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High Efficiency Single Inductor Buck-Boost Converter

1 General Description

The RT6154A/B is a high efficiency single inductor buck-boost converter that can operate with a wide input voltage range, such as a battery. It allows for input voltages higher or lower than the output voltage and can supply a load current up to 4A. The maximum peak current in the switches is limited to a typical value of 5A at V_{IN} = 3.6V and 2.6A at V_{IN} = 2.1V.

The RT6154A/B feedback loop is internally compensated for both buck and boost operation, providing seamless transition between buck and boost modes and optimal transient response. The RT6154A/B operates at a typical switching frequency of 2.4MHz in full synchronous operation.

The RT6154A/B operates in pulse skipped modulation, enhancing efficiency during low power RF transmission modes. The Power Save Mode (PSM) can be disabled, forcing the RT6154A/B to operate at a fixed switching frequency of 2.4MHz. The RT6154A/B can also be synchronized with an external frequency source ranging from 2.2MHz to 2.6MHz. The RT6154A output voltage is adjustable using an external resistor divider, while the RT6154B is fixed internally to 3.3V.

The recommended junction temperature range is –40°C to 125°C, and the ambient temperature range is –40°C to 85°C.

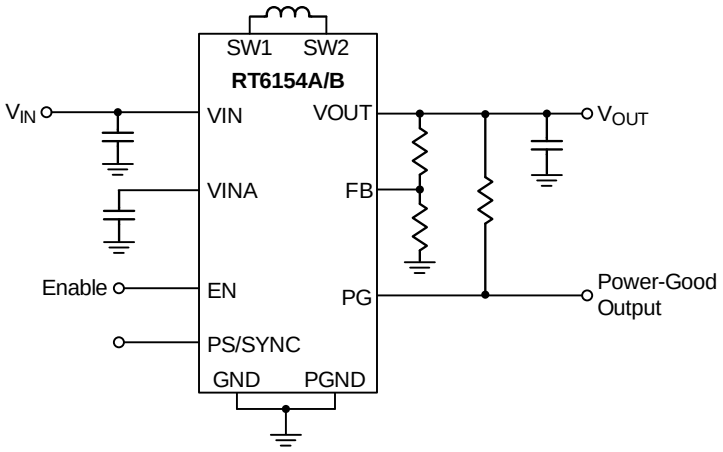
2 Features

- **Operate with a Single Li-Ion Cell: 1.8V to 5.5V**
- **Adjustable Output Voltage: 1.8V to 5.5V**
- **3A Maximum Load Capability for V_{IN} > 3.6V, V_{OUT} = 3.3V**
- **Power Save Mode (PSM) for Improving Low Output Power Efficiency**
- **Fixed Frequency Operation at 2.4MHz or Synchronized with External Frequency Source Ranging from 2.2MHz to 2.6MHz**
- **Up to 96% Efficiency**
- **Input Current Limit**
- **Internal Compensation**

3 Applications

- e-Cigarettes
- Internet Protocol Cameras
- Doorbells
- EPOS Systems

4 Simplified Application Circuit



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5 Ordering Information

RT6154A/B □□

Package Type(1)
QW: WDFN-14AL 4x3 (W-Type)

Lead Plating System
G: Richtek Green Policy Compliant(2)

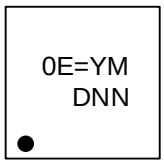
Output Voltage
RT6154A: Adjustable
RT6154B: Fixed 3.3V

Note 1.

- Marked with (1) indicated: Compatible with the current requirements of IPC/JEDEC J-STD-020.
- Marked with (2) indicated: Richtek products are Richtek Green Policy compliant.

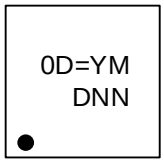
6 Marking Information

RT6154AGQW



0E=: Product Code
YMDNN: Date Code

RT6154BGQW



0D=: Product Code
YMDNN: Date Code

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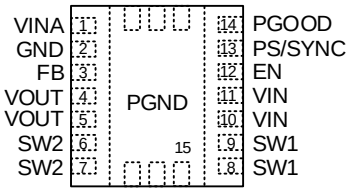
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7 Pin Configuration

(TOP VIEW)



WDFN-14AL 4x3

8 Functional Pin Description

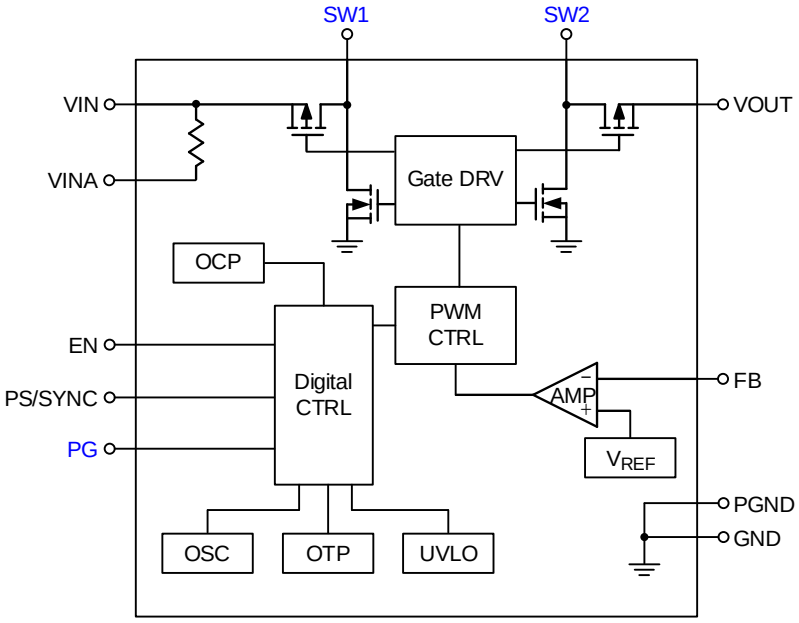
Pin No.	Pin Name	Pin Function
1	VINA	Supply voltage input.
2	GND	Analog ground.
3	FB	Voltage feedback of adjustable versions. It must be connected to VOUT on fixed output voltage versions.
4, 5	VOUT	Buck-boost converter output.
6, 7	SW2	Second switch node.
8, 9	SW1	First switch node.
10, 11	VIN	Power input.
12	EN	Enable control input (1 enabled, 0 disabled). Must not be left floating.
13	PS/SYNC	Enable/disable control input for power save mode (1 disabled, 0 enabled, clock signal for synchronization). Must not be left floating.
14	PG	Power-good indicator output. (1 good, 0 failure; open drain).
15 (Exposed Pad)	PGND	Power ground. The exposed pad must be soldered to a large PCB and connected to PGND for maximum power dissipation.

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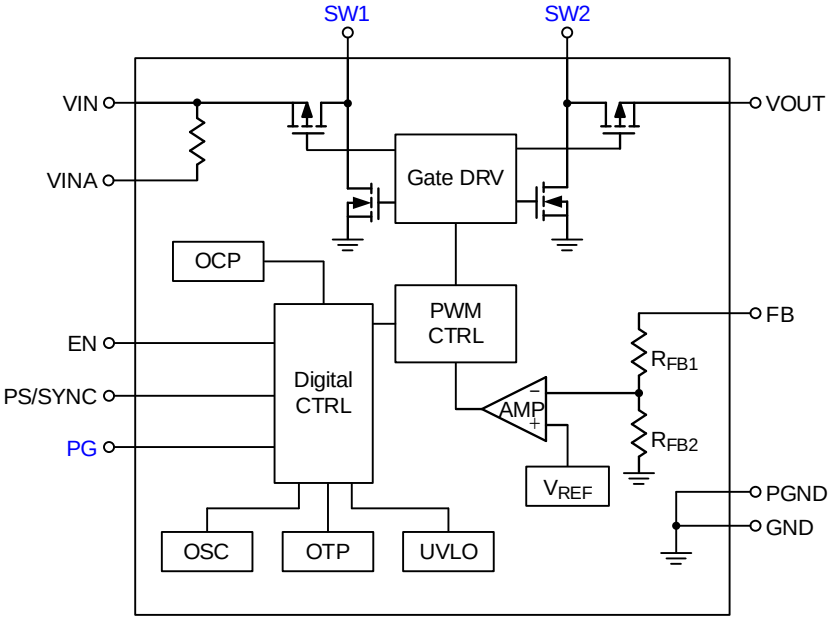
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9 Functional Block Diagram

9.1 RT6154A (Adjustable Output Voltage)



9.2 RT6154B (Fixed 3.3V Output Voltage)



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10 Absolute Maximum Ratings

(Note 2)

- Input Voltage, V_{IN} / V_{INA} ---------- –0.2V to 6V
- Output Voltage, V_{OUT} ---------- –0.2V to 6.5V
- Other I/O Pins Voltages (EN, PS/SYNC) ---------- –0.2V to (VIN + 0.2V) with 6V Max
- Feedback Voltage, V_{FB} ---------- –0.2V to (VIN + 0.2V) with 6V Max
- Switch Node Voltage, SW1
  - DC ---------- (PGND – 0.2V) to (VIN + 0.2V) with 6V Max
  - AC (< 20ns) ---------- –3V to 8.5V
- Switch Node Voltage, SW2
  - DC ---------- (PGND – 0.2V) to (VIN + 0.2V) with 6.5V Max
  - AC (< 20ns) ---------- –3V to 8.5V
- Power Dissipation, P_D @ T_A = 25°C
  - WDFN-14AL 4x3 ---------- 3.49W
- Package Thermal Resistance (Note 3)
  - WDFN-14AL 4x3, θ_{JA} ---------- 28.6°C/W
  - WDFN-14AL 4x3, θ_{JC} ---------- 3.2°C/W
- Lead Temperature (Soldering, 10sec.) ---------- 260°C
- Junction Temperature ---------- 150°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 4)
  - HBM (Human Body Model) ---------- 2kV

Note 2. 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 may affect device reliability.

Note 3. θ_{JA} is simulated 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. θ_{JC} is simulated at the bottom of the package.

Note 4. Devices are ESD sensitive. Handling precautions are recommended.

11 Recommended Operating Conditions

(Note 5)

- Input Voltage, V_{IN} / V_{INA} ---------- 1.8V to 5.5V
- Output Voltage, V_{OUT} ---------- 1.8V to 5.5V
- Junction Temperature Range ---------- –40°C to 125°C
- Ambient Temperature Range ---------- –40°C to 85°C

Note 5. The device is not guaranteed to function outside its operating conditions.

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12 Electrical Characteristics

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

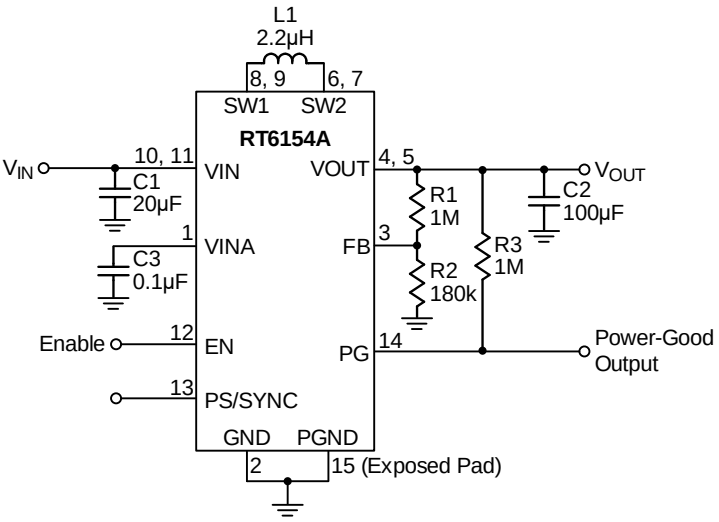
Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Undervoltage-Lockout Rising Threshold	V_{UVLO_R}		1.6	1.7	1.8	V
Undervoltage-Lockout Falling Threshold	V_{UVLO_F}		1.5	1.6	1.7	V
Minimum Input Voltage for Start-Up	V_{START_UP}		1.5	1.8	2.0	V
FB Voltage	V_{FB}	Forced PWM (RT6154A)	0.495	0.5	0.505	V
VOUT Voltage	V_{OUT}	Forced PWM (RT6154B)	3.267	3.3	3.333	V
Shutdown Current	I_{SHDN}	EN = 0V, PS/SYNC = 0V, PGOOD = 0V	--	0.1	1	μA
Switching Frequency	f_{SW}		2.2	2.4	2.6	MHz
Frequency Range for Synchronization	f_{SYNC}		2.2	2.4	2.6	MHz
Current Limit	I_{LIM_36}	V_{IN} = V_{INA} = 3.6V	3.9	5	5.8	A
	I_{LIM_21}	V_{IN} = V_{INA} = 2.1V	1.7	2.6	3.7	
On-Resistance of High-Side MOSFET	R_{DSON_H}	V_{IN} = V_{INA} = 3.6V	--	50	--	mΩ
On-Resistance of Low-Side MOSFET	R_{DSON_L}	V_{IN} = V_{INA} = 3.6V	--	50	--	mΩ
Quiescent Current	I_{Q_NSW}	Non-switching, EN = VINA, SYNC = 0V	--	20	40	μA
Leakage Current of FB Input	I_{LK_FB}	ADJ mode	–1	--	1	μA
Leakage Current of SW1 and SW2	I_{LK_SW1} I_{LK_SW2}	All switch off	--	--	5	μA
Line Regulation	V_{LINE_REG}	FPWM	--	0.5	--	%
Load Regulation	V_{LOAD_REG}	FPWM	--	0.5	--	%
EN, PS/SYNC Input Voltage Logic-High	V_{IH}		1.2	--	--	V
EN, PS/SYNC Input Voltage Logic-Low	V_{IL}		--	--	0.4	V
PS/SYNC Input Current	$I_{PS/SYNC}$		--	0.1	1	μA
EN Pull-Low Resistance	R_{PL_EN}		--	150	--	kΩ
PG Output Low Voltage	V_{PG_L}	V_{OUT} = 3.3V, I_{PG_L} = 10μA	--	0.04	0.4	V
PG Output Leakage Current	$I_{_LK_PG}$		--	0.01	0.1	μA
Output Overvoltage Protection	V_{OVP}		--	6.2	--	V
Over-Temperature Protection	T_{OTP}		--	160	--	°C
Over-Temperature Protection Hysteresis	T_{OTP_HYS}		--	30	--	°C

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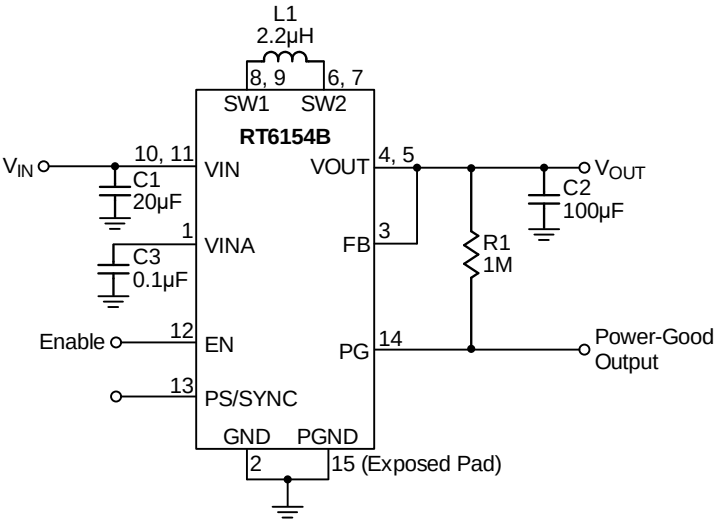
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13 Typical Application Circuit

13.1 RT6154A (Adjustable Output Voltage)



13.2 RT6154B (Fixed 3.3V Output Voltage)

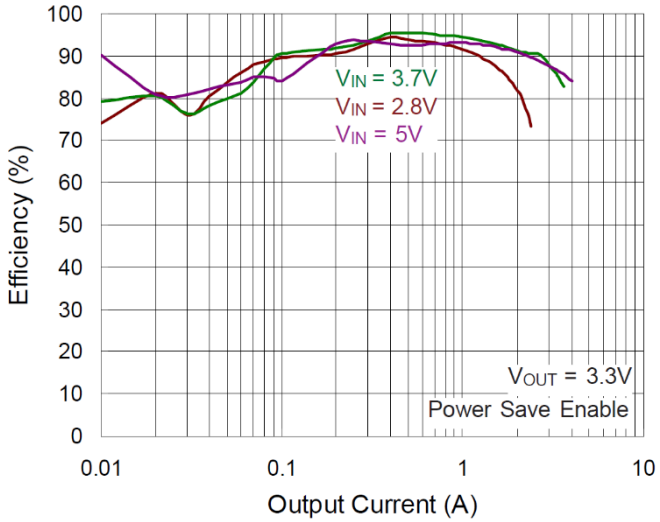


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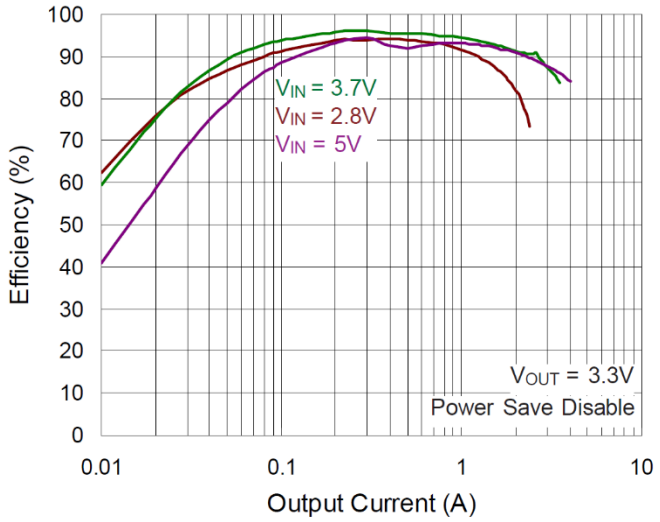
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14 Typical Operating Characteristics

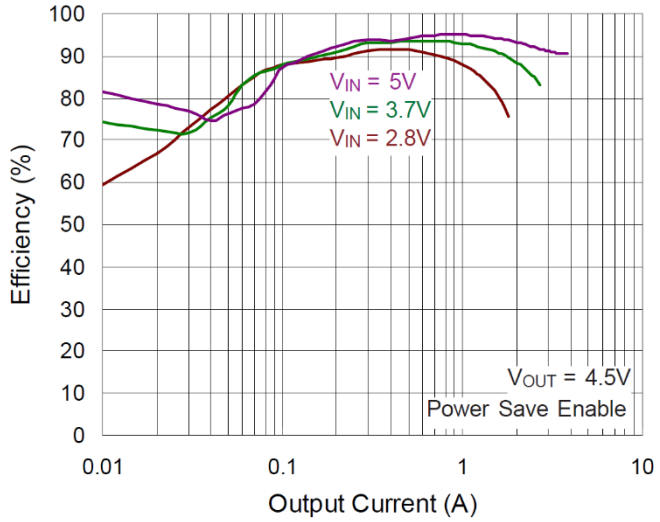
Efficiency vs. Output Current



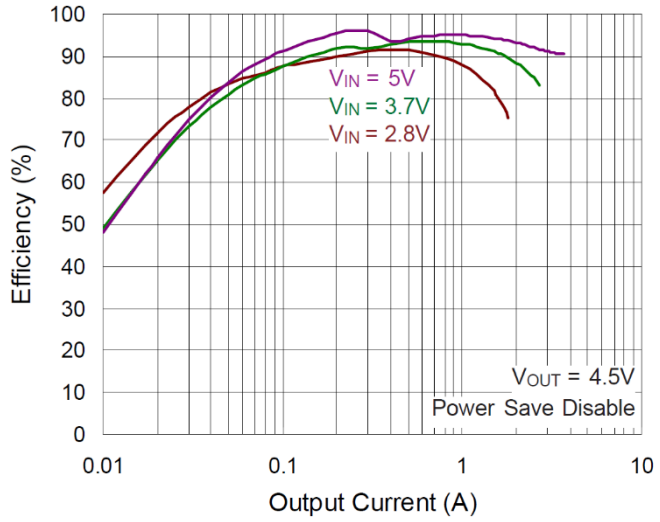
Efficiency vs. Output Current



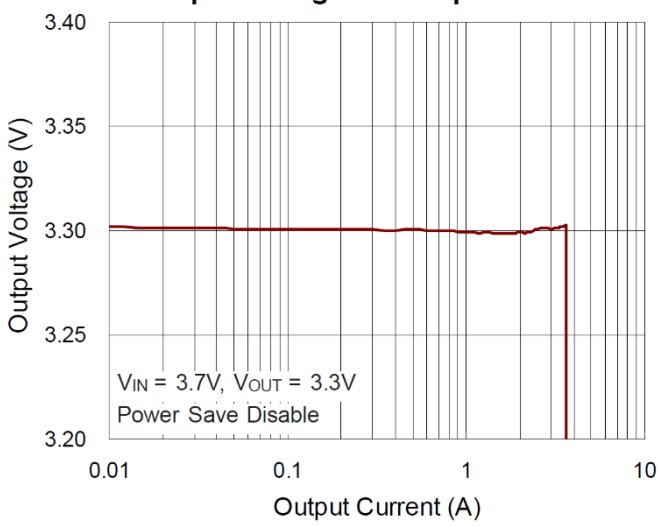
Efficiency vs. Output Current



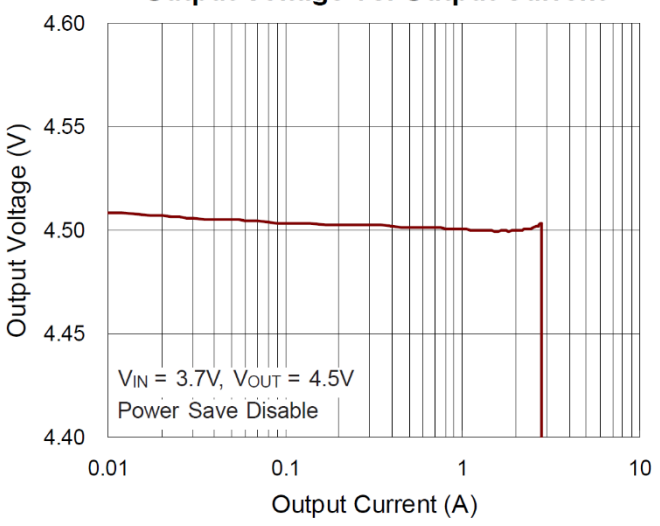
Efficiency vs. Output Current



Output Voltage vs. Output Current



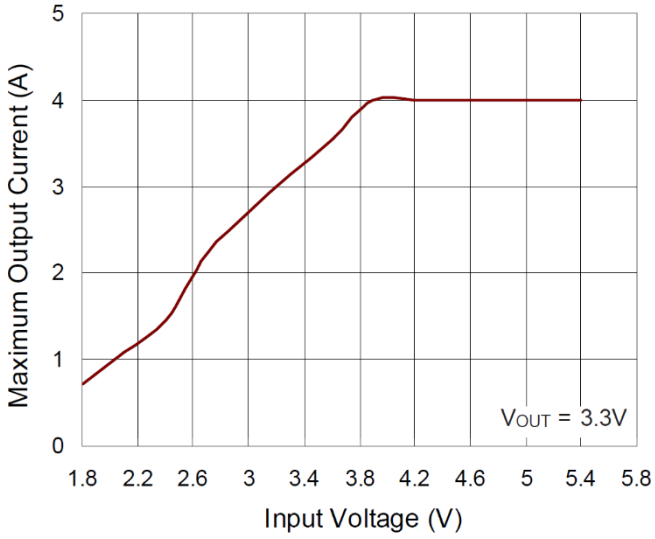
Output Voltage vs. Output Current



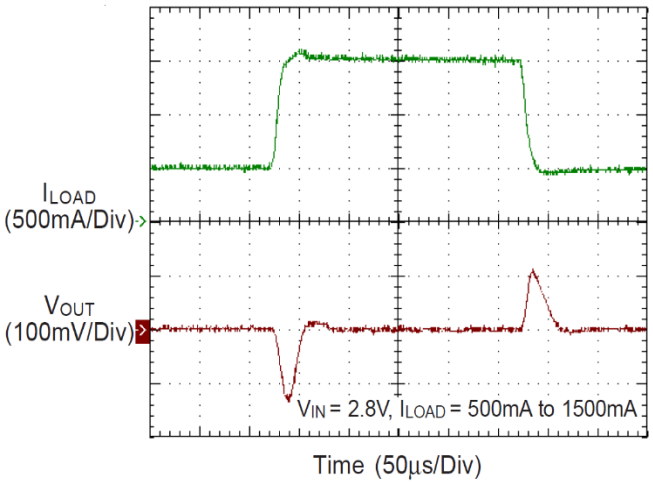
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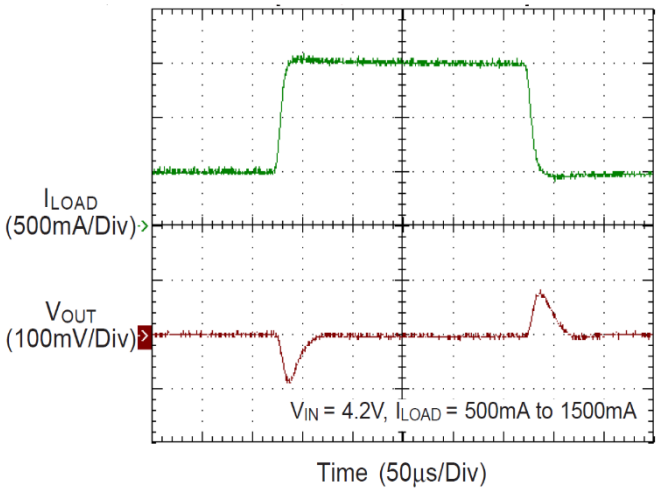
Maximum Output Current vs. Input Voltage



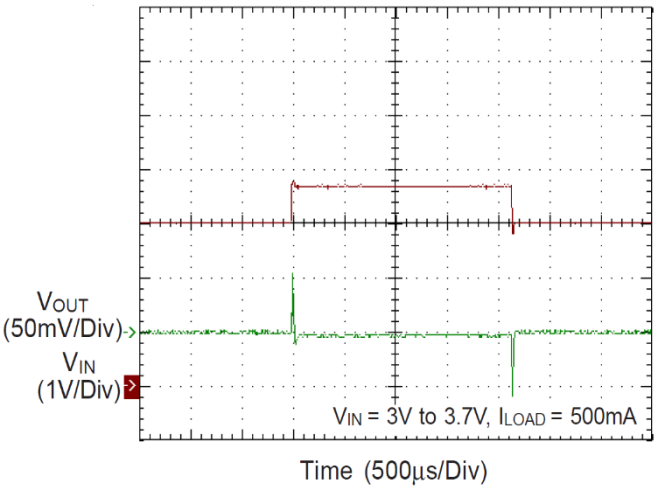
Load Transient Response



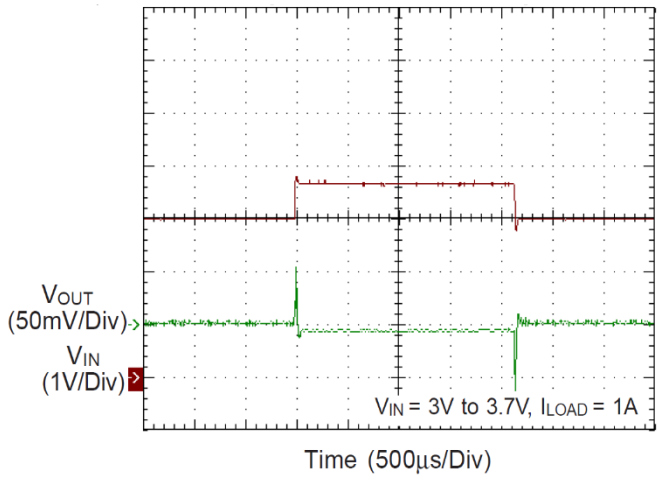
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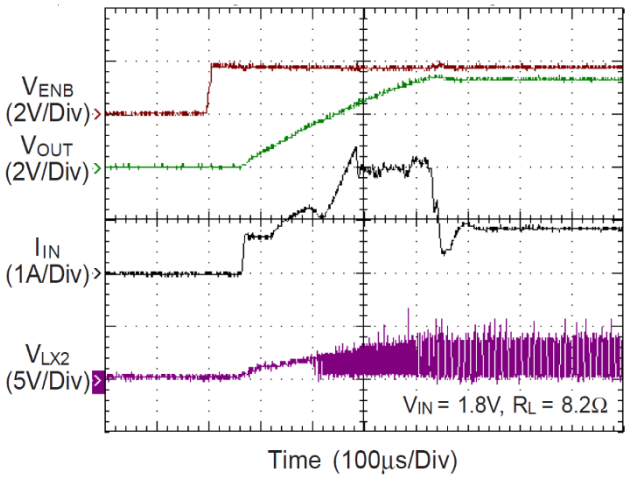
Line Transient Response



Line Transient Response



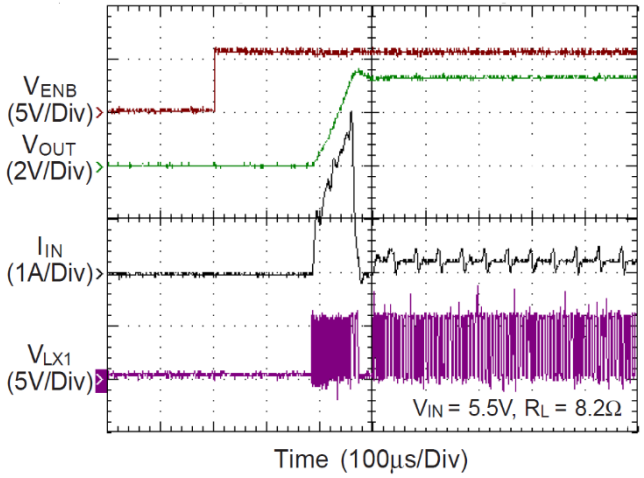
Startup After Enable



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15 Operation

The RT6154A/B is a synchronous current-mode switching buck-boost converter designed to provide an adjustable output voltage from an input supply that can be higher, equal to, or lower than 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 receives its feedback input from the FB pin. The output voltage of the RT6154A is adjustable and can be set by the external divider resistor value. For the RT6154B, the output voltage is fixed at 3.3V. When VIN is higher than VOUT, the device operates in buck mode. When VIN is lower than VOUT, the device operates in boost mode. When VIN is closed to VOUT, the RT6154A/B automatically enters either buck or boost mode. In that case, the converter will regulate the output voltage and maintain a minimum current ripple in the inductor to ensure good performance.

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16 Application Information

(Note 6)

The RT6154A/B Buck-Boost DC-DC converter can operate with a wide input voltage, such as a battery, which can be higher or lower than the output voltage, and it can supply a load current of up to 4A. The maximum peak current in the switches is limited to a typical value of 5A at V_{IN} = 3.6V and 2.6A at V_{IN} = 2.1V. The typical operating input voltage is between 1.8V and 5.5V. The RT6154A output voltage can be set from 1.8V to 5.5V by changing the external divider resistor on the FB pin. The RT6154B output voltage is fixed at 3.3V. The converter feedback loop is internally compensated for both buck and boost operations, providing seamless transition between buck and boost modes operation.

16.1 Enable

The device can be enabled or disabled by the EN pin. When the EN pin is higher than the logic-high threshold, the device starts operation with a soft-start. Once the EN pin is set to low, the device will shut down. In shutdown mode, the converter stops switching, the 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.

16.2 Output Voltage Setting

The RT6154A output voltage can be set from 1.8V to 5.5V by changing the external divider resistor on the FB pin. The RT6154B output voltage is fixed at 3.3V. When using the adjustable output voltage version, the resistor divider must be connected between VOUT, FB and GND. The typical voltage at the FB pin is 500mV and the RT6154A output voltage can be set from 1.8V to 5.5V. It is recommended to keep the resistor R2 value in the range of 200kΩ. The value of the resistors connected to the FB pin can be derived from the following equation:

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

16.3 Power-Good Function

The RT6154A/B has a built-in power-good function on the PG pin to indicate whether the output voltage is regulated properly. The PG pin output is an open-drain, so the logic level can be adjusted to any voltage level by connecting a pull-up resistor to the supply voltage. When the output voltage is regulated properly, the PGOOD pin will switch to high impedance, and the voltage will go high. When the output voltage is not regulated properly, the PG pin switches to low impedance, and the voltage will go low.

16.4 Power Save Mode and Synchronization

The PS/SYNC pin can be used to select different operation modes. Pulling the PS/SYNC pin low enters power save mode to improve efficiency. In this mode, the average inductor current reduces to approximately 400mA. The switching frequency will be lower, and the quiescent current will be small to maintain high efficiency. When the load increases above the minimum forced inductor current of about 400mA, the device will automatically switch to PWM mode. The power save mode can be disabled by pulling the PS/SYNC pin high. Connecting a clock signal to the PS/SYNC pin forces the RT6154A/B switching frequency to synchronize with the connected clock frequency. The PS/SYNC input supports standard logic thresholds, and the frequency range is between 2.2MHz to 2.6MHz.

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16.5 Dynamic Current Limit

To protect the device, the peak inductor current is limited internally within the IC. Under nominal operating conditions, this current limit is constant. The current limit value can be found in the electrical characteristics table. If the supply voltage at VIN drops below 2.3V, the current limit is reduced. This might happen when the batteries are almost discharged, or a heavy pulse load causes the VIN voltage to drop. The dynamic current limit has a minimum value while reaching the recommended supply voltage at the VIN pin.

16.6 Soft-Start and Short Circuit Protection

After being enabled, the device starts operating. The current limit ramps up from 1A initially. The current limit will increase as the voltage rises. When the output voltage reaches about 1.2V, the current limit will increase to the nominal value. If the output voltage does not increase, the current limit will not increase either. There is no timer implemented. Thus, the output voltage overshoot at startup, as well as the inrush current, is kept to a minimum. The device ramps up the output voltage in a controlled manner even if a large capacitor is connected at the output. When the output voltage does not rise higher than 1.2V, the device will regard it as a short circuit at the output and keep the current limit low to protect itself and the application. If the output pin is shorted to ground during operation, the current limit will also decrease accordingly.

16.7 Protection

Additional protections of the RT6154A/B include current limit protection, output overvoltage protection, and over-temperature protection. To protect the device from overheating, it 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 130°C, it will restart operation. The built-in hysteresis is designed to avoid unstable operation at IC temperatures near the over-temperature threshold.

16.8 Undervoltage-Lockout

The undervoltage-lockout circuit prevents the device from operating incorrectly at low input voltage. It prevents the converter from turning on the power switches under undefined conditions and protects the battery from deep discharge. The VIN voltage must be greater than 1.7V to enable the converter. During operation, if the VIN voltage drops below 1.6V, the converter will be disabled. The RT6154A/B will automatically restart if the input voltage recovers to a level higher than the UVLO rising threshold.

16.9 Inductor Selection

To properly configure the buck-boost converter, an inductor must be connected between the SW1 and SW2 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. A suitable inductor value is 2.2μH for generating a 3.3V output voltage from a Li-Ion battery ranging 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 conditions.

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Table 1. Inductor Suggestion

Vendor	Inductor Series
Taiyo Yuden	LSEUB4040WKT2R2MJ

16.10 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 the application requires large capacitors that cannot be placed close to the IC, using a small ceramic capacitor in parallel with 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 shown below:

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

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

If the RT6154A/B operates in buck mode, the largest voltage ripple occurs at the highest input voltage. When the RT6154A/B operates in boost mode, the largest voltage ripple occurs at the lowest input voltage.

The overshoot peak or undershoot valley is inversely proportional to the value of the output capacitor. To ensure stability and excellent transient response, it is recommended to use at least 100μF X7R capacitors at the output. For surface mount applications, Taiyo Yuden or TDK ceramic capacitors, X7R series multi-layer ceramic capacitor are recommended.

A capacitor with a value larger than the calculated minimum should be used. This is required to maintain control loop stability. There is no additional requirement 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.

16.11 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 WDFN-14AL 4x3 package, the thermal resistance, θ_{JA}, is 28.6°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) / (28.6°C/W) = 3.49W for a WDFN-14AL 4x3 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 curve in Figure 1 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

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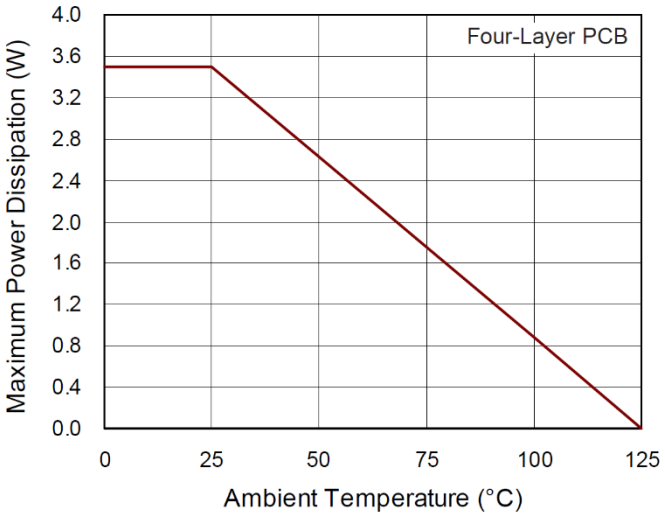


Figure 1. Derating Curve of Maximum Power Dissipation

16.12 Layout Considerations

For the best performance, the following PCB layout guidelines must be strictly followed:

- Place the input and output capacitors as closed as possible to the input and output pins.
- Keep the main power traces as wide and short as possible.
- Connect the GND and exposed pad to a large ground plane for maximum thermal dissipation and noise protection.
- The switch node has high-frequency voltage swings and should be kept in a small area. Keep analog components away from the switch node to prevent stray capacitive noise pick-up.

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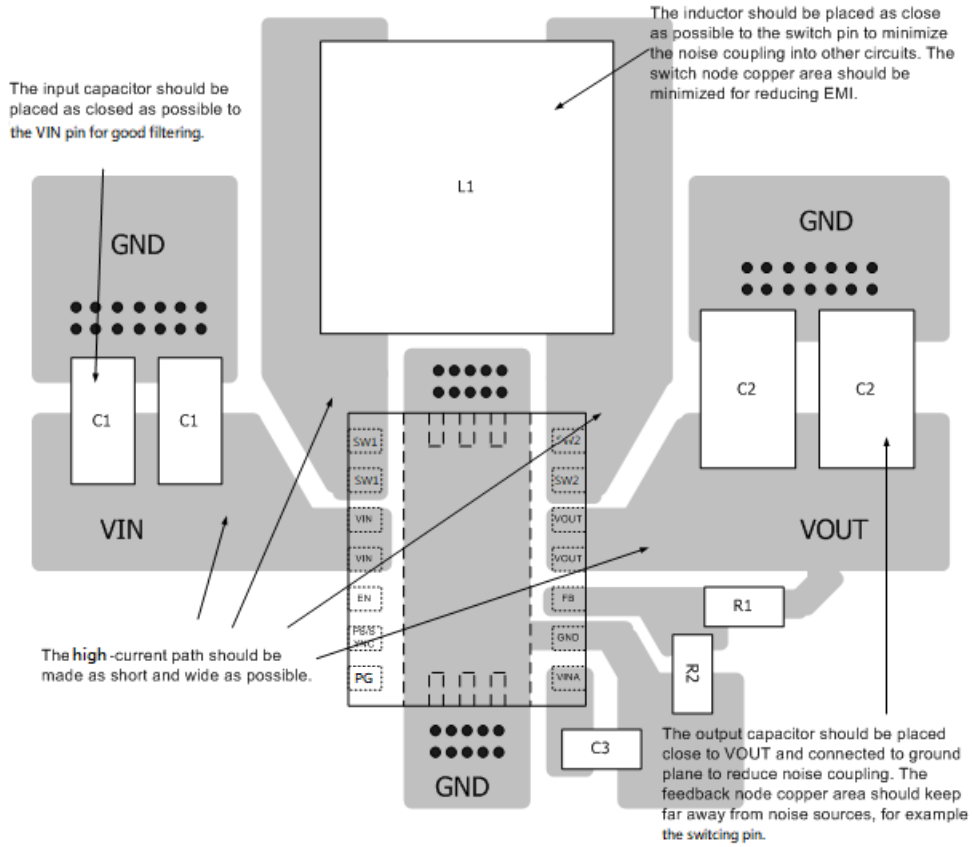


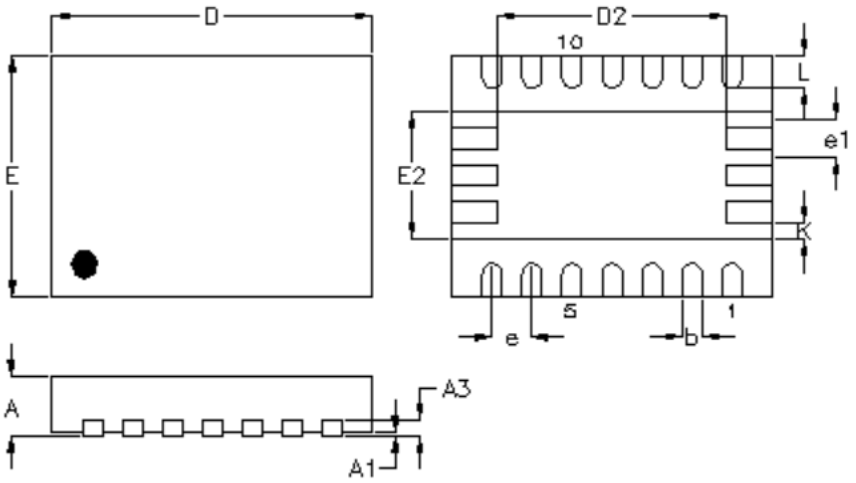
Figure 2. PCB Layout Guide

Note 6. The information provided in this section is for reference only. The customer is solely responsible for designing, validating, and testing any applications incorporating Richtek's product(s). The customer is also responsible for applicable standards and any safety, security, or other requirements.

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17 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.

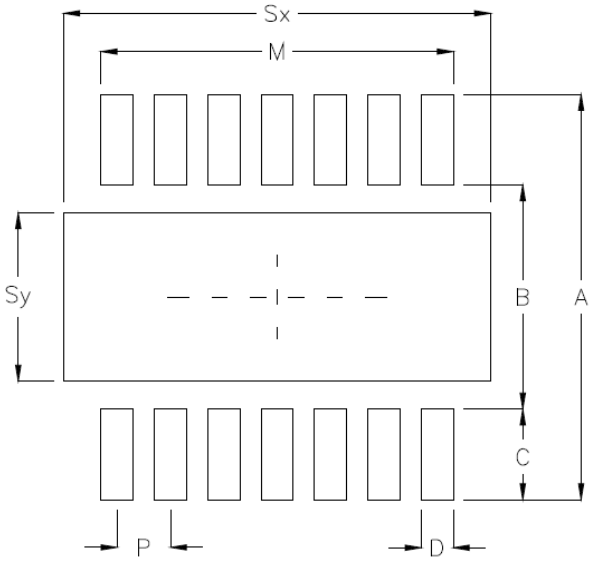
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.200	0.300	0.008	0.012
D	3.900	4.100	0.154	0.161
D2	2.800	2.900	0.110	0.114
E	2.900	3.100	0.114	0.122
E2	1.530	1.630	0.060	0.064
e	0.500		0.020	
e1	0.460		0.018	
K	0.150	0.250	0.006	0.010
L	0.350	0.450	0.014	0.018

W-Type 14AL DFN 4x3 Package

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18 Footprint Information



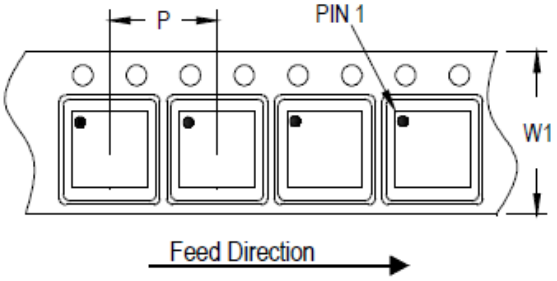
Package	Number of Pin	Footprint Dimension (mm)								Tolerance
		P	A	B	C	D	Sx	Sy	M	
V/W/U/XDFN4x3-14A	14	0.50	3.80	2.10	0.85	0.30	4.00	1.58	3.30	±0.05

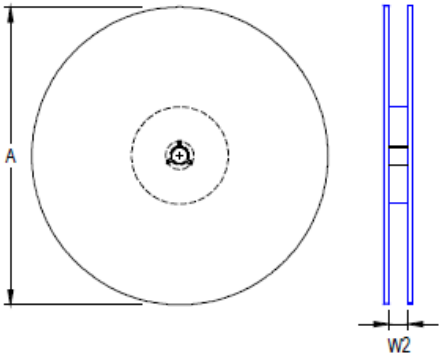
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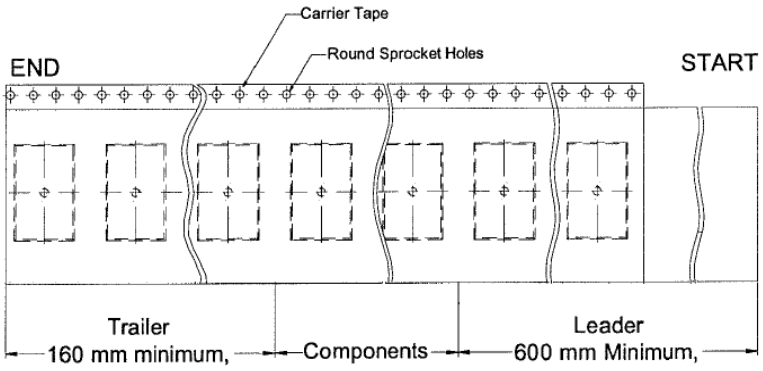
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19 Packing Information

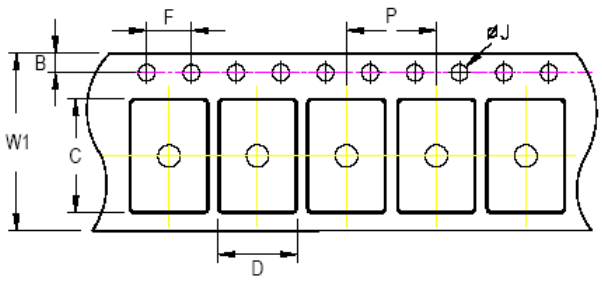
19.1 Tape and Reel Data







Package Type	Tape Size (W1) (mm)	Pocket Pitch (P) (mm)	Reel Size (A)		Units per Reel	Trailer (mm)	Leader (mm)	Reel Width (W2) Min/Max (mm)
			(mm)	(in)				
(V, W) QFN/DFN 4x3	12	8	180	7	1,500	160	600	12.4/14.4



C, D, and K are determined by component size. The clearance between the components and the cavity is as follows:

- For 12mm carrier tape: 0.5mm max.

Tape Size	W1	P		B		F		ØJ		K		H
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Max
12mm	12.3mm	7.9mm	8.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	1.0mm	1.3mm	0.6mm

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19.2 Tape and Reel Packing

Step	Photo/Description	Step	Photo/Description
1	 Reel 7”	4	 3 reels per inner box **Box A**
2	 HIC & Desiccant (1 Unit) inside	5	 12 inner boxes per outer box
3	 Caution label is on backside of Al bag	6	 Outer box **Carton A**

Container / Package	Reel		Box			Carton		
	Size	Units	Item	Reels	Units	Item	Boxes	Unit
(V, W) QFN & DFN 4x3	7”	1,500	Box A	3	4,500	Carton A	12	54,000
			Box E	1	1,500	For Combined or Partial Reel.		

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19.3 Packing Material Anti-ESD Property

Surface Resistance	Aluminum Bag	Reel	Cover tape	Carrier tape	Tube	Protection Band
Ω/cm^2	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**

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20 Datasheet Revision History

Version	Date	Description	Item
04	2023/6/8	Modify	Note 3 on P6 Application Information on P11, 12 Footprint Information on P16 Packing Information on P17, 18, 19
05	2024/11/13	Modify	*Changed the names of pin 6 and pin 7 to SW2, pin 8 and pin 9 to SW1, and pin 14 to PG.* *General Description on page 1* - Added Temperature range *Applications on page 1* - Updated applications *Ordering Information on page 2* - Added note Absolute Maximum Ratings on page 6 - Updated description *Electrical Characteristics on page 7* - Updated description and symbol *Application Information on page 17* - Modified declaration *Packing Information on page 20, 21* - Updated packing information

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