever is higher. For example, a suitable inductor value is 2.2µH for generating a 3.3V output voltage from a Li-Ion battery with the range from 2.5V to 4.2V. The recommended inductor value range is between 1.5µH and 4.7µH. In general, a higher inductor value offers better performance in high voltage conversion condition.

Input Capacitor Selection

At least a 10µF input capacitor is recommended to improve transient behavior of the regulator and EMI behavior of the total power supply circuit. A ceramic capacitor placed as close as possible to the VIN and GND pins of the IC is recommended.

Output Capacitor Selection

The output capacitor selection determines the output voltage ripple and transient response. It is recommended to use ceramic capacitors placed as close as possible to the VOUT and GND pins of the IC. If, for any reason, the application requires the use of large capacitors which can not be placed close to the IC, using a small ceramic capacitor in parallel to the large one is recommended. This small capacitor should be placed as close as possible to the VOUT and GND pins of the IC. The output voltage ripple for a given output capacitor is expressed as follows :

$$\Delta V_{OUT}, \text{ peak (Buck)} = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times 8 \times L \times (f_{OSC})^2 \times C_{OUT}}$$

$$\Delta V_{OUT}, \text{ peak (Boost)} = \frac{I_{LOAD} \times (V_{OUT} - V_{IN})}{C_{OUT} \times V_{OUT} \times f_{OSC}}$$

If the RT6150A/B operates in Buck mode, the worst-case voltage ripple occurs at the highest input voltage. When the RT6150A/B operates in boost mode, the worst-case voltage ripple occurs at the lowest input voltage.

The maximum voltage of overshoot or undershoot, is inversely proportional to the value of the output capacitor. To ensure stability and excellent transient response, it is recommended to use a minimum of 10µF/X7R/1206 capacitors at the output. For surface mount applications, Taiyo Yuden or TDK ceramic capacitors, X7R series Multi-layer Ceramic Capacitor is recommended.

A capacitor with a value in the range of the calculated minimum should be used. This is required to maintain control loop stability. There are no additional requirements regarding minimum ESR. Low ESR capacitors should be used to minimize output voltage ripple. Larger capacitors will cause lower output voltage ripple as well as lower output voltage drop during load transients.

Thermal Considerations

For continuous operation, do not exceed absolute maximum junction temperature. The maximum power dissipation depends on the thermal resistance of the IC package, PCB layout, rate of surrounding airflow, and difference between junction and ambient temperature. The maximum power dissipation can be calculated by the following formula :

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction to ambient thermal resistance.

For recommended operating condition specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, θ_{JA}, is layout dependent. For WDFN-10L 3x3 package, the thermal resistance, θ_{JA}, is 30.5°C/W on a standard JEDEC 51-7 four-layer thermal test board. For WDFN-10L 2.5x2.5 package, the thermal resistance, θ_{JA}, is 40.9°C/W on a standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at T_A = 25°C can be calculated by the following formula :

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$P_{D(MAX)}$ = (125°C – 25°C) / (30.5°C/W) = 3.28W for WDFN-10L 3x3 package

$P_{D(MAX)}$ = (125°C – 25°C) / (40.9°C/W) = 2.44W for WDFN-10L 2.5x2.5 package

The maximum power dissipation depends on the operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance, θ_{JA}. The derating curve in Figure 1 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

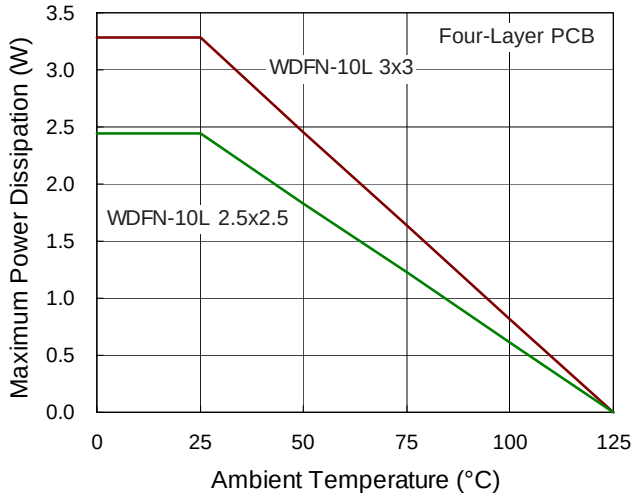

Figure 1. Derating Curve of Maximum Power Dissipation

Layout Considerations

For the best performance of the RT6150A/B, the following PCB layout guidelines must be strictly followed.

- Place the input and output capacitors as close as possible to the input and output pins respectively for good filtering.
- Keep the main power traces as wide and short as possible.
- The switching node area connected to LX and inductor should be minimized for lower EMI.
- Place the feedback components as close as possible to the FB pin and keep these components away from the noisy devices.
- Connect the GND and Exposed Pad to a strong ground plane for maximum thermal dissipation and noise protection.
- Directly connect the output capacitors to the feedback network to avoid bouncing caused by parasitic resistance and inductance from the PCB trace.

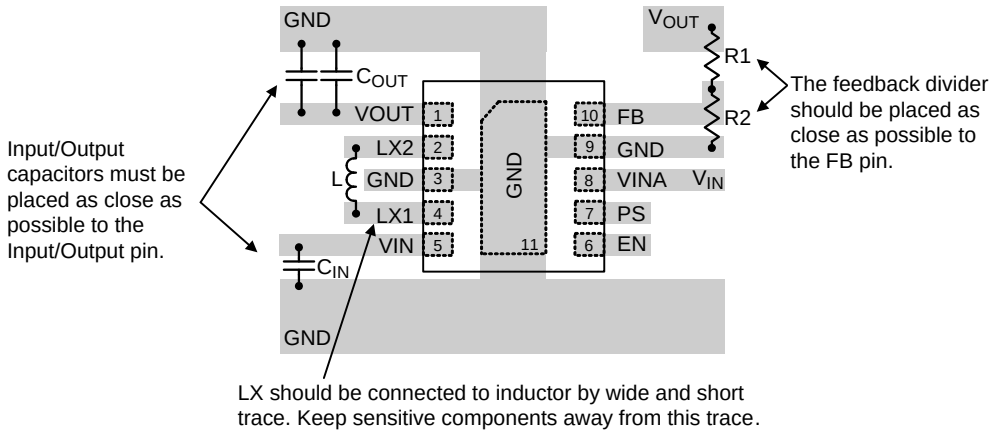

Figure 2. PCB Layout Guide

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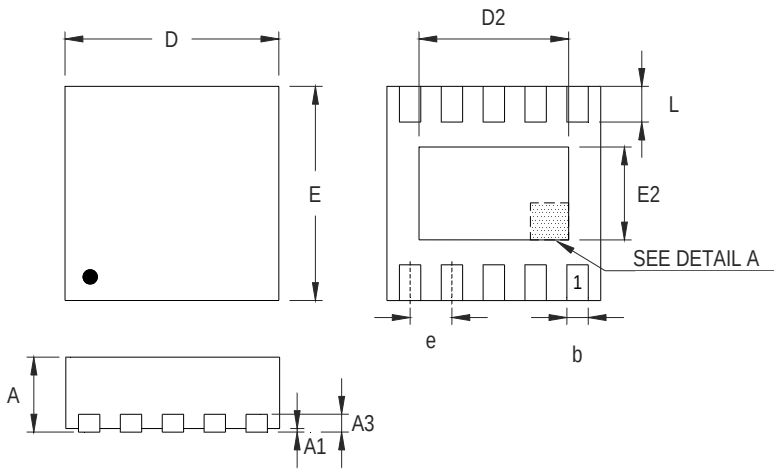
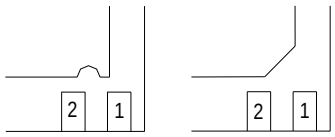
Outline Dimension





DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.180	0.300	0.007	0.012
D	2.950	3.050	0.116	0.120
D2	2.300	2.650	0.091	0.104
E	2.950	3.050	0.116	0.120
E2	1.500	1.750	0.059	0.069
e	0.500		0.020	
L	0.350	0.450	0.014	0.018

W-Type 10L DFN 3x3 Package

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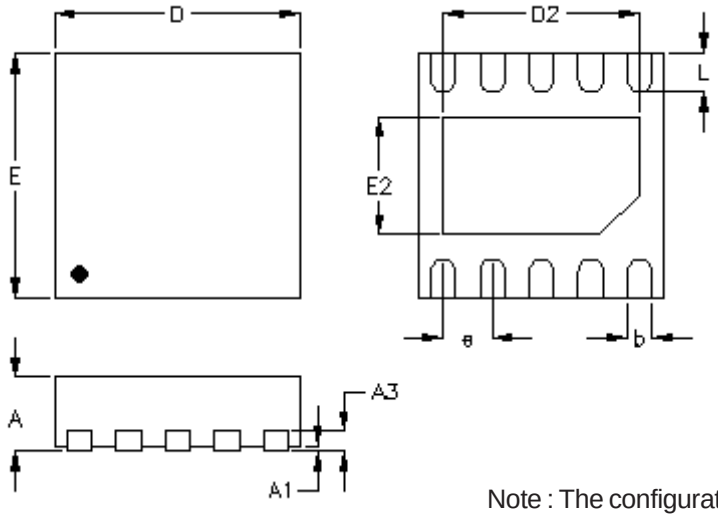

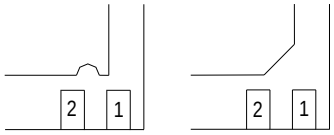

DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.200	0.300	0.008	0.012
D	2.400	2.600	0.094	0.102
D2	1.950	2.050	0.077	0.081
E	2.400	2.600	0.094	0.102
E2	1.150	1.250	0.045	0.049
e	0.500		0.020	
L	0.350	0.450	0.014	0.018

W-Type 10L DFN 2.5x2.5 Package

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