1.25MHz, 600mA, High Efficiency PWM Step-Down DC/DC Converter

General Description

The RT8009 is a high-efficiency pulse-width-modulated (PWM) step-down DC/DC converter. Capable of delivering 600mA output current over a wide input voltage range from 2.5 to 5.5V, the RT8009 is ideally suited for portable electronic devices that are powered from 1-cell Li-ion battery or from other power sources within the range such as cellular phones, PDAs and handy-terminals.

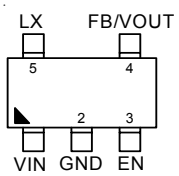
Internal synchronous rectifier with low $R_{DS(ON)}$ dramatically reduces conduction loss at PWM mode. No external Schottky diode is required in practical application. The RT8009 automatically turns off the synchronous rectifier while the inductor current is low and enters discontinuous PWM mode. This can increase efficiency at light load condition.

The RT8009 enters Low-Dropout mode when normal PWM cannot provide regulated output voltage by continuously turning on the upper P-MOSFET. RT8009 enter shutdown mode and consumes less than 0.1μA when EN pin is pulled low.

The switching ripple is easily smoothed-out by small package filtering elements due to a fixed operation frequency of 1.25MHz. This along with small SOT-23-5 and TSOT-23-5 package provides small PCB area application. Other features include soft start, lower internal reference voltage with 2% accuracy, over temperature protection, and over current protection.

Pin Configurations

(TOP VIEW)



SOT-23-5/TSOT-23-5

Marking Information

For marking information, contact our sales representative directly or through a Richtek distributor located in your area.

Features

- **2.5V to 5.5V Input Range**
- **Adjustable Output From 0.5V to V_{IN}**
- **1.0V, 1.2V, 1.3V, 1.5V, 1.8V, 2.5V and 3.3V Fixed/ Adjustable Output Voltage**
- **600mA Output Current**
- **95% Efficiency**
- **No Schottky Diode Required**
- **1.25MHz Fixed Frequency PWM Operation**
- **Small SOT-23-5 and TSOT-23-5 Package**
- **RoHS Compliant and 100% Lead (Pb)-Free**

Applications

- Cellular Telephones
- Personal Information Appliances
- Wireless and DSL Modems
- MP3 Players
- Portable Instruments

Ordering Information

RT8009(-□□)□□

Package Type
B : SOT-23-5
J5 : TSOT-23-5

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

Output Voltage
Default : Adjustable
10 : 1.0V
12 : 1.2V
13 : 1.3V
15 : 1.5V
18 : 1.8V
25 : 2.5V
33 : 3.3V

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.

Typical Application Circuit

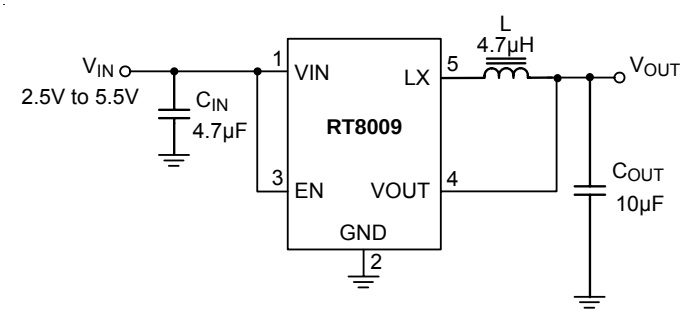
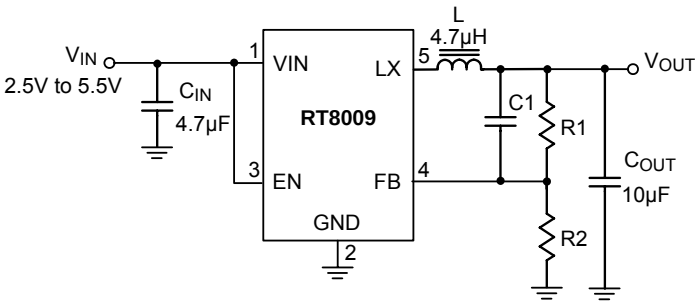


Figure 1. Fixed Voltage Regulator



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

with $R1 + R2 \leq 1M\Omega$ and

$V_{REF(Typ.)} = 0.5V$

Figure 2. Adjustable Voltage Regulator

Layout Guide

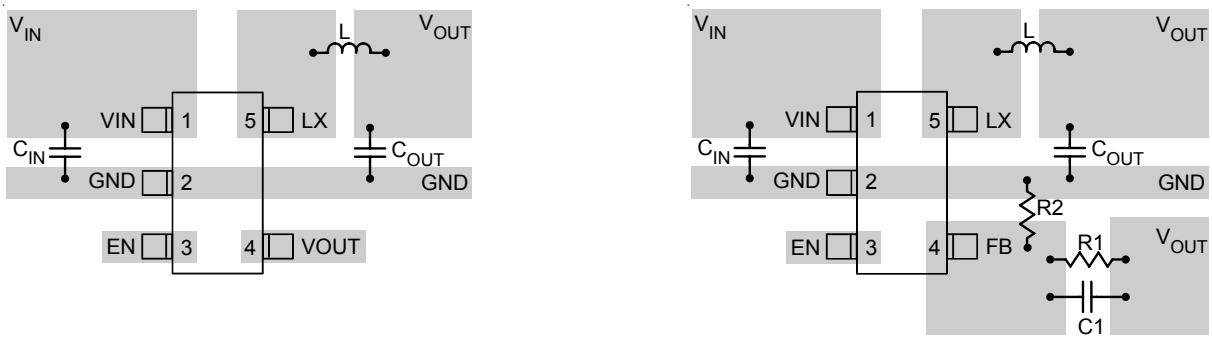


Figure 3

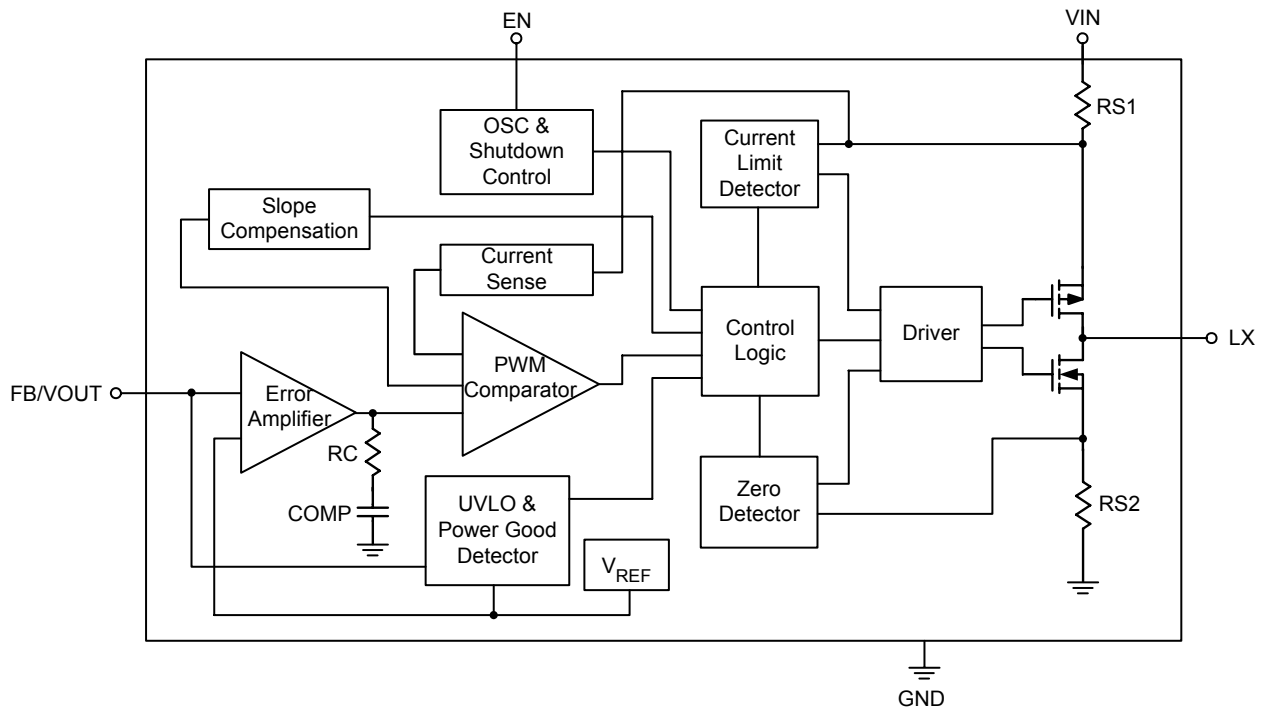
Layout note:

1. The distance that C_{IN} connects to V_{IN} is as close as possible (Under 2mm).
2. C_{OUT} should be placed near RT8009.

Functional Pin Description

Pin Number	Pin Name	Pin Function
1	VIN	Power Input.
2	GND	Ground.
3	EN	Chip Enable (Active High, do not leave EN pin floating, and V_{EN} < V_{IN} + 0.6V).
4	FB/VOUT	Feedback Input Pin.
5	LX	Pin for Switching.

Function Block Diagram



Absolute Maximum Ratings (Note 1)

- Supply Input Voltage ---------- 6.5V
- Enable, FB Voltage ---------- V_{IN} + 0.6V
- Power Dissipation, P_D @ T_A = 25°C
  SOT-23-5, TSOT-23-5 ---------- 0.4W
- Package Thermal Resistance (Note 2)
  SOT-23-5, TSOT-23-5, θ_{JA} ---------- 250°C/W
  SOT-23-5, TSOT-23-5, θ_{JC} ---------- 130°C/W
- Junction Temperature Range ---------- 150°C
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 3)
  HBM (Human Body Mode) ---------- 2kV
  MM (Machine Mode) ---------- 200V

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, V_{OUT} = 2.5V, V_{REF} = 0.5V, L = 4.7µH, C_{IN} = 4.7µF, C_{OUT} = 10µF, T_A = 25°C, I_{MAX} = 600mA unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Input Voltage Range		V_{IN}		2.5	--	5.5	V
Quiescent Current		I_Q	I_{OUT} = 0mA, V_{FB} = V_{REF} + 5%	--	50	100	µA
Shutdown Current		I_{SHDN}	EN = GND	--	0.1	1	µA
Reference Voltage		V_{REF}	For adjustable output voltage	0.49	0.5	0.51	V
Adjustable Output Range		V_{OUT}		V_{REF}	--	V_{IN} – 0.2	V
Output Voltage Accuracy	Fix	ΔV_{OUT}	V_{IN} = 2.5 to 5.5V, V_{OUT} = 1.0V 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = 2.5 to 5.5V, V_{OUT} = 1.2V 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = 2.5 to 5.5V, V_{OUT} = 1.3V 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = 2.5 to 5.5V, V_{OUT} = 1.5V 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = 2.5 to 5.5V, V_{OUT} = 1.8V 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = V_{OUT} + ΔV to 5.5V (Note 5) V_{OUT} = 2.5V, 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = V_{OUT} + ΔV to 5.5V (Note 5) V_{OUT} = 3.3V, 0A < I_{OUT} < 600mA	–3	--	3	%
		ΔV_{OUT}	V_{IN} = V_{OUT} + 0.2V to 5.5V 0A < I_{OUT} < 600mA	–3	--	3	%

To be continued

Parameter		Symbol	Test Conditions		Min	Typ	Max	Unit
Output Voltage Accuracy	Adjustable	ΔV_{OUT}	V_{IN} = V_{OUT} + ΔV to 5.5V (Note 5) 0A < I_{OUT} < 600mA		−3	--	3	%
FB Input Current		I_{FB}	V_{FB} = V_{IN}		−50	--	50	nA
$R_{DS(ON)}$ of P-Channel MOSFET		$R_{DS(ON)_P}$	I_{OUT} = 200mA	V_{IN} = 3.6V	--	0.3	0.65	Ω
				V_{IN} = 2.5V	--	0.4	0.80	
$R_{DS(ON)}$ of N-Channel MOSFET		$R_{DS(ON)_N}$	I_{OUT} = 200mA	V_{IN} = 3.6V	--	0.25	0.55	Ω
				V_{IN} = 2.5V	--	0.35	0.65	
P-Channel Current Limit		I_{LIM_P}	V_{IN} = 2.5V to 5.5 V		1	--	1.8	A
EN High-Level Input Voltage		V_{EN_H}	V_{IN} = 2.5V to 5.5V		1.5	--	--	V
EN Low-Level Input Voltage		V_{EN_L}	V_{IN} = 2.5V to 5.5V		--	--	0.4	V
Under Voltage Lockout Threshold					--	1.8	--	V
Hysteresis					--	0.1	--	V
Oscillator Frequency		f_{OSC}	V_{IN} = 3.6V, I_{OUT} = 100mA		0.8	1.25	1.85	MHz
Thermal Shutdown Temperature		T_{SD}			--	160	--	°C
Min. On Time					--	50	--	ns
Max. Duty Cycle					100	--	--	%
LX Leakage Current			V_{IN} = 3.6V, V_{LX} = 0V or V_{LX} = 3.6V		−1	--	1	μA

Note 1. Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. 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 remain possibility to affect device reliability.

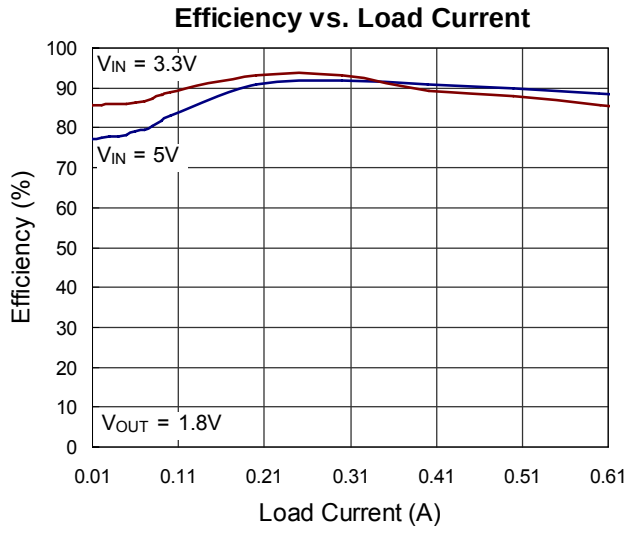
Note 2. θ_{JA} is measured in the natural convection at T_A = 25°C on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

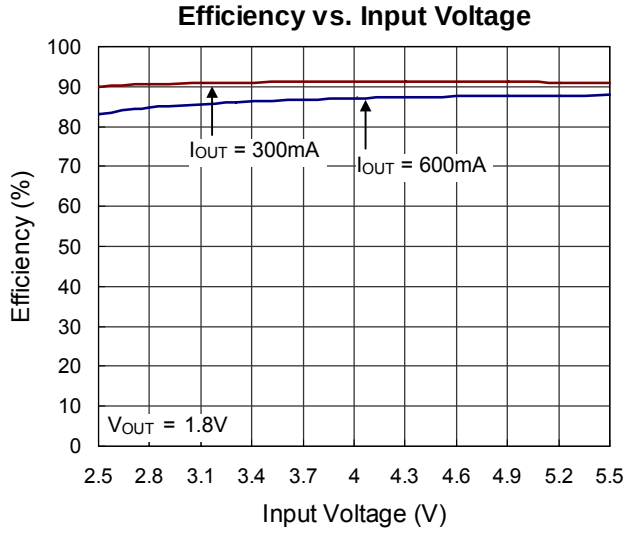
Note 3. Devices are ESD sensitive. Handling precaution recommended.

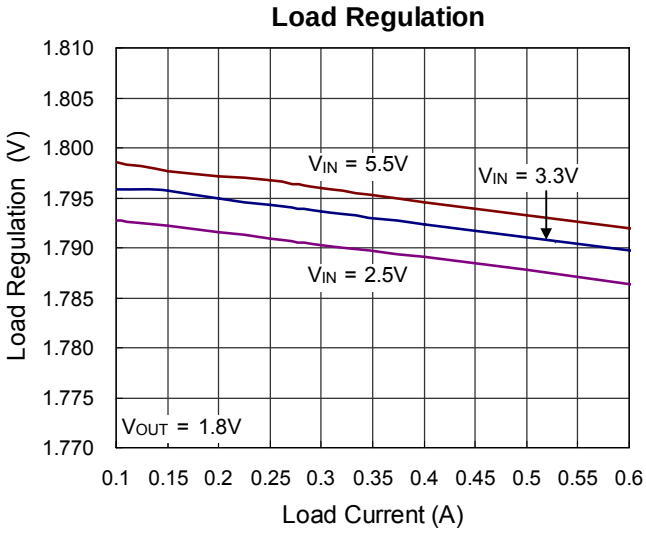
Note 4. The device is not guaranteed to function outside its operating conditions.

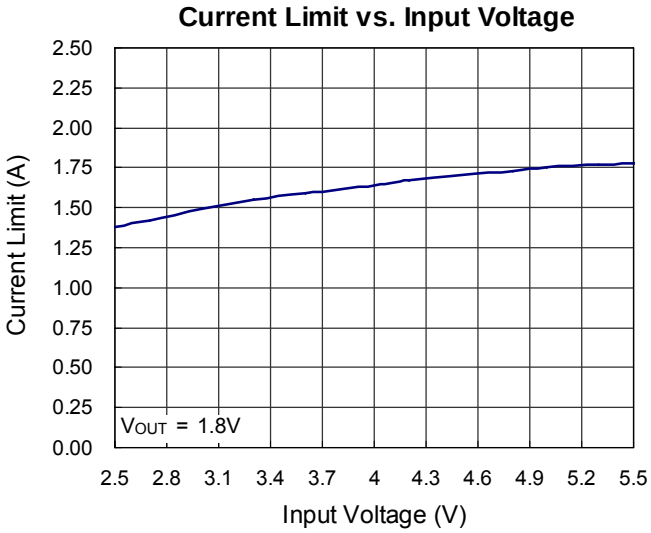
Note 5. $\Delta V = I_{OUT} \times R_{DS(ON)_P}$

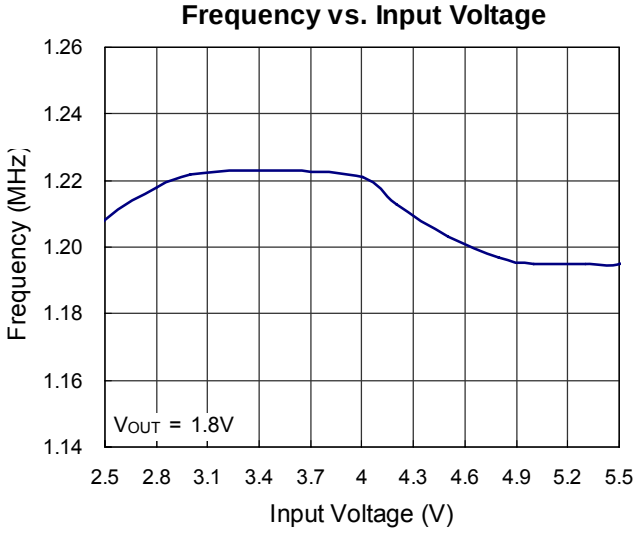
Typical Operating Characteristics

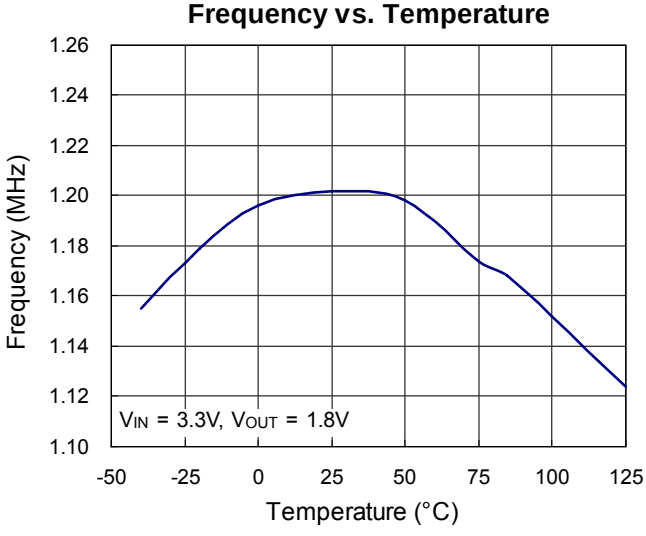




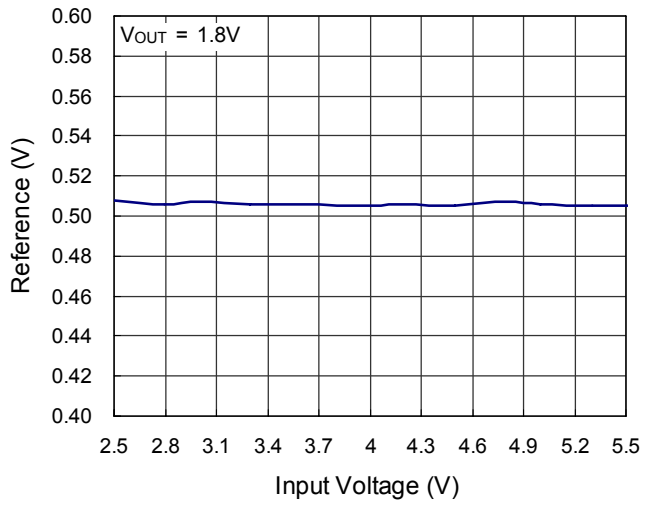




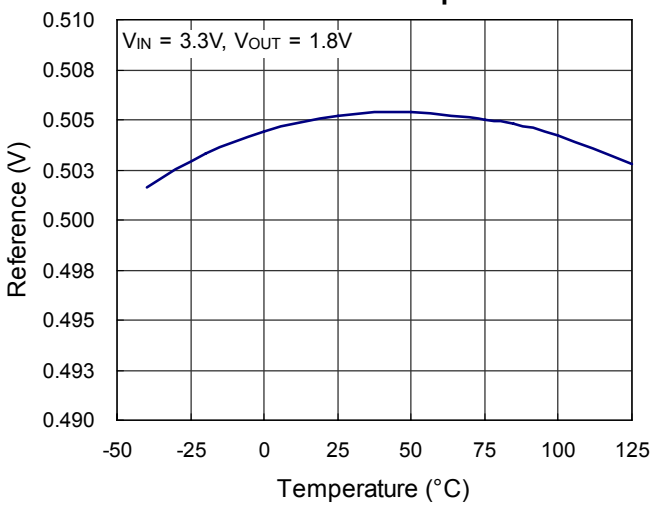




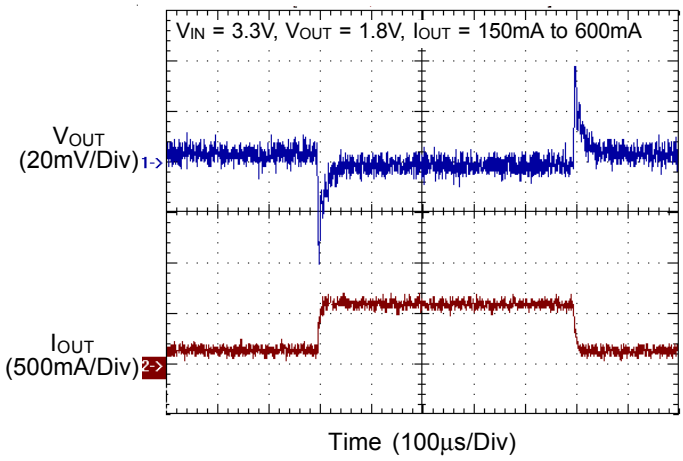
Reference vs. Input Voltage



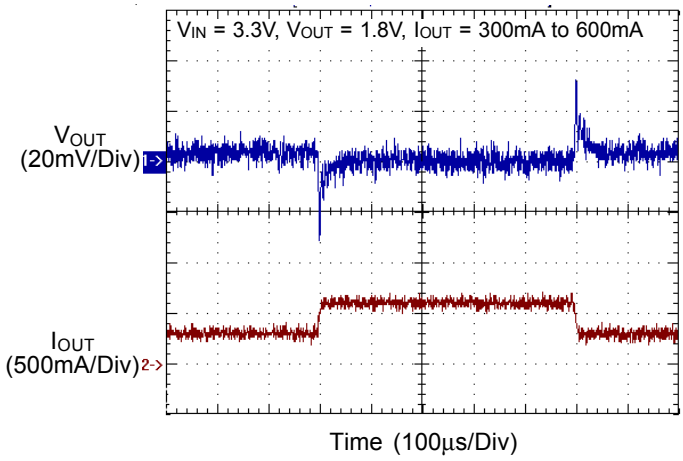
Reference vs. Temperature



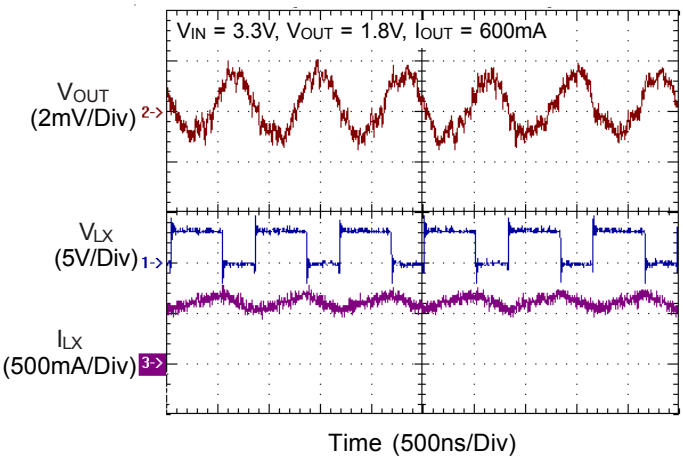
Load Transient Response



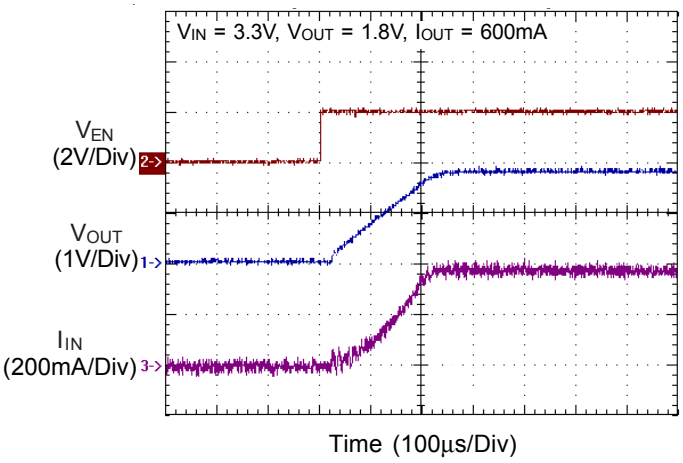
Load Transient Response



Output Ripple



Power On



Applications Information

The basic RT8009 application circuit is shown in Typical Application Circuit. External component selection is determined by the maximum load current and begins with the selection of the inductor value and operating frequency followed by C_{IN} and C_{OUT}.

Inductor Selection

For a given input and output voltage, the inductor value and operating frequency determine the ripple current. The ripple current ΔI_L increases with higher V_{IN} and decreases with higher inductance.

$$\Delta I_L = \left[\frac{V_{OUT}}{f \times L}\right]\left[1-\frac{V_{OUT}}{V_{IN}}\right]$$

Having a lower ripple current reduces the ESR losses in the output capacitors and the output voltage ripple. Highest efficiency operation is achieved at low frequency with small ripple current. This, however, requires a large inductor.

A reasonable starting point for selecting the ripple current is $\Delta I_L = 0.4(I_{MAX})$. The largest ripple current occurs at the highest V_{IN}. To guarantee that the ripple current stays below a specified maximum, the inductor value should be chosen according to the following equation :

$$L = \left[\frac{V_{OUT}}{f \times \Delta I_{L(MAX)}}\right]\left[1-\frac{V_{OUT}}{V_{IN(MAX)}}\right]$$

Inductor Core Selection

Once the value for L is known, the type of inductor must be selected. High efficiency converters generally cannot afford the core loss found in low cost powdered iron cores, forcing the use of more expensive ferrite or mollypermalloy cores. Actual core loss is independent of core size for a fixed inductor value but it is very dependent on the inductance selected. As the inductance increases, core losses decrease. Unfortunately, increased inductance requires more turns of wire and therefore copper losses will increase.

Ferrite designs have very low core losses and are preferred at high switching frequencies, so design goals can concentrate on copper loss and preventing saturation. Ferrite core material saturates “hard”, which means that inductance collapses abruptly when the peak design current is exceeded. This results in an abrupt increase in inductor ripple current and consequent output voltage ripple. Do not allow the core to saturate!

Different core materials and shapes will change the size/current and price/current relationship of an inductor.

Toroid or shielded pot cores in ferrite or permalloy materials are small and don’ t radiate energy but generally cost more than powdered iron core inductors with similar characteristics. The choice of which style inductor to use mainly depends on the price vs size requirements and any radiated field/EMI requirements.

C_{IN} and C_{OUT} Selection

The input capacitance, C_{IN}, is needed to filter the trapezoidal current at the source of the top MOSFET. To prevent large ripple voltage, a low ESR input capacitor sized for the maximum RMS current should be used. RMS current is given by :

$$I_{RMS} = I_{OUT(MAX)}\frac{V_{OUT}}{V_{IN}}\sqrt{\frac{V_{IN}}{V_{OUT}}-1}$$

This formula has a maximum at $V_{IN} = 2V_{OUT}$, where $I_{RMS} = I_{OUT}/2$. This simple worst-case condition is commonly used for design because even significant deviations do not offer much relief. Note that ripple current ratings from capacitor manufacturers are often based on only 2000 hours of life which makes it advisable to further derate the capacitor, or choose a capacitor rated at a higher temperature than required. Several capacitors may also be paralleled to meet size or height requirements in the design.

The selection of C_{OUT} is determined by the effective series resistance (ESR) that is required to minimize voltage ripple and load step transients, as well as the amount of bulk capacitance that is necessary to ensure that the control loop is stable. Loop stability can be checked by viewing the load transient response as described in a later section. The output ripple, ΔV_{OUT}, is determined by :

$$\Delta V_{OUT} \leq \Delta I_L\left[ESR+\frac{1}{8fC_{OUT}}\right]$$

The output ripple is highest at maximum input voltage since ΔI_L increases with input voltage. Multiple capacitors placed in parallel may be needed to meet the ESR and RMS current handling requirements. Dry tantalum, special

polymer, aluminum electrolytic and ceramic capacitors are all available in surface mount packages. Special polymer capacitors offer very low ESR but have lower capacitance density than other types. Tantalum capacitors have the highest capacitance density but it is important to only use types that have been surge tested for use in switching power supplies. Aluminum electrolytic capacitors have significantly higher ESR but can be used in cost-sensitive applications provided that consideration is given to ripple current ratings and long term reliability. Ceramic capacitors have excellent low ESR characteristics but can have a high voltage coefficient and audible piezoelectric effects. The high Q of ceramic capacitors with trace inductance can also lead to significant ringing.

Using Ceramic Input and Output Capacitors

Higher values, lower cost ceramic capacitors are now becoming available in smaller case sizes. Their high ripple current, high voltage rating and low ESR make them ideal for switching regulator applications. However, care must be taken when these capacitors are used at the input and output. When a ceramic capacitor is used at the input and the power is supplied by a wall adapter through long wires, a load step at the output can induce ringing at the input, V_{IN}. At best, this ringing can couple to the output and be mistaken as loop instability. At worst, a sudden inrush of current through the long wires can potentially cause a voltage spike at V_{IN} large enough to damage the part.

Output Voltage Programming

The resistive divider allows the V_{FB} pin to sense a fraction of the output voltage as shown in Figure 4.

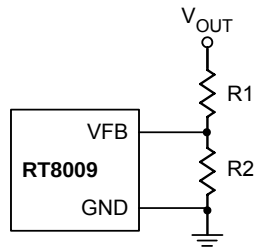


Figure 4. Setting the Output Voltage

For adjustable about voltage mode, the output voltage is set by an external resistive divider according to the following equation :

$$V_{OUT} = V_{REF}(1+\frac{R1}{R2})$$

where V_{REF} is the internal reference voltage (0.5V typ.)

Efficiency Considerations

The efficiency of a switching regulator is equal to the output power divided by the input power times 100%. It is often useful to analyze individual losses to determine what is limiting the efficiency and which change would produce the most improvement. Efficiency can be expressed as :

Efficiency = 100% – (L1+ L2+ L3+ ...)

where L1, L2, etc. are the individual losses as a percentage of input power. Although all dissipative elements in the circuit produce losses, two main sources usually account for most of the losses : VIN quiescent current and I^2R losses. The VIN quiescent current loss dominates the efficiency loss at very low load currents whereas the I^2R loss dominates the efficiency loss at medium to high load currents. In a typical efficiency plot, the efficiency curve at very low load currents can be misleading since the actual power lost is of no consequence.

1. The VIN quiescent current is due to two components : the DC bias current as given in the electrical characteristics and the internal main switch and synchronous switch gate charge currents. The gate charge current results from switching the gate capacitance of the internal power MOSFET switches. Each time the gate is switched from high to low to high again, a packet of charge ΔQ moves from V_{IN} to ground.

The resulting $\Delta Q/\Delta t$ is the current out of V_{IN} that is typically larger than the DC bias current. In continuous mode,

$I_{GATECHG} = f(Q_T+Q_B)$

where Q_T and Q_B are the gate charges of the internal top and bottom switches. Both the DC bias and gate charge losses are proportional to V_{IN} and thus their effects will be more pronounced at higher supply voltages.

2. I^2R losses are calculated from the resistances of the internal switches, R_{SW} and external inductor R_L. In continuous mode the average output current flowing through inductor L is “chopped” between the main switch and the synchronous switch. Thus, the series resistance looking into the LX pin is a function of both top and bottom MOSFET $R_{DS(ON)}$ and the duty cycle (DC) as follows :

$R_{SW} = R_{DS(ON)TOP} \times DC + R_{DS(ON)BOT} \times (1–DC)$

The $R_{DS(ON)}$ for both the top and bottom MOSFETs can be obtained from the Typical Performance Characteristics

curves. Thus, to obtain I^2R losses, simply add R_{SW} to R_L and multiply the result by the square of the average output current.

Other losses including C_{IN} and C_{OUT} ESR dissipative losses and inductor core losses generally account for less than 2% of the total loss.

Thermal Considerations

The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula :

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

Where $T_{J(MAX)}$ is the maximum operation junction temperature 125°C, T_A is the ambient temperature and the θ_{JA} is the junction to ambient thermal resistance.

For recommended operating conditions specification of RT8009 DC/DC converter, where $T_{J(MAX)}$ is the maximum junction temperature of the die (125°C) and T_A is the maximum ambient temperature. The junction to ambient thermal resistance θ_{JA} is layout dependent. For SOT-23-5/TSOT-23-5 packages, the thermal resistance θ_{JA} is 250°C/W on the standard JEDEC 51-3 single-layer thermal test board. The maximum power dissipation at T_A = 25°C can be calculated by following formula :

$P_{D(MAX)} = (125°C - 25°C) / 250 = 0.4$ W for SOT-23-5/ TSOT-23-5 packages

The maximum power dissipation depends on operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance θ_{JA}. For RT8009 packages, the Figure 5 of derating curves allows the designer to see the effect of rising ambient temperature on the maximum power allowed.

The value of junction to case thermal resistance θ_{JC} is popular for users. This thermal parameter is convenient for users to estimate the internal junction operated temperature of packages while IC operating. It's independent of PCB layout, the surroundings airflow effects and temperature difference between junction to ambient. The operated junction temperature can be calculated by following formula :

$T_J = T_C + P_D \times \theta_{JC}$

Where T_C is the package case (Pin 2 of package leads) temperature measured by thermal sensor, P_D is the power dissipation defined by user's function and the θ_{JC} is the junction to case thermal resistance provided by IC manufacturer. Therefore it's easy to estimate the junction temperature by any condition.

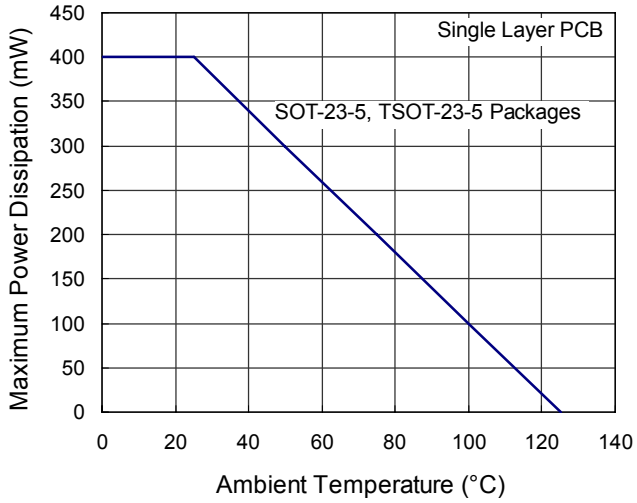


Figure 5. Derating Curves for RT8009 Package

Checking Transient Response

The regulator loop response can be checked by looking at the load transient response. Switching regulators take several cycles to respond to a step in load current. When a load step occurs, V_{OUT} immediately shifts by an amount equal to ΔI_{LOAD} (ESR), where ESR is the effective series resistance of C_{OUT}. ΔI_{LOAD} also begins to charge or discharge C_{OUT} generating a feedback error signal used by the regulator to return V_{OUT} to its steady-state value. During this recovery time, V_{OUT} can be monitored for overshoot or ringing that would indicate a stability problem.

Layout Considerations

Follow the PCB layout guidelines for optimal performance of RT8009.

- For the main current paths as indicated in bold lines in Figure 6 keep their traces short and wide.
- Put the input capacitor as close as possible to the device pins (VIN and GND).
- LX node is with high frequency voltage swing and should be kept small area. Keep analog components away from LX node to prevent stray capacitive noise pick-up.

- Connect feedback network behind the output capacitors. Keep the loop area small. Place the feedback components near the RT8009.
- Connect all analog grounds to a command node and then connect the command node to the power ground behind the output capacitors.
- An example of 2-layer PCB layout is shown in Figure 7 and Figure 8 for reference.

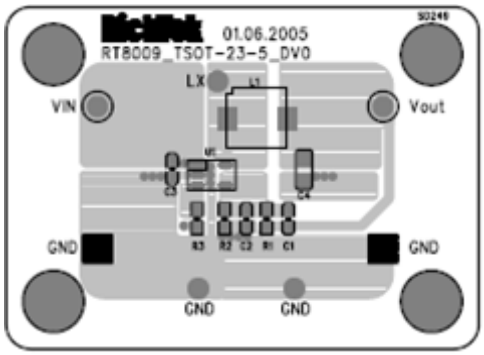


Figure 7. Top Layer

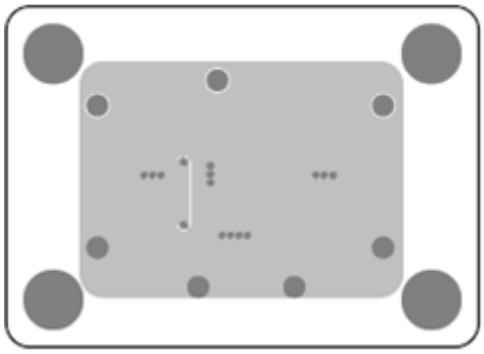


Figure 8. Bottom Layer

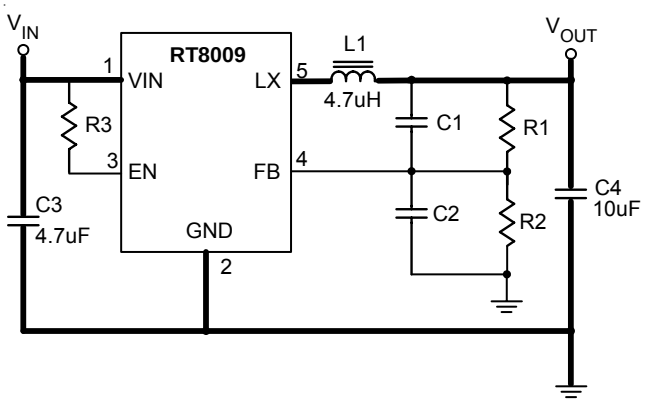


Figure 6. EVB Schematic

Recommended component selection for Typical Application

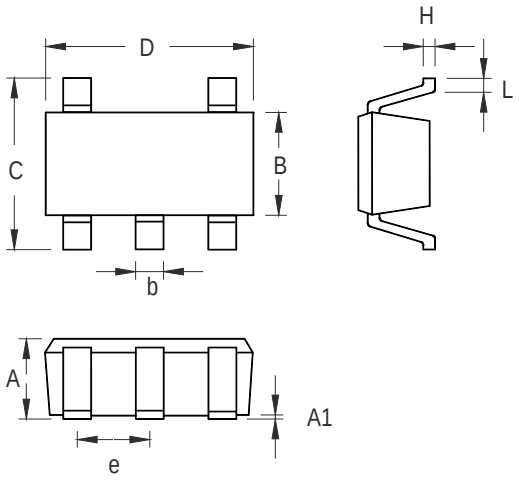
Table 1. Inductors

Component Supplier	Series	Inductance (µH)	DCR (mΩ)	Current Rating (mA)	Dimensions (mm)
TAIYO YUDEN	NR 3015	2.2	60	1480	3x3x1.5
TAIYO YUDEN	NR 3015	4.7	120	1020	3x3x1.5
Sumida	CDRH2D14	2.2	75	1500	4.5x3.2x1.55
Sumida	CDRH2D14	4.7	135	1000	4.5x3.2x1.55
GOTREND	GTSD32	2.2	58	1500	3.85x3.85x1.8
GOTREND	GTSD32	4.7	146	1100	3.85x3.85x1.8

Table 2. Capacitors for C_{IN} and C_{OUT}

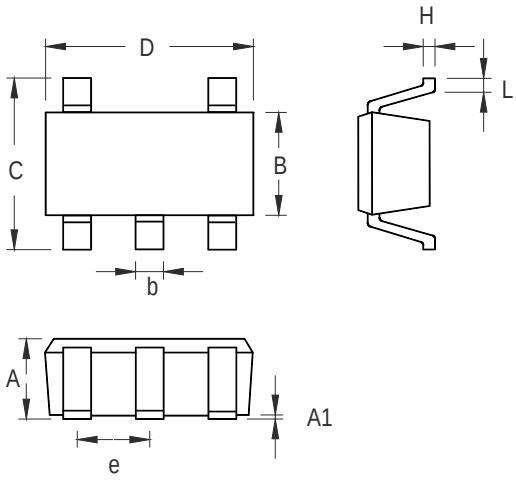
Component Supplier	Part No.	Capacitance (µF)	Case Size
TDK	C1608JB0J475M	4.7	0603
TDK	C2012JB0J106M	10	0805
MURATA	GRM188R60J475KE19	4.7	0603
MURATA	GRM219R60J106ME19	10	0805
MURATA	GRM219R60J106KE19	10	0805
TAIYO YUDEN	JMK107BJ475RA	4.7	0603
TAIYO YUDEN	JMK107BJ106MA	10	0603
TAIYO YUDEN	JMK212BJ106RD	10	0805

Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.889	1.295	0.035	0.051
A1	0.000	0.152	0.000	0.006
B	1.397	1.803	0.055	0.071
b	0.356	0.559	0.014	0.022
C	2.591	2.997	0.102	0.118
D	2.692	3.099	0.106	0.122
e	0.838	1.041	0.033	0.041
H	0.080	0.254	0.003	0.010
L	0.300	0.610	0.012	0.024

SOT-23-5 Surface Mount Package



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	1.000	0.028	0.039
A1	0.000	0.100	0.000	0.004
B	1.397	1.803	0.055	0.071
b	0.300	0.559	0.012	0.022
C	2.591	3.000	0.102	0.118
D	2.692	3.099	0.106	0.122
e	0.838	1.041	0.033	0.041
H	0.080	0.254	0.003	0.010
L	0.300	0.610	0.012	0.024

TSOT-23-5 Surface Mount Package

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