0.6A, 36V, 1.2MHz Step-Down Converter

General Description

The RT6200 is a high voltage Buck converter that can support the input voltage range from 4.5V to 36V and the output current can be up to 0.6A. Current mode operation provides fast transient response and eases loop stabilization.

The chip also provides protection functions such as cycle-by-cycle current limit and thermal shutdown protection. The RT6200 is available in the SOT-23-6 package.

Ordering Information

RT6200□□

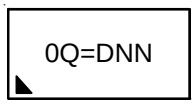
- Package Type
  E : SOT-23-6
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

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



0Q= : Product Code

DNN : Date Code

Features

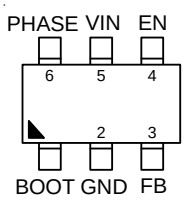
- **Wide Operating Input Voltage Range : 4.5V to 36V**
- **Adjustable Output Voltage Range : 0.8V to 15V**
- **0.6A Output Current**
- **0.35Ω Internal Power MOSFET Switch**
- **High Efficiency up to 95%**
- **1.2MHz Fixed Switching Frequency (Duty <90%)**
- **Support duty up to 95%**
- **Stable with Low ESR Output Ceramic Capacitors**
- **Thermal Shutdown**
- **Cycle-By-Cycle Over-Current Protection**

Applications

- Distributed Power Systems
- Battery Chargers
- Pre-Regulator for Linear Regulators
- WLED Drivers

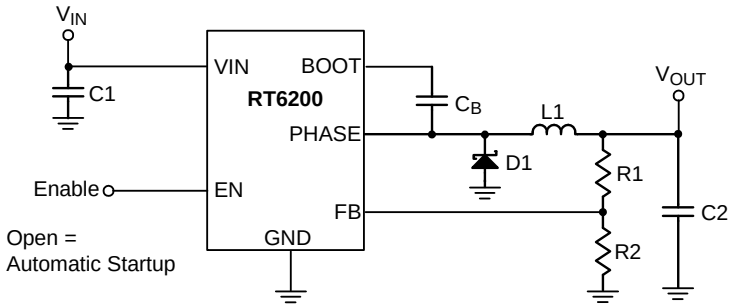
Pin Configurations

(TOP VIEW)



SOT-23-6

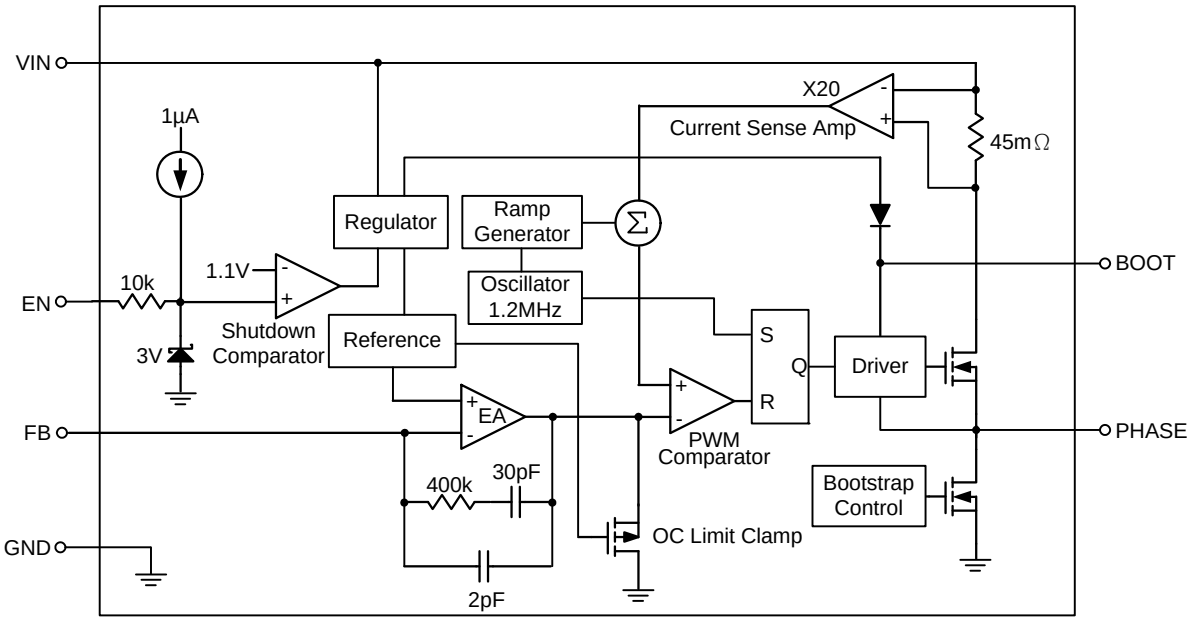
Simplified Application Circuit



Functional Pin Description

Pin No.	Pin Name	Pin Function
1	BOOT	Bootstrap Supply for High-Side Gate Driver. A capacitor is connected between the PHASE and BOOT pins to form a floating supply across the power switch driver. This capacitor is needed to drive the power switch's gate above the supply voltage.
2	GND	Ground. This pin is the voltage reference for the regulated output voltage. For this reason, care must be taken in its layout. This node should be placed outside of the D1 to C1 ground path to prevent switching current spikes from inducing voltage noise into the part.
3	FB	Feedback Voltage Input. An external resistor divider from the output to GND tapped to the FB pin sets the output voltage. The value of the divider resistors also set loop bandwidth.
4	EN	Enable Control Input (Active High). If the EN pin is open, it will be pulled to high by internal circuit. If using pull high resistor connected to VIN, the recommended value is larger than 250kΩ.
5	VIN	Supply Voltage Input. Bypass VIN to GND with a suitable large capacitor to prevent large voltage spikes from appearing at the input.
6	PHASE	Switch Node.

Function Block Diagram



Operation

The RT6200 is a constant frequency, current mode asynchronous step-down converter. In normal operation, the high side N-MOSFET is turned on when the S-R latch is set by the oscillator and is turned off when the current comparator resets the S-R latch. While the N-MOSFET is turned off, the inductor current conducts through the external diode.

Error Amplifier

The error amplifier adjusts its output voltage by comparing the feedback signal (V_{FB}) with the internal 0.8V reference. When the load current increases, it causes a drop in the feedback voltage relative to the reference, the error amplifier's output voltage then rises to allow higher inductor current to match the load current.

Oscillator

The internal oscillator runs at fixed frequency 1.2MHz. The RT6200 can support duty up to 95% by decreasing switching frequency to 600kHz. In short circuit condition, the frequency is reduced for low power consumption.

Internal Regulator

The regulator provides low voltage power to supply the internal control circuits and the bootstrap power for high-side gate driver.

Enable

The converter is turned on when the EN pin is higher than 1.2V and turned off when the EN pin is lower than 0.94V. When the EN pin is open, it will be pulled up to logic-high by 1µA current internally.

Soft-Start (SS)

An internal current source charges an internal capacitor to build a soft-start ramp voltage. The FB voltage will track the internal ramp voltage during soft-start interval. The typical soft-start time is 700µs.

Thermal Shutdown

The over temperature protection function will shut down the switching operation when the junction temperature exceeds 150°C. Once the junction temperature cools down by approximately 20°C, the converter will automatically resume switching.

Absolute Maximum Ratings (Note 1)

- Supply Voltage, V_{IN} ---------- 40V
- PHASE Voltage ---------- –0.3V to (V_{IN} + 0.3V)
- BOOT Voltage ---------- V_{PHASE} + 6V
- Other Pins ---------- 0.3V to 6V
- Power Dissipation, P_D @ T_A = 25°C
  SOT-23-6 ---------- 0.48W
- Package Thermal Resistance (Note 2)
  SOT-23-6, θ_{JA} ---------- 208.2°C/W
- Junction Temperature ---------- 150°C
- Lead Temperature (Soldering, 10 sec.) ---------- 260°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 Voltage, V_{IN} ---------- 4.5V to 36V
- Output Voltage, V_{OUT} ---------- 0.8V to 15V
- EN Voltage, V_{EN} ---------- 0V to 5.5V
- Junction Temperature Range ---------- –40°C to 125°C
- Ambient Temperature Range ---------- –40°C to 85°C

Electrical Characteristics

(V_{IN} = 12V, T_A = 25°C unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Feedback Reference Voltage		V_{FB}	4.5V ≤ V_{IN} ≤ 36V	0.784	0.8	0.816	V
Feedback Current		I_{FB}	V_{FB} = 0.8V	--	0.1	0.3	μA
Switch On Resistance		$R_{DS(ON)}$	V_{BOOT} – V_{PHASE} = 4.8V	--	0.35	--	Ω
Switch Leakage			V_{EN} = 0V, V_{PHASE} = 0V	--	--	10	μA
Current Limit		I_{LIM}	V_{BOOT} – V_{PHASE} = 4.8V, duty = 90%	--	1.2	--	A
Oscillator Frequency		f_{SW}	Duty < 90%	1	1.2	1.4	MHz
Maximum Duty Cycle				--	95	--	%
Minimum On-Time		t_{ON}		--	80	--	ns
Under-Voltage Lockout Threshold			Rising	3.9	4.2	4.5	V
Under-Voltage Lockout Threshold Hysteresis				--	200	--	mV
EN Input Voltage	Logic-High	V_{IH}		0.98	1.08	1.2	V
	Logic-Low	V_{IL}		0.94	1	1.06	

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
EN Pull-Up Current		V_{EN} = 0V	--	1	--	μA
Shutdown Current	I_{SHDN}	V_{EN} = 0V	--	20	--	μA
Quiescent Current	I_Q	V_{EN} = 2V, V_{FB} = 1V (Not Switching)	--	0.55	0.8	mA
Thermal Shutdown	T_{SD}		--	150	--	°C

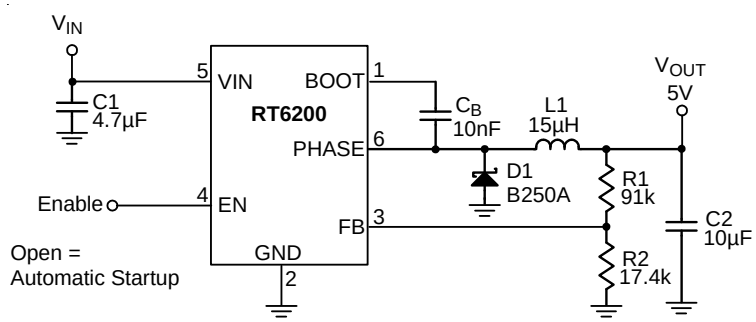
Note 1. Stresses beyond those listed "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure 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.

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

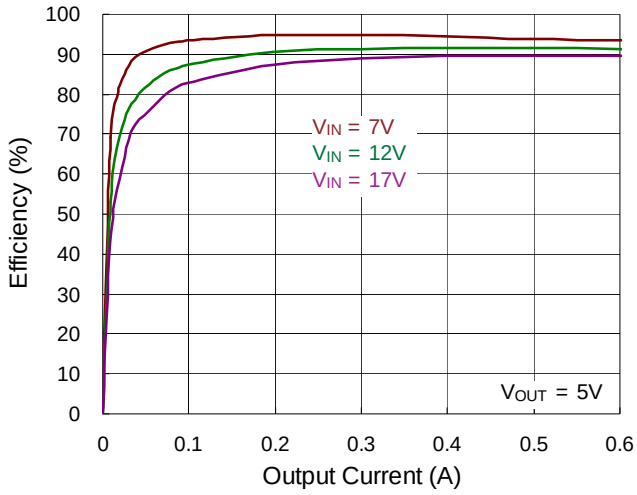
Note 4. The device is not guaranteed to function outside its operating conditions.

Typical Application Circuit

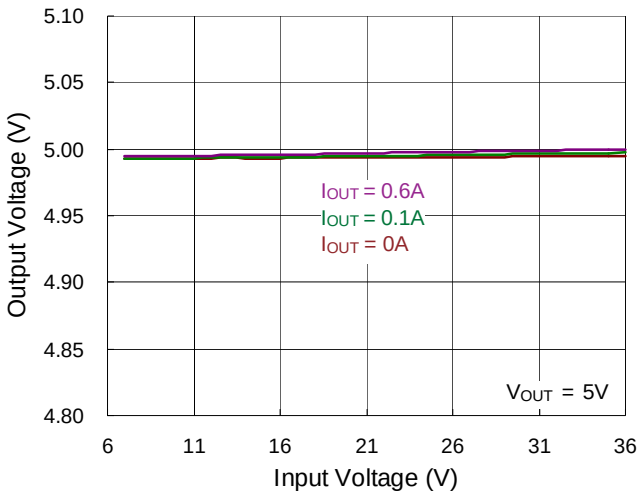


Typical Operating Characteristics

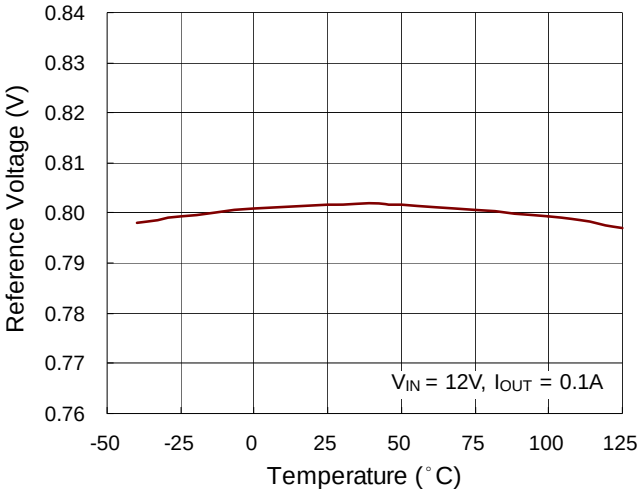
Efficiency vs. Output Current



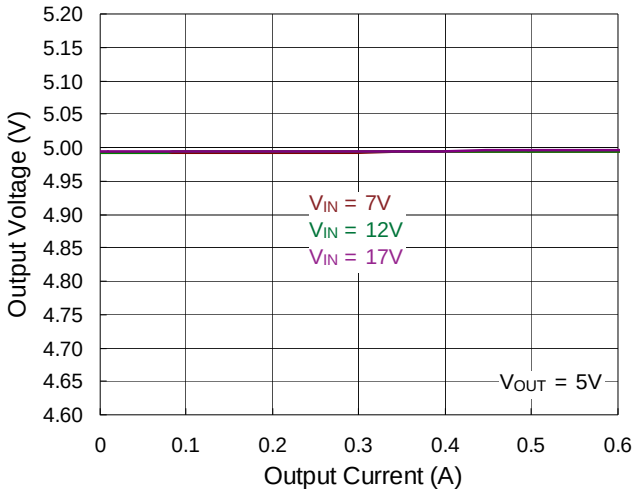
Output Voltage vs. Input Voltage



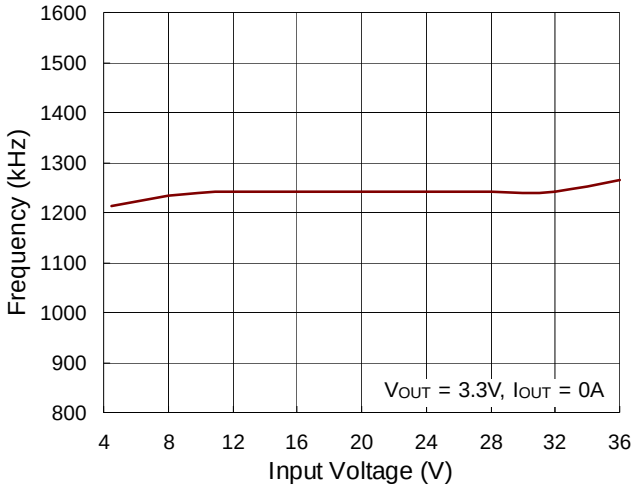
Reference Voltage vs. Temperature



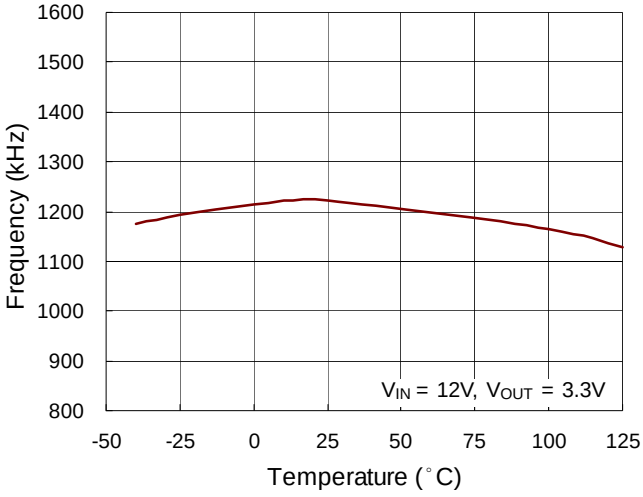
Output Voltage vs. Output Current



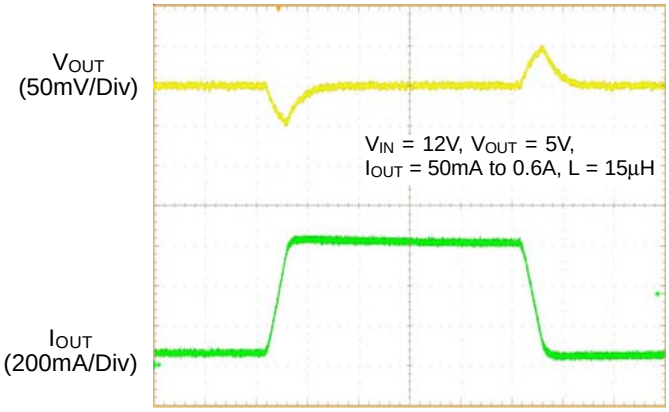
Frequency vs. Input Voltage



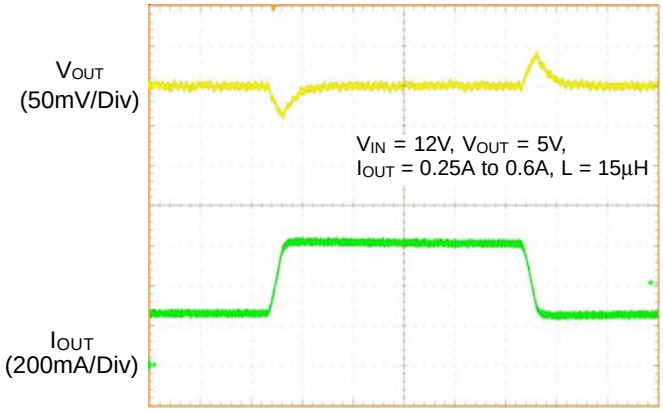
Frequency vs. Temperature



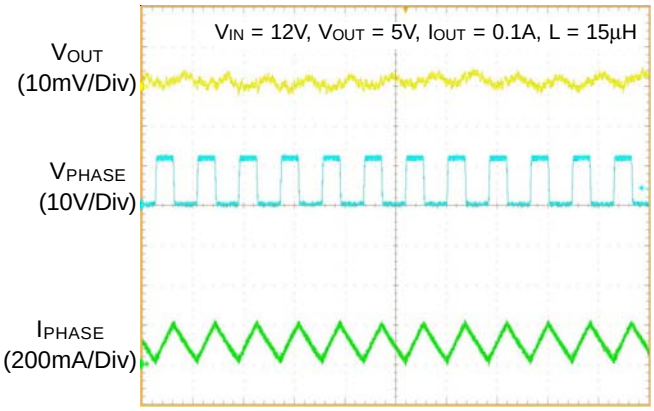
Load Transient Response



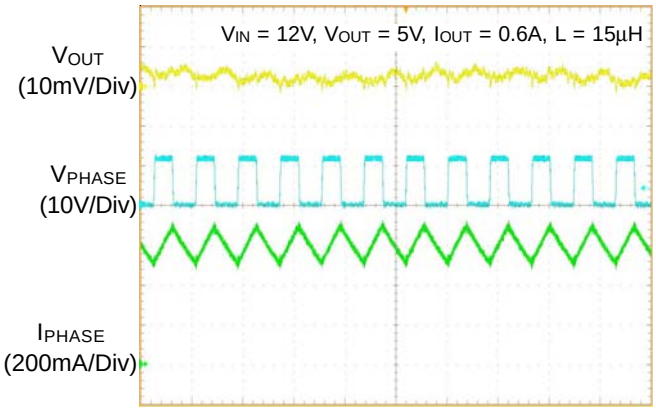
Load Transient Response



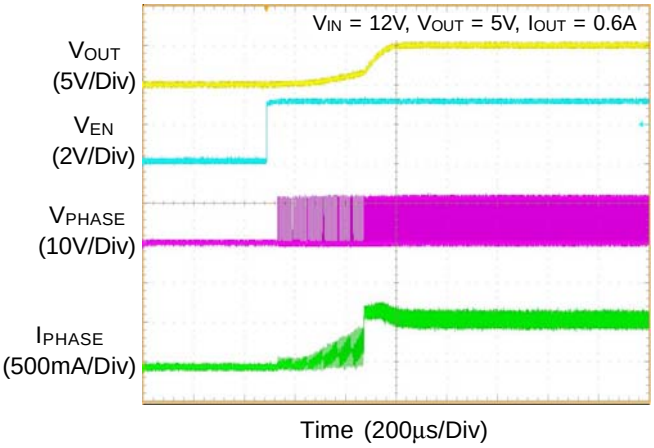
Output Ripple Voltage



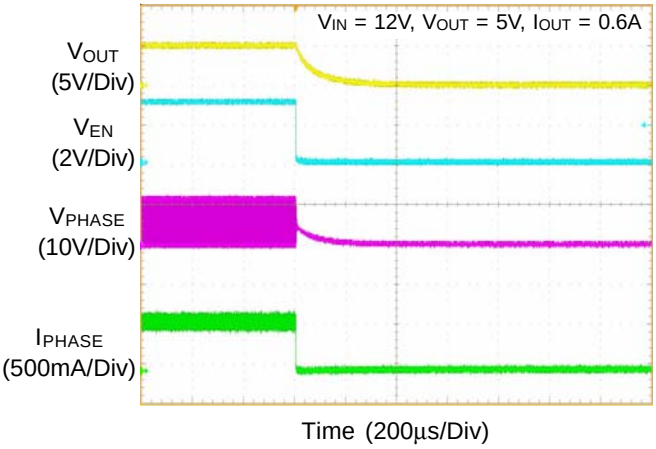
Output Ripple Voltage



Power On from EN



Power Off from EN



Application Information

The RT6200 is a high voltage buck converter that can support the input voltage range from 4.5V to 36V and the output current can be up to 0.6A.

Output Voltage Setting

The resistive voltage divider allows the FB pin to sense a fraction of the output voltage as shown in Figure 1.

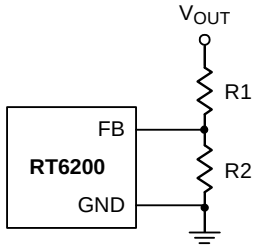


Figure 1. Output Voltage Setting

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

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

Where V_{FB} is the feedback reference voltage (0.8V typ.).

External Bootstrap Diode

Connect a 10nF low ESR ceramic capacitor between the BOOT pin and PHASE pin. This capacitor provides the gate driver voltage for the high side MOSFET.

It is recommended to add an external bootstrap diode between an external 5V and the BOOT pin for efficiency improvement when input voltage is lower than 5.5V or duty ratio is higher than 65%. The bootstrap diode can be a low cost one such as 1N4148 or BAT54.

The external 5V can be a 5V fixed input from system or a 5V output of the RT6200.

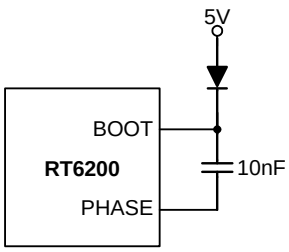


Figure 2. External Bootstrap Diode

Inductor Selection

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

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

Having a lower ripple current reduces not only the ESR losses in the output capacitors but also the output voltage ripple. High frequency with small ripple current can achieve highest efficiency operation. However, it requires a large inductor to achieve this goal.

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

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

Inductor Core Selection

The inductor type must be selected once the value for L is known. Generally speaking, high efficiency converters can not afford the core loss found in low cost powdered iron cores. So, the more expensive ferrite or mollypermalloy cores will be a better choice.

The selected inductance rather than the core size for a fixed inductor value is the key for actual core loss. As the inductance increases, core losses decrease. Unfortunately, increase of the inductance requires more turns of wire and therefore the copper losses will increase.

Ferrite designs are preferred at high switching frequency due to the characteristics of very low core losses. So, design goals can focus on the reduction of copper loss and the saturation prevention.

Ferrite core material saturates “hard”, which means that inductance collapses abruptly when the peak design current is exceeded. The previous situation 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 do not radiate energy. However, they are usually more expensive than the similar powdered iron inductors. The rule for inductor choice mainly depends on the price vs. size requirement and any radiated field/ EMI requirements.

Diode Selection

When the power switch turns off, the path for the current is through the diode connected between the switch output and ground. This forward biased diode must have a minimum voltage drop and recovery times. Schottky diode is recommended and it should be able to handle those current. The reverse voltage rating of the diode should be greater than the maximum input voltage, and current rating should be greater than the maximum load current.

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 current, a low ESR input capacitor sized for the maximum RMS current should be used. The 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.

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 required Effective Series Resistance (ESR) to minimize voltage ripple.

Moreover, the amount of bulk capacitance is also a key for C_{OUT} selection 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 will be highest at the 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 requirement. Dry tantalum, special polymer, aluminum electrolytic and ceramic capacitors are all available in surface mount packages. Special polymer capacitors offer very low ESR value. However, it provides lower capacitance density than other types. Although Tantalum capacitors have the highest capacitance density, it is important to only use types that pass the surge test for use in switching power supplies. Aluminum electrolytic capacitors have significantly higher ESR. However, it can be used in cost-sensitive applications for ripple current rating and long term reliability considerations. 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.

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 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.

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) also begins to charge or discharge C_{OUT} generating a feedback error signal for 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.

Thermal Considerations

For continuous operation, do not exceed the maximum operation junction temperature 125°C. 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, T_A is the ambient temperature and the θ_{JA} is the junction to ambient thermal resistance.

For recommended operating conditions specifications, the maximum junction temperature of the die is 125°C. The junction to ambient thermal resistance θ_{JA} is layout dependent. For SOT-23-6 package, the thermal resistance θ_{JA} is 208.2°C/W on standard JEDEC 51-7 four-layers 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) / (208.2°C/W) = 0.48W for SOT-23-6 packages

The maximum power dissipation depends on operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance θ_{JA}. The derating curves in Figure 3 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

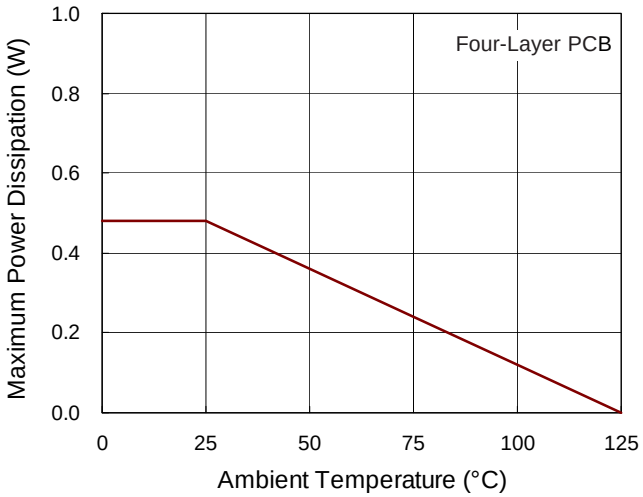


Figure 3. Derating Curves of Maximum Power Dissipation

Layout Consideration

Follow the PCB layout guidelines for optimal performance of RT6200.

- Keep the traces of the main current paths as short and wide as possible.
- Put the input capacitor as close as possible to the device pins (VIN and GND).
- PHASE node is with high frequency voltage swing and should be kept at small area. Keep sensitive components away from the PHASE node to prevent stray capacitive noise pick-up.
- Place the feedback components to the FB pin as close as possible.
- Connect GND to a ground plane for noise reduction and thermal dissipation.

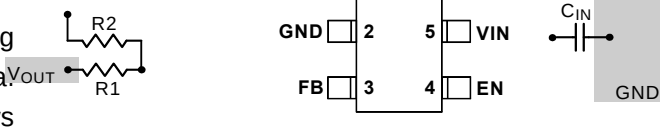
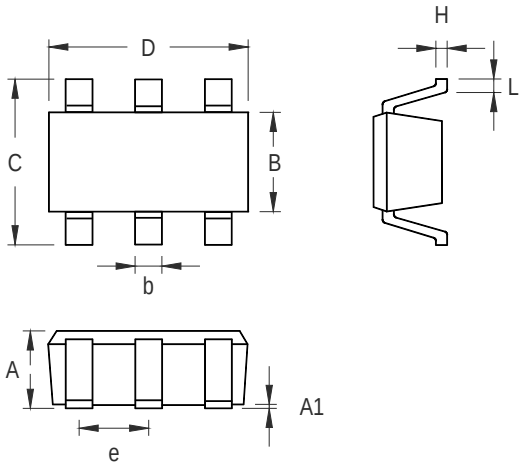


Figure 4. PCB Layout Guide

Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.889	1.295	0.031	0.051
A1	0.000	0.152	0.000	0.006
B	1.397	1.803	0.055	0.071
b	0.250	0.560	0.010	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