High Efficiency, Low Quiescent, 3A Buck-Boost Converter

General Description

The RT6158H converter is a high efficiency single inductor converter which can operate with wide input voltage such as battery which is higher or lower than the output voltage and it can supply the load current up to 3A. The maximum peak current in the switches is limited to a typical value of 6.5A. Feedback loop is internally compensated for both Buck and Boost operation and it provides seamless transition between Buck and Boost modes and optimal transient response. The Buck-Boost operates at 1.5MHz typical switching frequency in full synchronous operation.

The RT6158H operates in Pulse Frequency Modulation (PFM) mode for increasing efficiency during low power RF transmission modes. The PFM mode can be disabled, forcing the RT6158H to operate at a fixed switching frequency operation at 2MHz. The RT6158H can also be synchronized with external frequency from 2.2MHz to 2.6MHz. The RT6158H output voltage is programmable using an external resistor divider; the output voltage range is from 2.1V to 5.2V.

Features

- **Input Voltage Range : 2.5V to 5.5V**
- **Adjustable Output Voltage : 2.1V to 5.2V by External Divided Resistors**
- **Up to 3A Maximum Load Capability for V_{IN} = 3V, V_{OUT} = 3.5V**
- **Up to 96% Efficiency**
- **OCP, OVP, OTP Protected Function**
- **2MHz Switching Frequency**
- **5μA Non-Switching Low Quiescent Maximizes Light Load Efficiency**
- **Forced PWM and Automatic PFM/PWM Mode Selection**
- **Output Fast Discharge Function**
- **Automatic / Seamless Step Up and Step Down Mode Transitions**
- **25-Ball WL-CSP Package**

Applications

- **Cellular Telephones**
- **RF Power Amplifiers**
- **Tablet PC**
- **Portable Instrument**

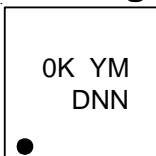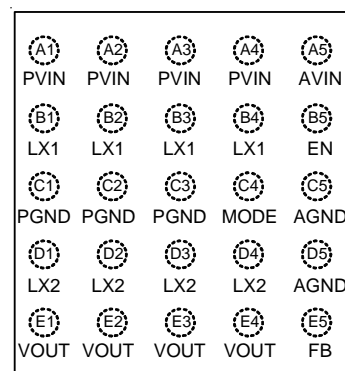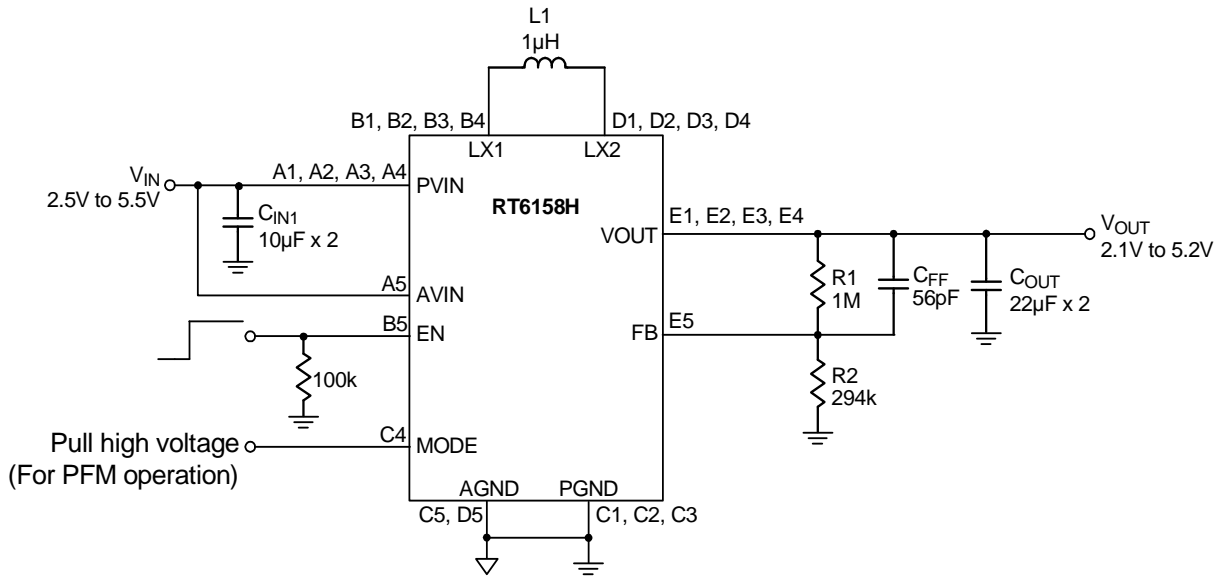## Ordering Information

RT6158H□

 └─ Package Type
    WSC : WL-CSP-25B 2.07x2.33 (BSC)

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.

Marking Information

0K YM
DNN

0K : Product Code

YMDNN : Date Code

Pin Configuration

(TOP VIEW)

A1 PVIN	A2 PVIN	A3 PVIN	A4 PVIN	A5 AVIN
B1 LX1	B2 LX1	B3 LX1	B4 LX1	B5 EN
C1 PGND	C2 PGND	C3 PGND	C4 MODE	C5 AGND
D1 LX2	D2 LX2	D3 LX2	D4 LX2	D5 AGND
E1 VOUT	E2 VOUT	E3 VOUT	E4 VOUT	E5 FB

WL-CSP-25B 2.07x2.33 (BSC)

Typical Application Circuit

BOM List

Reference	Description	Manufacturer	Package	Parameter	Typ	Unit
C_{IN}	10μF/6.3V/X5R	Murata – GRJ155R60J106ME11D	0402	C	10	μF
C_{OUT}	22μF/6.3V/X5R	Murata – GRM188R60J226ME15D	0603	C	22	μF
C_{FF}	56pF/50V/X5R	Murata – GRM0335C1H560JA01D	0201	C	56	pF
L1	1μH, ±20%	DFE252010F – 1R0M = P02	2520	L	1	μH
				DCR (Series R)	48	mΩ

Functional Pin Description

Pin No.	Pin Name	Pin Function
A1, A2, A3, A4	PVIN	Power input supply.
A5	AVIN	Analog input supply.
B1, B2, B3, B4	LX1	Phase 1. Switching node 1. Connect to inductor.
B5	EN	Chip enable. This input must not be left floating and must be terminated.
C1, C2, C3	PGND	Power ground.
C4	MODE	High for PFM mode, low for FCCM mode. This pin also can be used to synchronous switching frequency with 2.2MHz to 2.6MHz. This input must not be left floating and must be terminated.
C5, D5	AGND	Analog ground.
D1, D2, D3, D4	LX2	Phase 2. Switching node 2. Connect to inductor.
E1, E2, E3, E4	VOUT	Output power.
E5	FB	Voltage feedback.

Functional Block Diagram
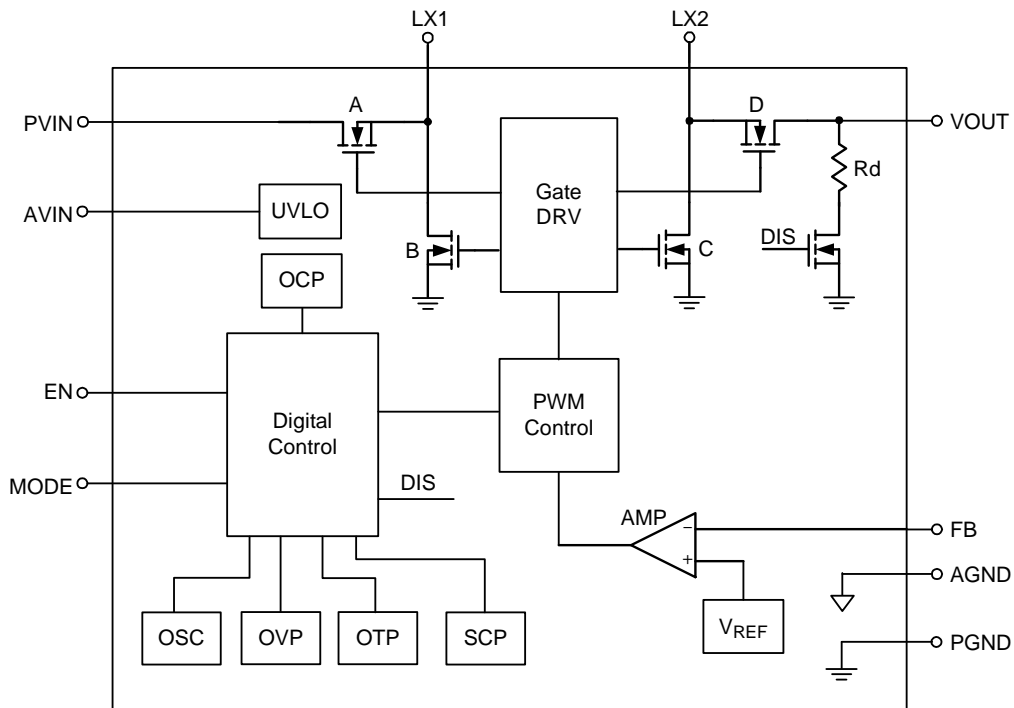
Operation

The RT6158H is a synchronous current mode constant on/off time (CMCOT) switching Buck-Boost converter designed to an adjustable output voltage from an input supply that can be above, equal, or below the output voltage. The 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. The output voltage of the RT6158H is adjustable, and can be set by the external divider resistor value. 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 RT6158H automatically enters Buck or Boost mode. In that case, the converter will maintain the regulation for output voltage and keep a minimum current ripple in the inductor to guarantee good performance.

RT6158H

Absolute Maximum Ratings   (Note 1)

- Supply Input Voltage -- −0.3V to 6V
- LX1, LX2 --- −0.3V to 6V
  - < 20ns -- −3V to 8.5V
- Other Pins --- −0.3V to 6V
- Power Dissipation, P_D @ T_A = 25°C
  WL-CSP-25B 2.07x2.33 (BSC) --- 2.8W
- Package Thermal Resistance   (Note 2)
  WL-CSP-25B 2.07x2.33 (BSC), θ_{JA} --- 35.7°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

Recommended Operating Conditions   (Note 4)

- Supply Input Voltage --- 2.5V to 5.5V
- Junction Temperature Range --- −40°C to 125°C
- Ambient Temperature Range -- −40°C to 85°C

Electrical Characteristics

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

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Input Power Source						
Input Voltage Range			2.5	--	5.5	V
Logic Input High Threshold	V_{IH}		1.2	--	--	V
Logic Input Low Threshold	V_{IL}		--	--	0.4	V
Under-Voltage Lockout	V_{UVLO}		2.05	--	2.25	V
Under-Voltage Lockout Hysteresis	V_{UVLO_H}		--	0.1	--	V
Shutdown Current	I_{SHDN}	V_{IN} = 3.5V, EN = L	--	--	1	μA
Input Quiescent Current	I_{QVIN}	Non-switching. V_{IN} = 4.2V, V_{OUT} = 3.5V, EN = VIN, Mode = VIN	--	5	7	μA
Switching Quiescent Current	I_{QSW}	I_{LOAD} = 0A. V_{IN} = 4.2V, V_{OUT} = 3.5V, EN = VIN, Mode = VIN	--	8	10	μA
Switching Frequency	f_{SWCOT}	MODE = H, |V_{IN} - V_{OUT}| > 1V	--	2	--	MHz
Switching Frequency	f_{SWCCM}	MODE = L	--	2	--	MHz
Synchronous Switching Frequency Range	f_{SWSYNC}	MODE = square wave, 10% < duty < 90%	2.2	--	2.6	MHz

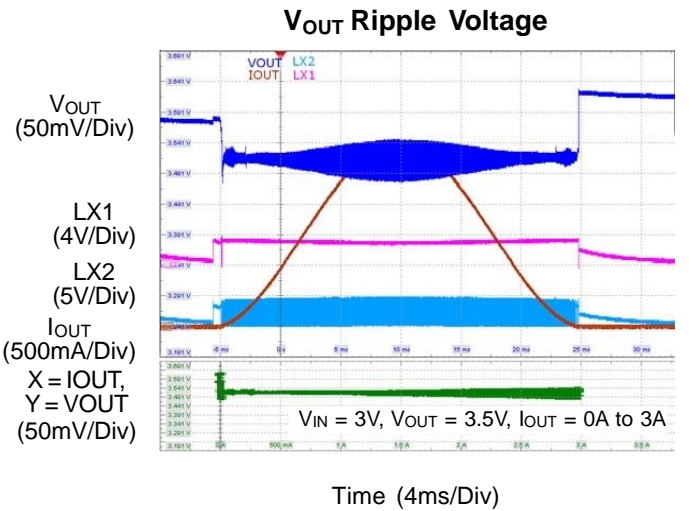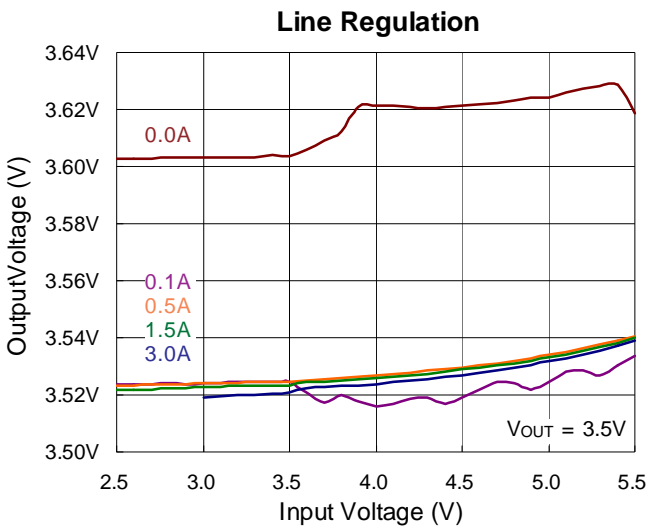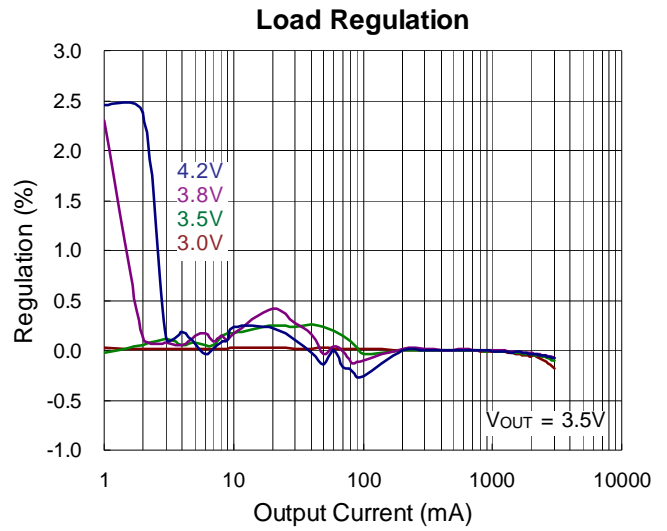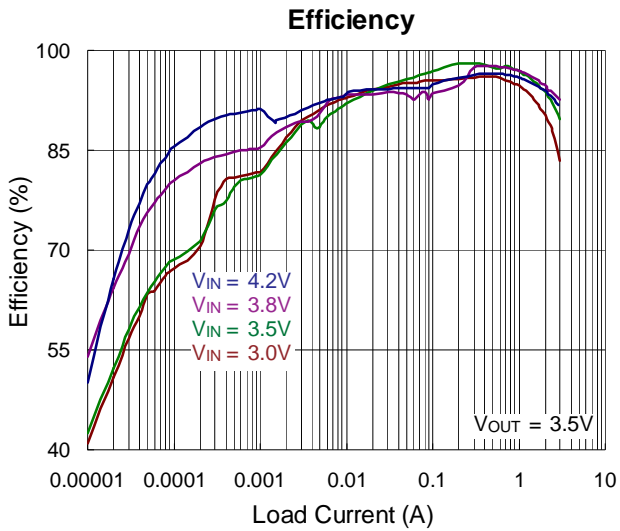| Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Soft-Start Time	t_{SS_EN}	Time from EN goes H to VOUT starts ramp up	--	1	--	ms
	t_{SS}	V_{IN} = 4V, V_{OUT} = 3.5V, I_{LOAD} = 200mA	--	1	--	ms
	t_{SS}	V_{IN} = 2.5V, V_{OUT} = 3.5V, I_{LOAD} = 200mA	--	2	--	ms
Minimum Off Time	t_{OFF_MIN}		--	40	--	ns
Minimum On Time	t_{ON_MIN}		--	40	--	ns
FB Voltage		CCM operation	0.792	0.8	0.808	V
High Side Switch $R_{DS(ON)}$	$R_{DS(ON)\_A, D}$	V_{OUT} = 5V	12	20	30	mΩ
Low Side Switch $R_{DS(ON)}$	$R_{DS(ON)\_B, C}$	V_{OUT} = 5V	12	20	30	mΩ
Output Over-Voltage Protection	V_{OVP}		5.3	5.6	5.9	V
Load Current Threshold, PFM to PWM	I_{TH_PWM}	V_{IN} = 3.6V, V_{OUT} = 3.3V	--	200	--	mA
Load Current Threshold, PWM to PFM	I_{TH_PFM}	V_{IN} = 3.6V, V_{OUT} = 3.3V	--	200	--	mA
FAULT Time	T_{FAULT}		--	40	--	ms
Thermal Shutdown			--	160	--	°C
Over-Temperature Protection Hysteresis	T_{OTP_HYS}		--	20	--	°C
Inductor Peak Current Limit	I_{CL}		6	6.5	7	A
Line Regulation		V_{IN} = 2.5V to 5.5V, V_{OUT} = 3.5V, CCM, I_{LOAD} = 1.5A	--	0.6	--	%
Load Regulation		V_{IN} = 2.5V to 5.5V, V_{OUT} = 3.5V, CCM operation, I_{LOAD} < 3A	--	0.6	--	%
Output Voltage Ripple	$V_{OUTp-to-p}$	V_{IN} = 2.5V to 5.5V, I_{LOAD} > 1A	--	20	--	mV
Line Transient	$V_{OUTp-to-p}$	V_{IN} = 3V to 3.6V at 10μs, V_{OUT} = 3.5V, I_{LOAD} = 1A	--	100	--	mV
Load Transient		V_{IN} = 3.4V, V_{OUT} = 3.5V, Loading = 0.5A to 1A at 1μs	--	±60	--	mV

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 under natural convection (still air) at T_A = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard.
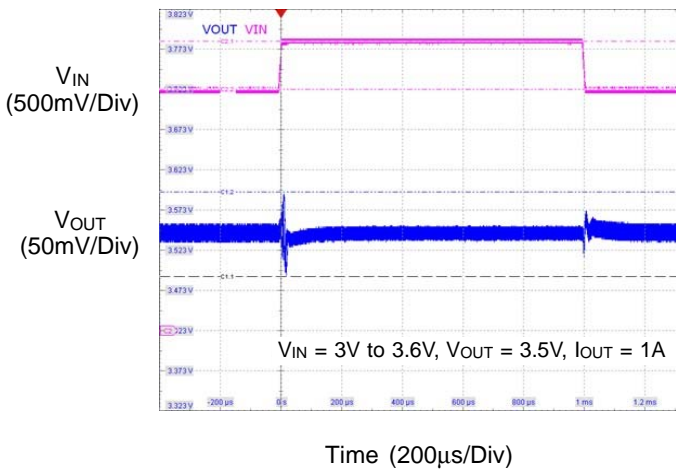
Note 3. Devices are ESD sensitive. Handling precaution is recommended.

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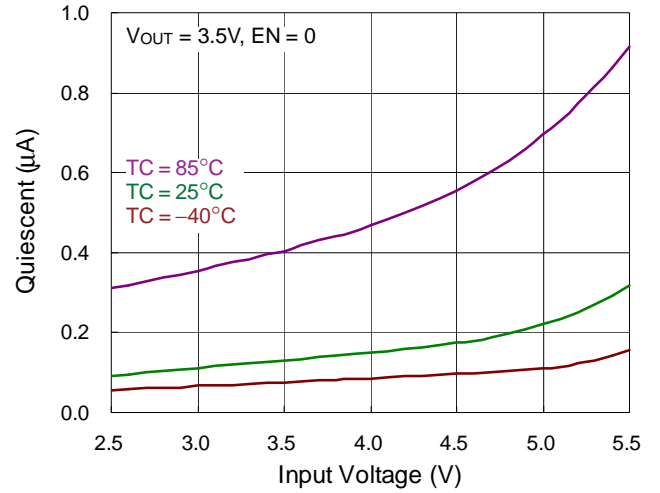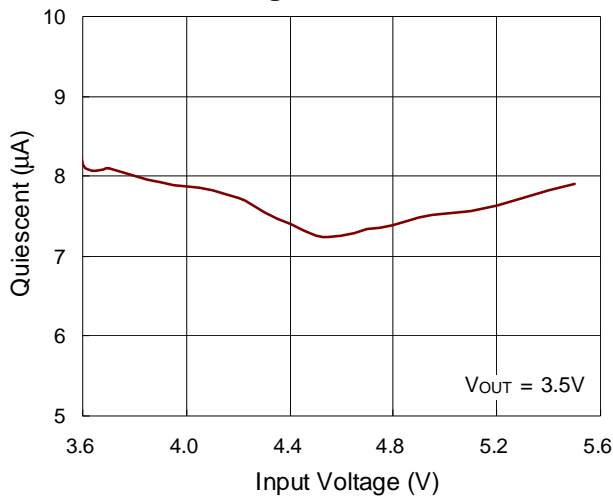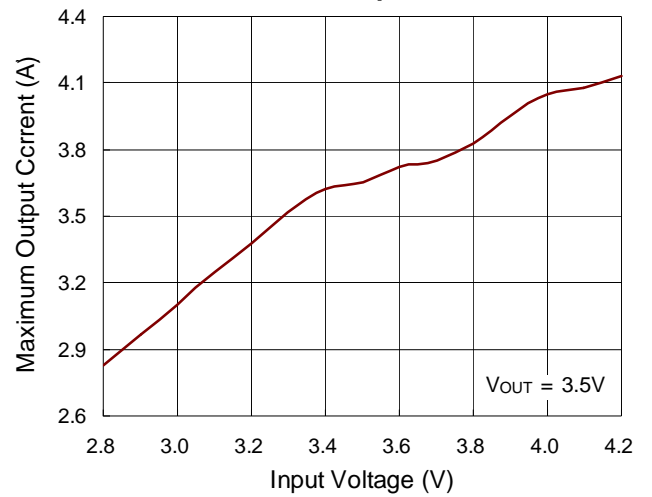
Typical Operating Characteristics

Efficiency

Load Regulation

Line Regulation

V$_{OUT}$ Ripple Voltage

V_{IN} = 3V, V_{OUT} = 3.5V, I_{OUT} = 0A to 3A

Time (4ms/Div)

V$_{OUT}$ Ripple Voltage

V_{IN} = 4.5V, V_{OUT} = 3.5V, I_{OUT} = 0A to 3A

Time (4ms/Div)

Load Transient

V_{IN} = 3.6V, V_{OUT} = 3.5V,
t_R = t_F = 1µs, I_{OUT} = 0A to 3A

Time (75µs/Div)

Line Transient

V_{IN} (500mV/Div)

V_{OUT} (50mV/Div)

V_{IN} = 3V to 3.6V, V_{OUT} = 3.5V, I_{OUT} = 1A

Time (200μs/Div)

Shutdown Current

V_{OUT} = 3.5V, EN = 0

TC = 85°C
TC = 25°C
TC = −40°C

Input Voltage (V)

Switching Quiescent Current

V_{OUT} = 3.5V

Input Voltage (V)

Maximum Output Current

V_{OUT} = 3.5V

Input Voltage (V)

Power On

V_{IN} = 3.6V, V_{OUT} = 3.5V, I_{OUT} = 3A

V_{EN} (2V/Div)

V_{OUT} (1V/Div)

I_{LX} (1V/Div)

Time (200μs/Div)

Power Off

V_{IN} = 3.6V, V_{OUT} = 3.5V, I_{OUT} = 3A

V_{EN} (2V/Div)

V_{OUT} (1V/Div)

I_{LX} (1V/Div)

Time (40μs/Div)

Application Information

The RT6158H Buck-Boost DC-DC converter can operate with wide input voltage such as battery which is higher or lower than the output voltage and it can supply the load current up to 3A. The maximum peak current in the switches is limited to a typical value of 6.5A. The typical operating input voltage is between 2.5V and 5.5V. The RT6158H output voltage can be set from 2.1V to 5.2V by changing the external divider resistor on the FB pin. The converter feedback loop is internally compensated for both Buck and Boost operation and it provides seamless transition between Buck and Boost modes operation.

Enable

The device can be enabled or 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. This input must not be left floating and must be terminated.

Output Voltage Setting

The RT6158H output voltage can be set from 2.1V to 5.2V by changing the external divider resistor on the FB pin. The resistor divider must be connected between VOUT, FB and GND. The typical value of the voltage at the FB pin is 800mV. For decrease the leakage current on FB pin, it is recommended to keep the resistor R2 large value. For example, it can be R1 = 1MΩ and R2 = 294kΩ for V_{OUT} = 3.5V application, the following Equation is as below :

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

MODE states and Synchronization

The MODE pin can be used to select different operation modes. When MODE is set high, it means the RT6158H will operate at PFM mode for used to improve efficiency. At this point the converter operates with reduced switching frequency and with a minimum quiescent current to maintain high efficiency. When the load increases, the device will automatically switch to PWM mode. The PFM mode can be disabled by programming the MODE pin low. Connecting a clock signal at MODE pin can force the RT6158H switching frequency to synchronize to the connected clock frequency. The MODE pin input supports standard logic thresholds and the frequency range is between 2.2MHz to 2.6MHz. This input must not be left floating and must be terminated.

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. VIN voltage must be greater than 2.5V to enable the converter. During operation, if VIN voltage drops below 1.8V, the converter is disabled until the supply exceeds the UVLO rising threshold. The RT6158H automatically restarts if the input voltage recovers to the input voltage UVLO high level.

Short Circuit Protection

When the output is shorted to ground, the inductor current decays very slowly rate during a single switching cycle. A current runaway detector is used to monitor inductor current. As current increasing beyond the control of current loop, switching cycles will be skipped to prevent current runaway form occurring.

Over-Temperature Protection

The device has a built-in temperature sensor which monitors the internal junction temperature. If the temperature exceeds a threshold, the device stops operating. As soon as the IC temperature decreases below the threshold with a hysteresis, it starts operating again.

Over-Voltage Protection

When the VOUTS pin is floating, the device will trigger the over-voltage protection to avoid the output voltage exceeding critical values for device. In case it reaches the OVP threshold, the device will regulate the output voltage to this value.

Protection Type	Threshold Refer to Electrical spec.	Protection Method	Shut Down Delay Time	Reset Method
OCP	$I_L > 6.5A$	Turn on B, D MOS	CL will trigger right away.	$I_L < 6.5A$
UVP	$V_{IN} < 1.9V$	Shutdown	$100\mu s$	$V_{IN} > 2.3V$
OTP	TEMP > 160°C	Shutdown	No delay	OTP Hysteresis = 20°C
Output OVP	$V_{OUT} > 5.6V$	Stop switching	No delay	$V_{OUT} < 5.3V$
SCP	$V_{OUT} < 1.2V$	f_{SW} become 1/4	No delay	After FAULT 40ms

Inductor Selection

The recommended power inductor is 1μH with over 6.5A saturation current rating. In applications, need to select an inductor with the low DCR to provide good performance and efficiency.

Input and Output Capacitor Selection

The input and output capacitors should be ceramic X5R type with low ESL and ESR. The recommended input capacitor value is 2 x 10μF. The recommended output capacitor value is 2 x 22μF.

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 cannot 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:

If the RT6158H operates in Buck mode, the worst-case voltage ripple occurs at the highest input voltage. When the Buck-boost 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. 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

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using 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 continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, θ_{JA}, is highly package dependent. For a WL-CSP-25B 2.07x2.33 (BSC) package, the thermal resistance, θ_{JA}, is 35.7°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at $T_A = 25$°C can be calculated as below :

$P_{D(MAX)} = (125$°C $- 25$°C$) / (35.7$°C/W$) = 2.8W$ for a WL-CSP-25B 2.07x2.33 (BSC) package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, θ_{JA}. The derating curves in Figure 1 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.
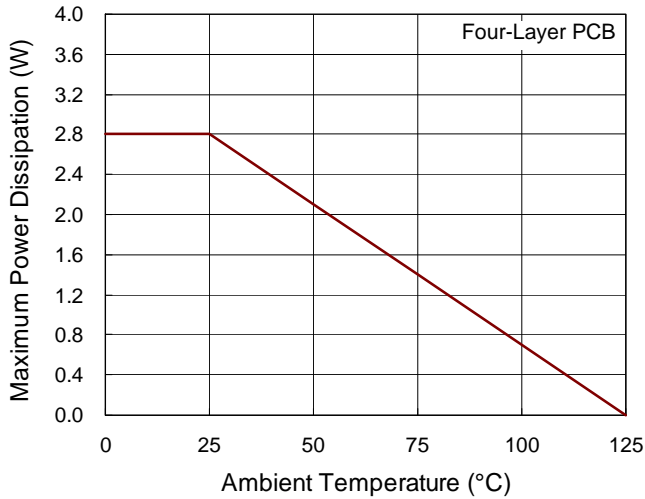
RT6158H

Figure 1. Derating Curve of Maximum Power Dissipation

Layout Considerations

Some PCB layout guidelines for optimal performance of the RT6158H list as following. Following figure shows the real PCB layout considerations and it is based on the real component size whose unit is millimeter (mm).

‣ The input capacitor should be placed as closed as possible to PVIN pin for good filtering.

‣ The high current path should be made as short and wide as possible.

‣ The inductor should be placed as close to LX1 and LX2 pin for reducing EMI.

‣ The output capacitor should be placed as closed as PGND pin to ground plane to reduce noise coupling.
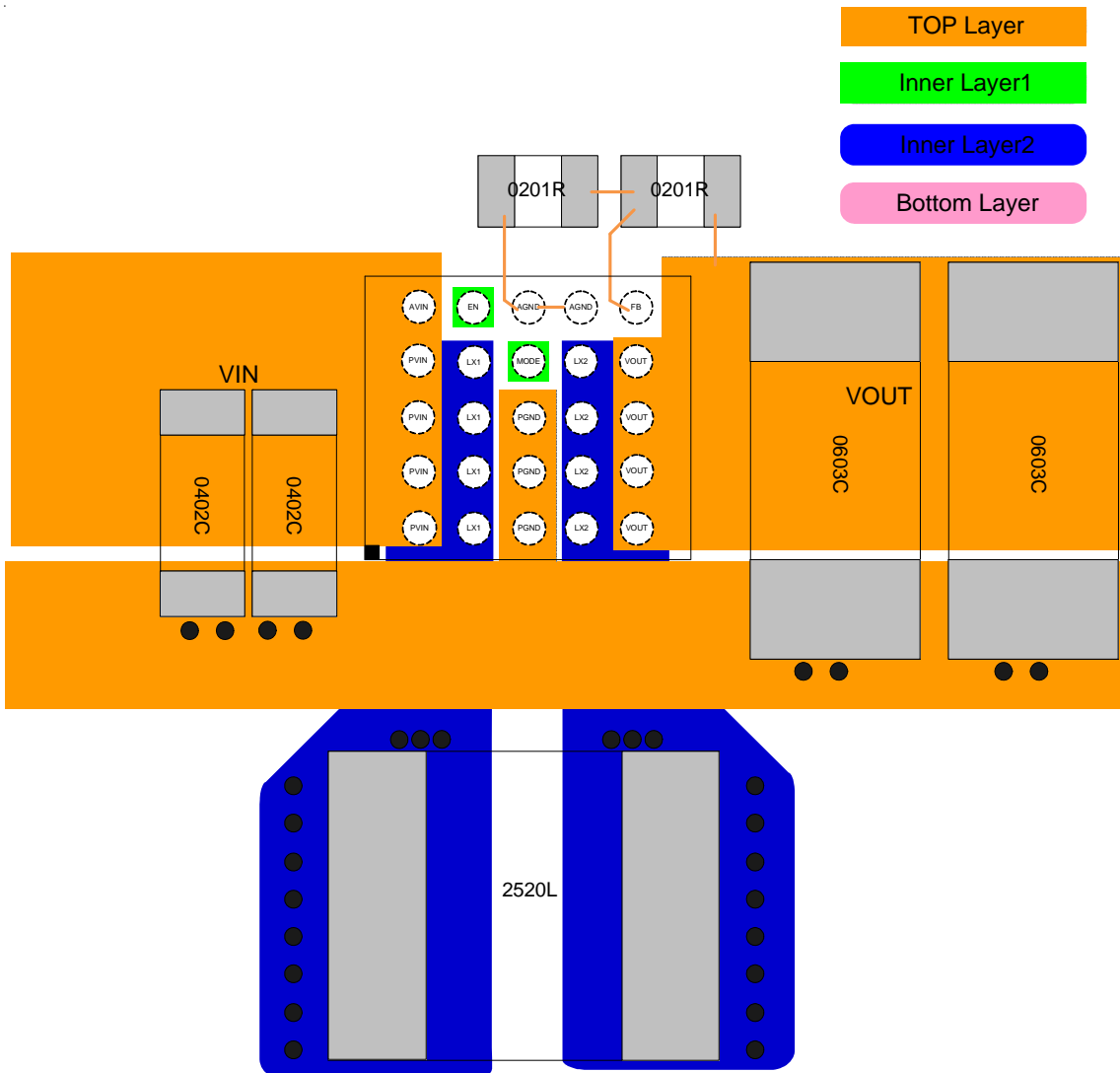
Figure 2. PCB Layout Guide

Outline Dimension
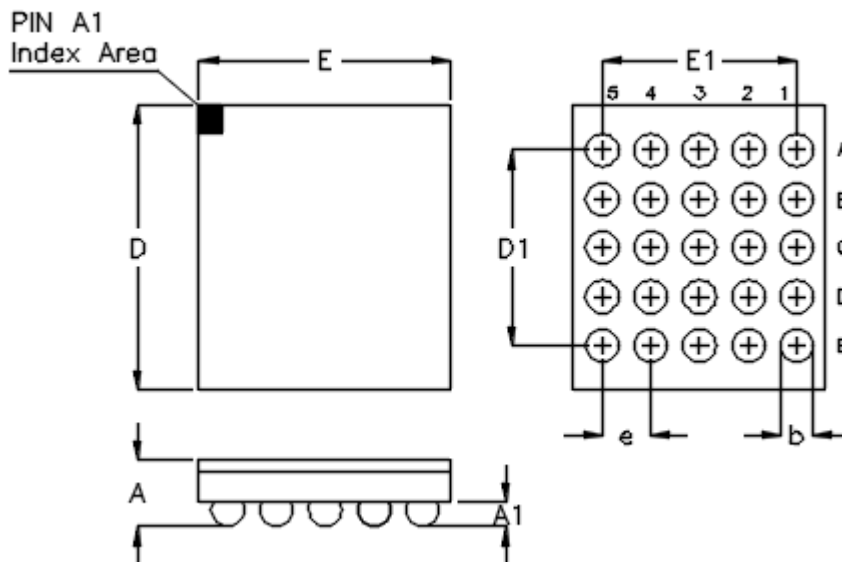
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	**Max**	**Min**	**Max**
A	0.500	0.600	0.020	0.024
A1	0.170	0.230	0.007	0.009
b	0.240	0.300	0.009	0.012
D	2.280	2.380	0.090	0.094
D1	1.600		0.063	
E	2.020	2.120	0.080	0.083
E1	1.600		0.063	
e	0.400		0.016	

25B WL-CSP 2.07x2.33 Package (BSC)

RICHTEK

Footprint Information
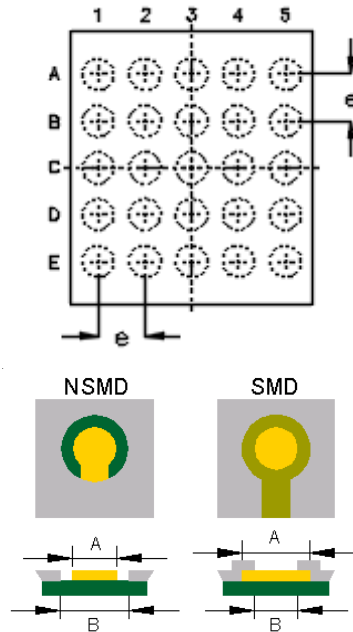
Package	Number of Pin	Type	Footprint Dimension (mm)			Tolerance
			e	A	B	
WL-CSP2.07*2.33-25(BSC)	25	NSMD	0.400	0.240	0.340	±0.025
		SMD		0.270	0.240	

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