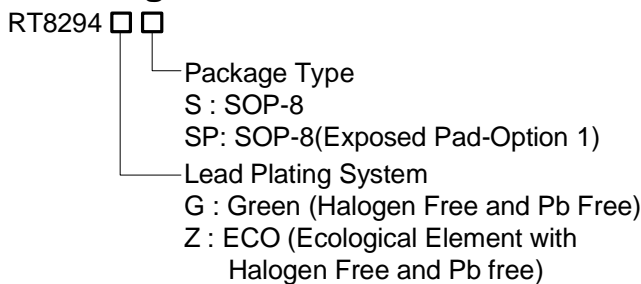


# 2A, 23V, 340kHz Synchronous Step-Down Converter

## General Description

The RT8294 is a high efficiency, monolithic synchronous step-down DC/DC converter that can deliver up to 2A output current from a 4.5V to 23V input supply. The RT8294's current mode architecture and external compensation allow the transient response to be optimized over a wide range of loads and output capacitors. Cycle-by-cycle current limit provides protection against shorted outputs and soft-start eliminates input current surge during start up. The RT8294 also provides under voltage protection and thermal shutdown protection. The low current (< 3μA) shutdown mode provides output disconnection, enabling easy power management in battery-powered systems. The RT8294 is available in SOP-8 and SOP-8 (Exposed Pad) packages.

## Ordering Information



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.

## Features

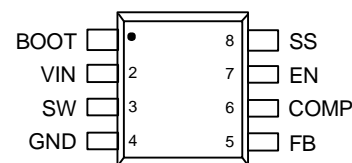
- | ±1.5% High Accuracy Feedback Voltage
- | Input Voltage Range : 4.5V to 23V
- | 2A Output Current
- | Integrated N-MOSFETs
- | Current Mode Control
- | 340kHz Fixed Frequency Operation
- | Output Adjustable Voltage Range : 0.923V to 20V
- | Efficiency Up to 95%
- | Programmable Soft-Start
- | Stable with Low ESR Ceramic Output Capacitors
- | Cycle-by Cycle Over Current Protection
- | Input Under Voltage Lockout
- | Output Under Voltage Protection
- | Thermal Shutdown Protection
- | RoHS Compliant and Halogen Free

## Applications

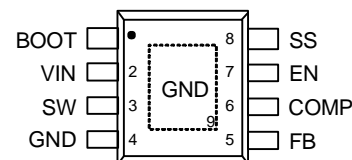
- | Wireless AP/Router
- | Set-Top-Box
- | Industrial and Commercial Low Power Systems
- | LCD Monitors and TVs
- | Green Electronics/Appliances
- | Point of Load Regulation of High-Performance DSPs

## Pin Configurations

(TOP VIEW)



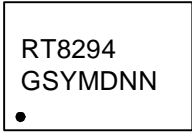
SOP-8



SOP-8 (Exposed Pad)

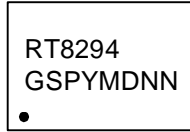
## Marking Information

RT8294GS



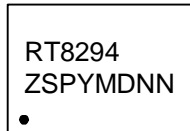
RT8294GS : Product Number  
YMDNN : Date Code

RT8294GSP



RT8294GSP : Product Number  
YMDNN : Date Code

RT8294ZSP



RT8294ZSP : Product Number  
YMDNN : Date Code

## Typical Application Circuit

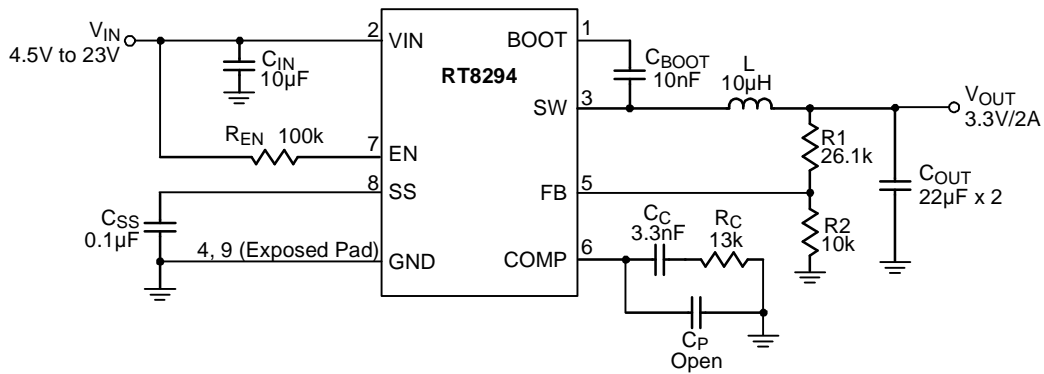


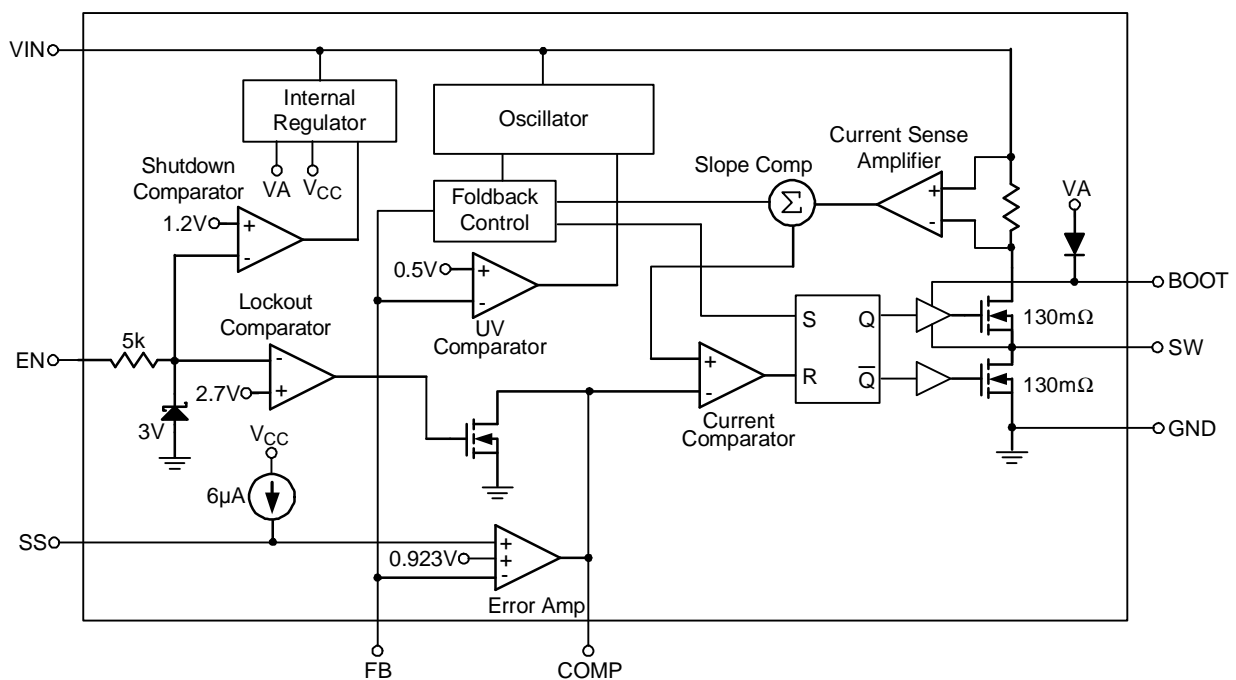
Table 1. Recommended Component Selection

V <sub>OUT</sub> (V)	R <sub>1</sub> (kW)	R <sub>2</sub> (kW)	R <sub>C</sub> (kW)	C <sub>C</sub> (nF)	L (mH)	C <sub>OUT</sub> (µF)
8	76.8	10	27	3.3	22	22 x 2
5	45.3	10	20	3.3	15	22 x 2
3.3	26.1	10	13	3.3	10	22 x 2
2.5	16.9	10	9.1	3.3	6.8	22 x 2
1.8	9.53	10	5.6	3.3	4.7	22 x 2
1.2	3	10	3.6	3.3	3.6	22 x 2

**Functional Pin Description**

Pin No.		Pin Name	Pin Function
SOP-8	SOP-8 (Exposed Pad)		
1	1	BOOT	Bootstrap for High Side Gate Driver. Connect a 10nF or greater ceramic capacitor from BOOT to SW pins.
2	2	VIN	Input Supply Voltage, 4.5V to 23V. Must bypass with a suitably large ceramic capacitor.
3	3	SW	Phase Node. Connect this pin to external L-C filter.
4	4, 9 (Exposed Pad)	GND	Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation.
5	5	FB	Feedback Input Pin. This pin is connected to the converter output. It is used to set the output of the converter to regulate to the desired value via an internal resistive voltage divider. For an adjustable output, an external resistive voltage divider is connected to this pin.
6	6	COMP	Compensation Node. COMP is used to compensate the regulation control loop. Connect a series RC network from COMP to GND. In some cases, an additional capacitor from COMP to GND is required.
7	7	EN	Enable Input pin. A logic high enables the converter; a logic low forces the RT8294 into shutdown mode reducing the supply current to less than 3μA. Attach this pin to VIN with a 100kΩ pull up resistor for automatic startup.
8	8	SS	Soft-Start Control Input. SS controls the soft-start period. Connect a capacitor from SS to GND to set the soft-start period. A 0.1μF capacitor sets the soft-start period to 15.5ms .

**Function Block Diagram**



## Absolute Maximum Ratings (Note 1)

Supply Voltage, $V_{IN}$ -----	-0.3V to 25V
Input Voltage, SW -----	-0.3V to ( $V_{IN} + 0.3V$ )
$V_{BOOT} - V_{SW}$ -----	-0.3V to 6V
Other Pins Voltages -----	-0.3V to 6V
Power Dissipation, $P_D$ @ $T_A = 25^\circ C$	
SOP-8 -----	1.111W
SOP-8 (Exposed Pad) -----	1.333W
Package Thermal Resistance (Note 2)	
SOP-8, $\theta_{JA}$ -----	90°C/W
SOP-8 (Exposed Pad), $\theta_{JA}$ -----	75°C
SOP-8 (Exposed Pad), $\theta_{JC}$ -----	15°C
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 Mode) -----	2kV
MM (Machine Mode) -----	200V

## Recommended Operating Conditions (Note 4)

Supply Voltage, $V_{IN}$ -----	4.5V to 23V
Junction Temperature Range -----	-40°C to 125°C
Ambient Temperature Range -----	-40°C to 85°C

## Electrical Characteristics

( $V_{IN} = 12V$ ,  $T_A = 25^\circ C$  unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Shutdown Supply Current		$V_{EN} = 0V$	--	0.5	3	$\mu A$
Supply Current	$I_{CC}$	$V_{EN} = 3V$ , $V_{FB} = 1V$	--	0.8	1.2	mA
Feedback Voltage	$V_{FB}$	$4.5V \leq V_{IN} \leq 23V$	0.909	0.923	0.937	V
Error Amplifier Transconductance	$G_{EA}$	$\Delta I_C = \pm 10\mu A$	--	940	--	$\mu A/V$
High-Side Switch-On Resistance	$R_{DS(ON)1}$		--	130	--	m $\Omega$
Low-Side Switch-On Resistance	$R_{DS(ON)2}$		--	130	--	m $\Omega$
High-Side Switch Leakage Current		$V_{EN} = 0V$ , $V_{SW} = 0V$	--	0	10	$\mu A$
Upper Switch Current Limit		Min. Duty Cycle, $V_{BOOT-SW} = 4.8V$	--	4.3	--	A
Low Switch Current Limit		From Drain to Source	--	1.3	--	A
COMP to Current Sense Transconductance	$G_{CS}$		--	4	--	A/V
Oscillator Frequency	$f_{OSC1}$		300	340	380	kHz
Short Circuit Oscillation Frequency	$f_{OSC2}$	$V_{FB} = 0V$	--	100	--	kHz
Maximum Duty Cycle	$D_{MAX}$	$V_{FB} = 0.7V$	--	93	--	%
Minimum On-Time	$t_{ON}$		--	100	--	ns

*To be continued*

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
EN Input Threshold Voltage	Logic High	$V_{IH}$		2.7	--	5.5	V
	Logic Low	$V_{IL}$		--	--	0.4	
Input Under Voltage Lockout Threshold		$V_{UVLO}$	$V_{IN}$ Rising	3.8	4.2	4.5	V
Input Under Voltage Lockout Hysteresis		$\Delta V_{UVLO}$		--	320	--	mV
Soft-Start Current		$I_{SS}$	$V_{SS} = 0V$	--	6	--	$\mu A$
Soft-Start Period		$t_{SS}$	$C_{SS} = 0.1\mu F$	--	15.5	--	ms
Thermal Shutdown		$T_{SD}$		--	150	--	$^{\circ}C$

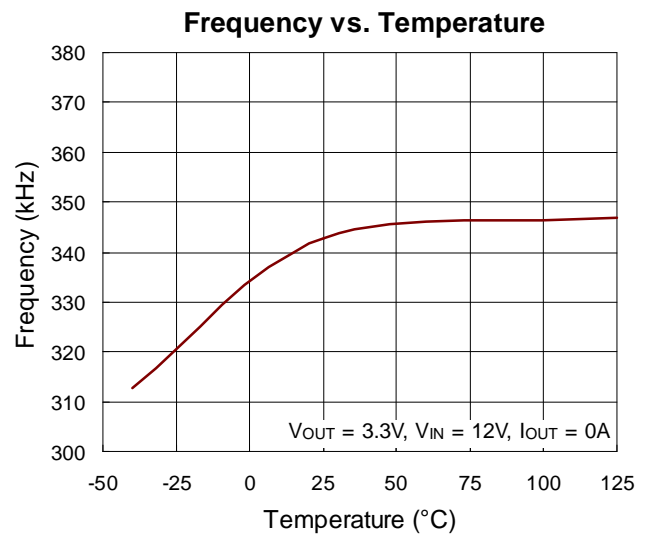
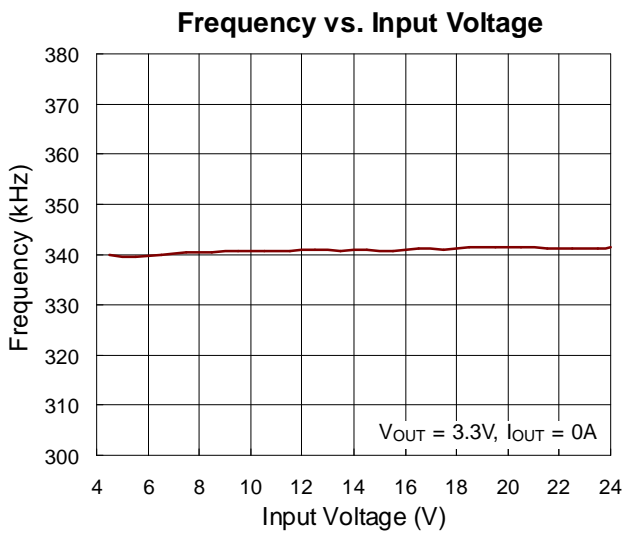
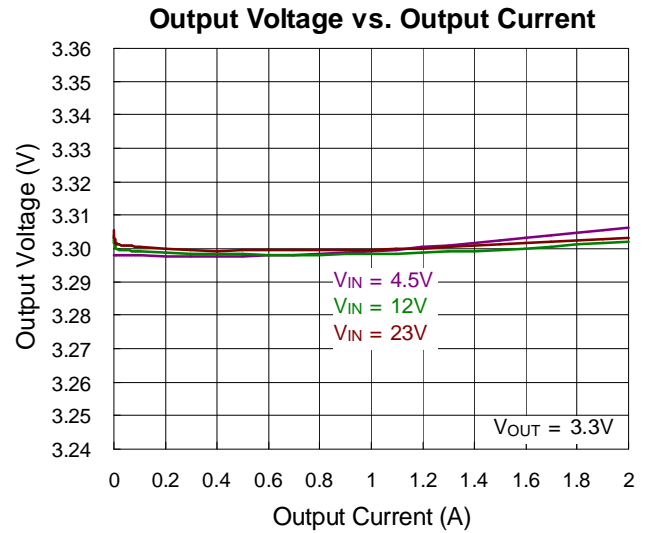
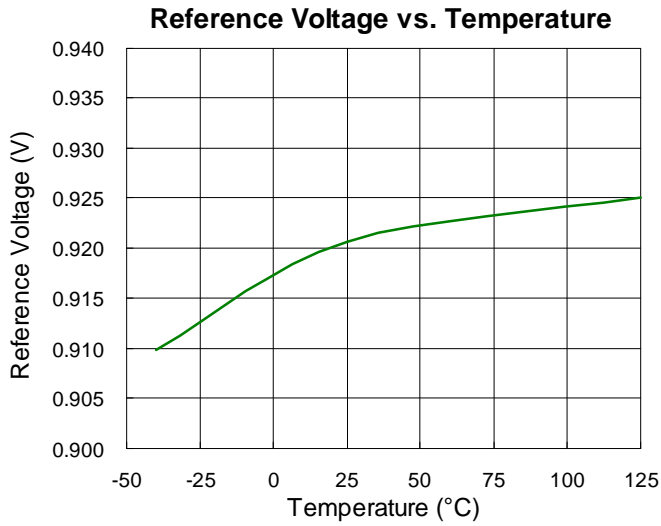
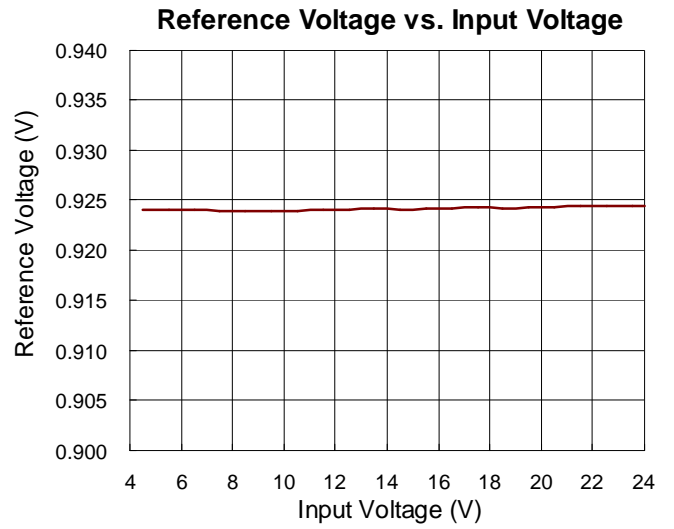
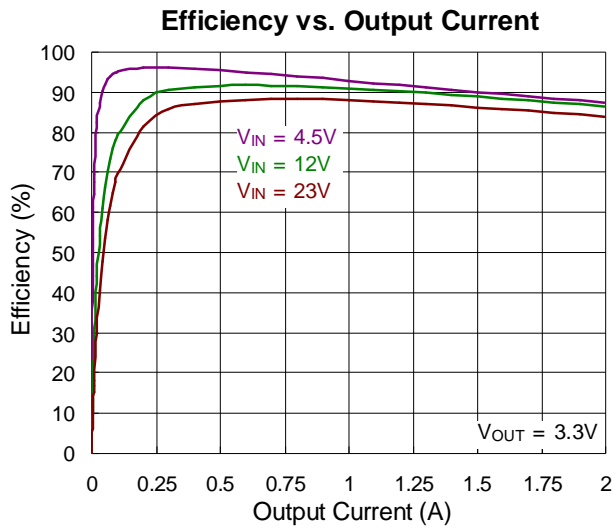
**Note 1.** Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

**Note 2.**  $\theta_{JA}$  is measured in natural convection at  $T_A = 25^{\circ}C$  on a high effective thermal conductivity four-layer test board, of JEDEC 51-7 thermal measurement standard. The measurement case position of  $\theta_{JC}$  is on the exposed pad of the package.

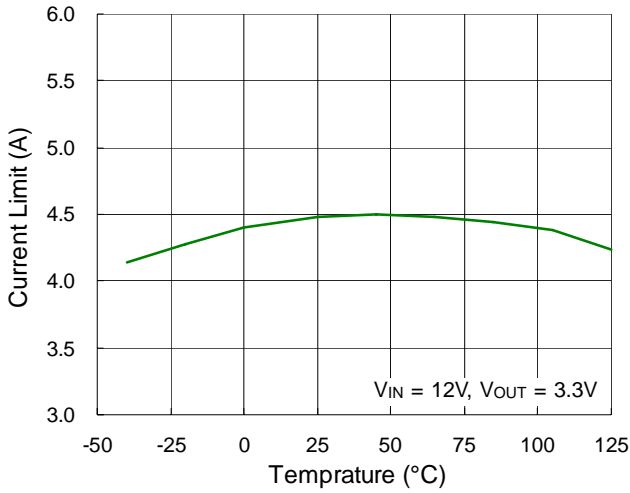
**Note 3.** Devices are ESD sensitive. Handling precaution is recommended.

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

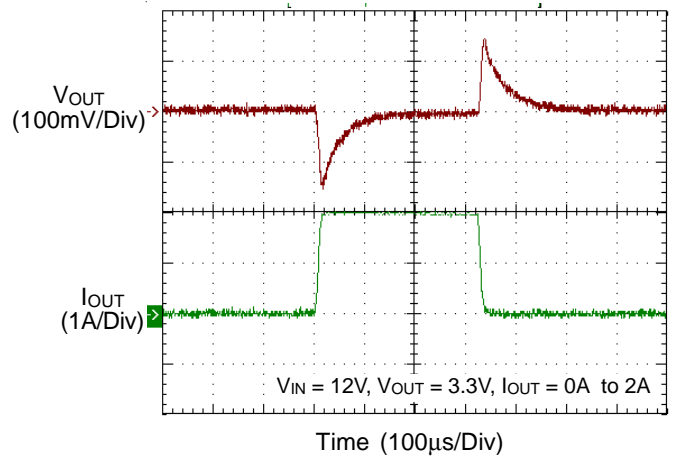
Typical Operating Characteristics



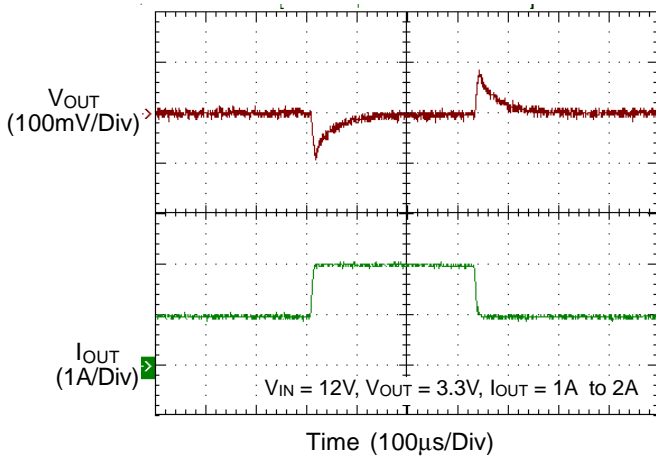
Current Limit vs. Temperature



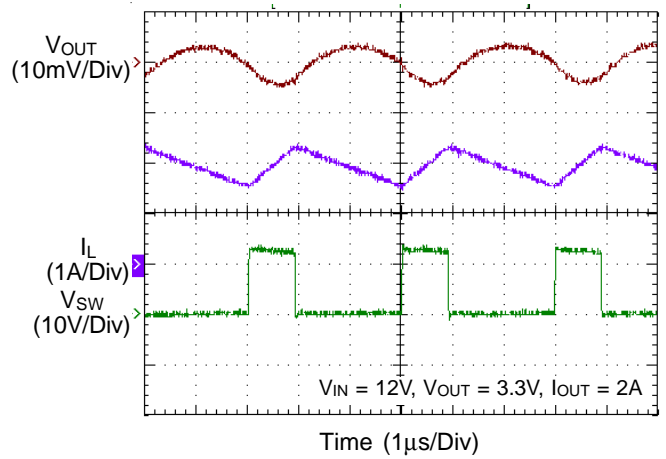
Load Transient Response



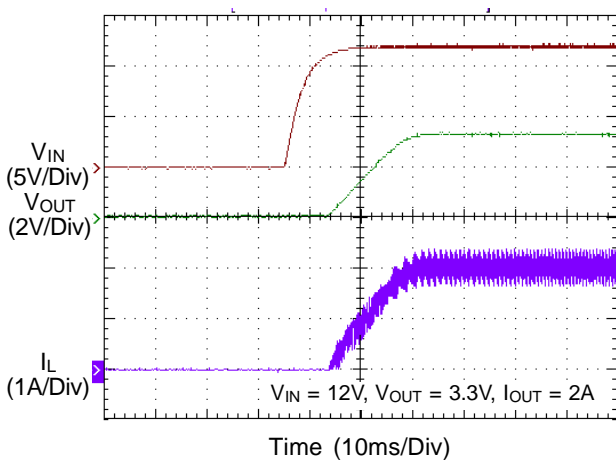
Load Transient Response



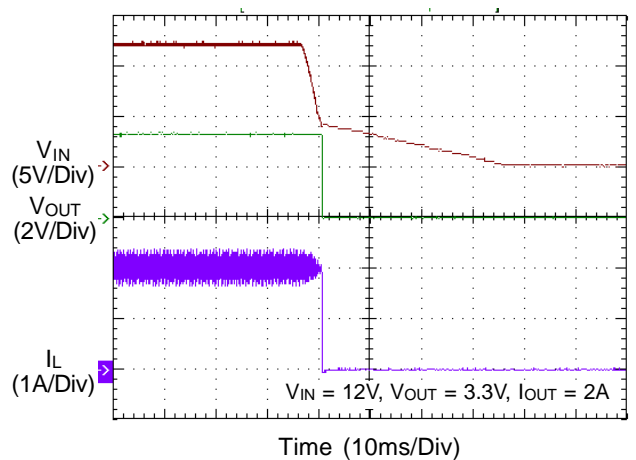
Switching



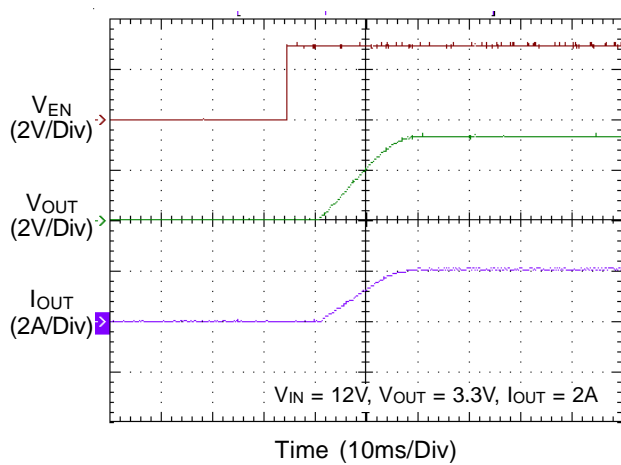
Power On from VIN



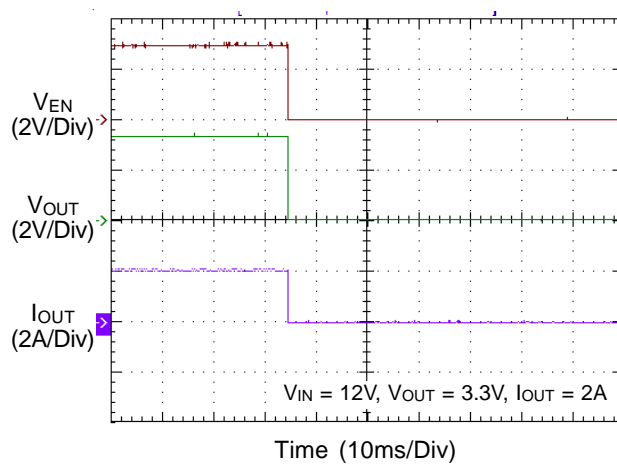
Power Off from VIN



### Power On from EN



### Power Off from EN





## Application Information

The RT8294 is a synchronous high voltage buck converter that can support the input voltage range from 4.5V to 23V and the output current can be up to 2A.

### Output Voltage Setting

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

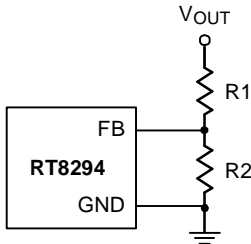


Figure 1. Output Voltage Setting

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 0.923V (typ.).

### External Bootstrap Diode

Connect a 10nF low ESR ceramic capacitor between the BOOT pin and SW 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 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 IN4148 or BAT54. The external 5V can be a 5V fixed input from system or a 5V output of the RT8294. Note that the external boot voltage must be lower than 5.5V

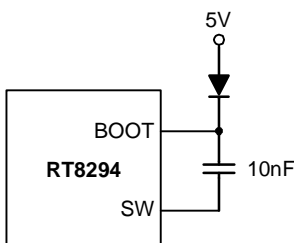


Figure 2. External Bootstrap Diode

### Soft-Start

The RT8294 contains an external soft-start clamp that gradually raises the output voltage. The soft-start timing can be programmed by the external capacitor between SS pin and GND. The chip provides a 6μA charge current for the external capacitor. If 0.1μF capacitor is used to set the soft-start, the period will be 15.5ms (typ.).

### Chip Enable Operation

The EN pin is the chip enable input. Pulling the EN pin low (<0.4V) will shut down the device. During shutdown mode, the RT8294 quiescent current drops to lower than 3μA. Driving the EN pin high (> 2.7V, < 5.5V) will turn on the device again. For external timing control (e.g.RC), the EN pin can also be externally pulled high by adding a  $R_{EN}^*$  resistor and  $C_{EN}^*$  capacitor from the VIN pin (see Figure 5).

An external MOSFET can be added to implement digital control on the EN pin when no system voltage above 2.5V is available, as shown in Figure 3. In this case, a 100kΩ pull-up resistor,  $R_{EN}$ , is connected between  $V_{IN}$  and the EN pin. MOSFET Q1 will be under logic control to pull down the EN pin.

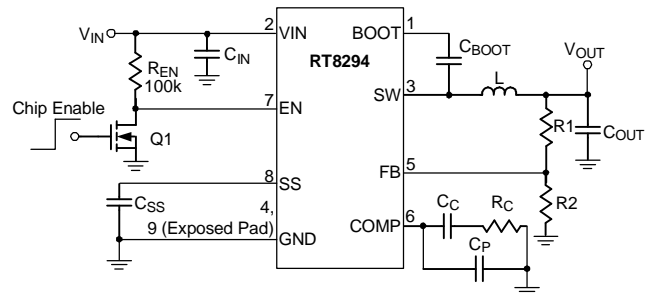


Figure 3. Enable Control Circuit for Logic Control with Low Voltage

To prevent enabling circuit when  $V_{IN}$  is smaller than the  $V_{OUT}$  target value, a resistive voltage divider can be placed between the input voltage and ground and connected to the EN pin to adjust IC lockout threshold, as shown in Figure 4. For example, if an 8V output voltage is regulated from a 12V input voltage, the resistor,  $R_{EN2}$ , can be selected to set input lockout threshold larger than 8V.

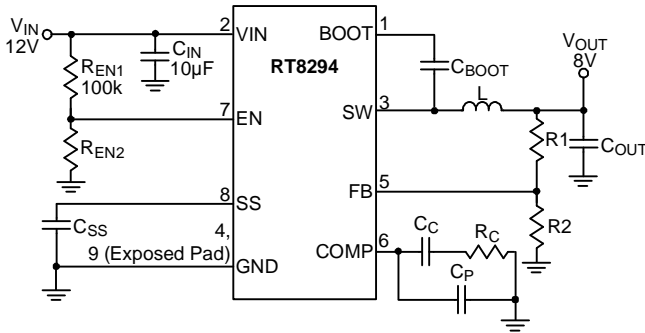


Figure 4. The Resistors can be Selected to Set IC Lockout Threshold

**Hiccup Mode**

For the RT8294, Hiccup Mode Under Voltage Protection (UVP) is provided. When the FB voltage,  $V_{FB}$ , drops below 0.5V, the UVP function will be triggered and the RT8294 will shut down for a period of time and then recover automatically. The Hiccup Mode UVP can reduce input current in short circuit conditions.

**Inductor Selection**

The inductor value and operating frequency determine the ripple current according to a specific input and output voltage. The ripple current  $\Delta I_L$  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  $\Delta I_L = 0.24(I_{MAX})$  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 :

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

The inductor's current rating (caused a 40°C temperature rising from 25°C ambient) should be greater than the maximum load current and its saturation current should be greater than the short circuit peak current limit. Please see Table 2 for the inductor selection reference.

Table 2. Suggested Inductors for Typical Application Circuit

Component Supplier	Series	Dimensions (mm)
TDK	VLF10045	10 x 9.7 x 4.5
TDK	SLF12565	12.5 x 12.5 x 6.5
TAIYO YUDEN	NR8040	8 x 8 x 4

**$C_{IN}$  and  $C_{OUT}$  Selection**

The input capacitance,  $C_{IN}$ , is needed to filter the trapezoidal current at the source of the high side 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.

For the input capacitor, one 10µF low ESR ceramic capacitors are recommended. For the recommended capacitor, please refer to table 3 for more detail.

The selection of  $C_{OUT}$  is determined by the required 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,  $\Delta V_{OUT}$ , 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  $\Delta I_L$  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  $\Delta I_{LOAD} (ESR)$  and  $C_{OUT}$  also begins to be charge or discharged to generate 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.

**EMI Consideration**

Since parasitic inductance and capacitance effects in PCB circuitry would cause a spike voltage on SW pin when high side MOSFET is turned-on/off, this spike voltage on SW may impact on EMI performance in the system. In order to enhance EMI performance, there are two methods to suppress the spike voltage. One way is by placing an R-C snubber between SW and GND and locating them as close as possible to the SW pin (see Figure 5). Another method is by adding a resistor in series with the bootstrap capacitor,  $C_{BOOT}$ , but this method will decrease the driving capability to the high side MOSFET. It is strongly recommended to reserve the R-C snubber during PCB layout for EMI improvement. Moreover, reducing the SW trace area and keeping the main power in a small loop will be helpful on EMI performance. For detailed PCB layout guide, please refer to the section Layout Considerations.

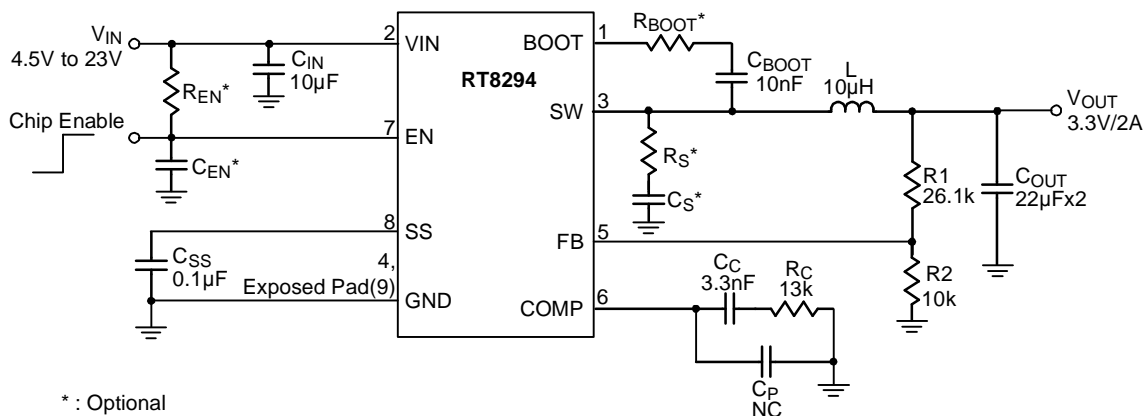


Figure 5. Reference Circuit with Snubber and Enable Timing Control

## Thermal Considerations

For continuous operation, do not exceed absolute 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 junctions 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  $\theta_{JA}$  is the junction to ambient thermal resistance.

For recommended operating conditions specification of RT8294, the maximum junction temperature is 125°C. The junction to ambient thermal resistance  $\theta_{JA}$  is layout dependent. For SOP-8 (Exposed Pad) package, the thermal resistance  $\theta_{JA}$  is 75°C/W on the standard JEDEC 51-7 four layers thermal test board. For SOP-8 package, the thermal resistance  $\theta_{JA}$  is 90°C/W on the standard JEDEC 51-7 four layers thermal test board. The maximum power dissipation at  $T_A = 25^\circ\text{C}$  can be calculated by following formula :

$$P_{D(MAX)} = (125^\circ\text{C} - 25^\circ\text{C}) / (75^\circ\text{C/W}) = 1.33\text{W}$$

(min. copper area PCB layout with SOP-8 Exposed Pad)

$$P_{D(MAX)} = (125^\circ\text{C} - 25^\circ\text{C}) / (49^\circ\text{C/W}) = 2.04\text{W}$$

(70mm<sup>2</sup> copper area PCB layout with SOP-8 Exposed Pad)

$$P_{D(MAX)} = (125^\circ\text{C} - 25^\circ\text{C}) / (90^\circ\text{C/W}) = 1.11\text{W}$$

(min. copper area PCB layout with SOP-8)

The thermal resistance  $\theta_{JA}$  of SOP-8 (Exposed Pad) is determined by the package architecture design and the PCB layout design. However, the package architecture design had been designed. If possible, it's useful to increase thermal performance by the PCB layout copper design. The thermal resistance  $\theta_{JA}$  can be decreased by adding copper area under the exposed pad of SOP-8 (Exposed Pad) package.

As shown in Figure 6, the amount of copper area to which the SOP-8 (Exposed Pad) is mounted affects thermal performance. When mounted to the standard SOP-8 (Exposed Pad) pad (Figure 6.a),  $\theta_{JA}$  is 75°C/W. Adding copper area of pad under the SOP-8 (Exposed Pad) (Figure

6.b) reduces the  $\theta_{JA}$  to 64°C/W. Even further, increasing the copper area of pad to 70mm<sup>2</sup> (Figure 6.e) reduces the  $\theta_{JA}$  to 49°C/W.

The maximum power dissipation depends on operating ambient temperature for fixed  $T_{J(MAX)}$  and thermal resistance  $\theta_{JA}$ . For RT8294 packages, the of de-rating curves in Figure 7 allow the designer to see the effect of rising ambient temperature on the maximum power dissipation allowed.

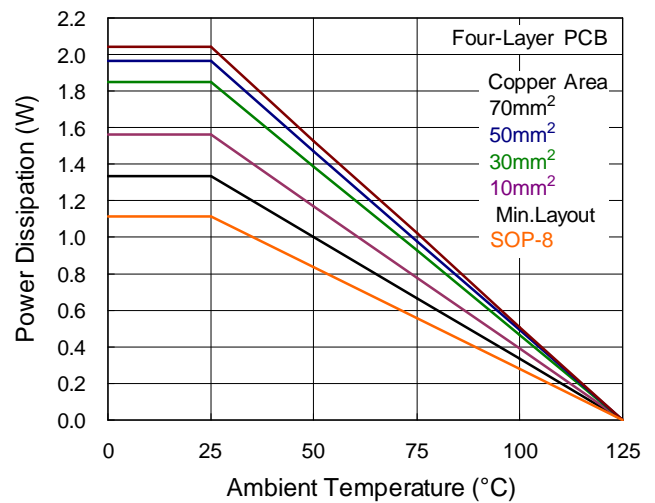
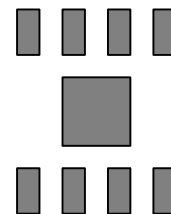
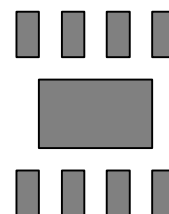


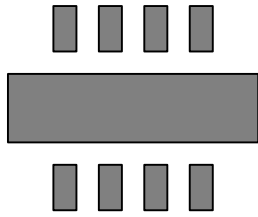
Figure 7. Derating Curves for RT8294 Package



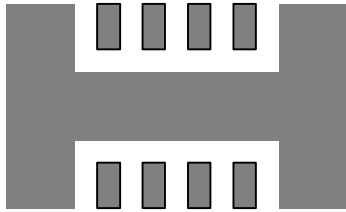
(a) Copper Area = (2.3 x 2.3) mm<sup>2</sup>,  $\theta_{JA} = 75^\circ\text{C/W}$



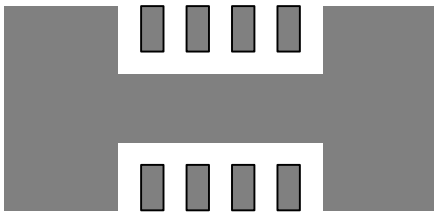
(b) Copper Area = 10mm<sup>2</sup>,  $\theta_{JA} = 64^\circ\text{C/W}$



(c) Copper Area = 30mm<sup>2</sup>,  $\theta_{JA}$  = 54°C/W



(d) Copper Area = 50mm<sup>2</sup>,  $\theta_{JA}$  = 51°C/W



(e) Copper Area = 70mm<sup>2</sup>,  $\theta_{JA}$  = 49°C/W

Figure 6. Thermal Resistance vs. Copper Area Layout Design

**Layout Considerations**

For best performance of the RT8294, the following layout guidelines must be strictly followed.

- } Input capacitor must be placed as close to the IC as possible.
- } SW should be connected to inductor by wide and short trace. Keep sensitive components away from this trace.
- } The feedback components must be connected as close to the device as possible

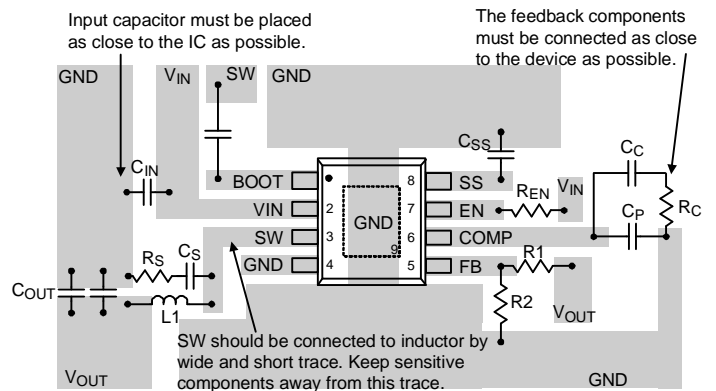
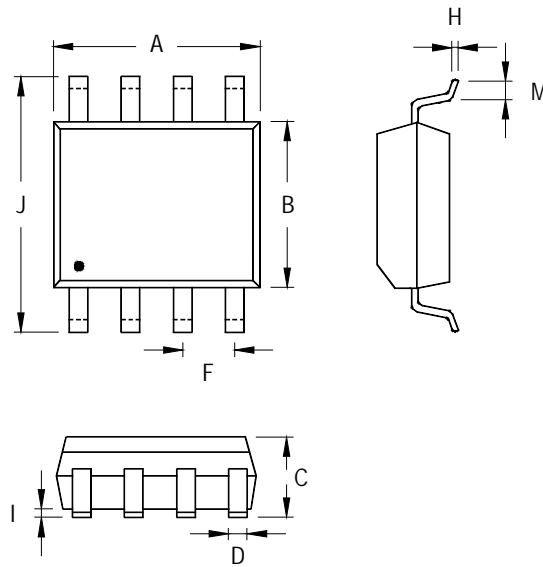


Figure 8. PCB Layout Guide

**Table 3. Suggested Capacitors for C<sub>IN</sub> and C<sub>OUT</sub>**

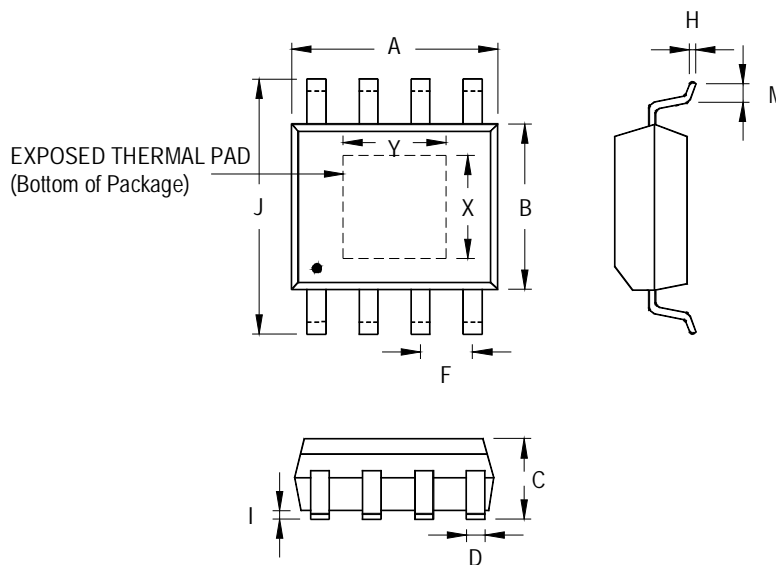
Location	Component Supplier	Part No.	Capacitance (µF)	Case Size
C <sub>IN</sub>	MURATA	GRM31CR61E106K	10	1206
C <sub>IN</sub>	TDK	C3225X5R1E106K	10	1206
C <sub>IN</sub>	TAIYO YUDEN	TMK316BJ106ML	10	1206
C <sub>OUT</sub>	MURATA	GRM31CR60J476M	47	1206
C <sub>OUT</sub>	TDK	C3225X5R0J476M	47	1210
C <sub>OUT</sub>	MURATA	GRM32ER71C226M	22	1210
C <sub>OUT</sub>	TDK	C3225X5R1C22M	22	1210

## Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	4.801	5.004	0.189	0.197
B	3.810	3.988	0.150	0.157
C	1.346	1.753	0.053	0.069
D	0.330	0.508	0.013	0.020
F	1.194	1.346	0.047	0.053
H	0.170	0.254	0.007	0.010
I	0.050	0.254	0.002	0.010
J	5.791	6.200	0.228	0.244
M	0.400	1.270	0.016	0.050

**8-Lead SOP Plastic Package**



Symbol	Dimensions In Millimeters		Dimensions In Inches		
	Min	Max	Min	Max	
A	4.801	5.004	0.189	0.197	
B	3.810	4.000	0.150	0.157	
C	1.346	1.753	0.053	0.069	
D	0.330	0.510	0.013	0.020	
F	1.194	1.346	0.047	0.053	
H	0.170	0.254	0.007	0.010	
I	0.000	0.152	0.000	0.006	
J	5.791	6.200	0.228	0.244	
M	0.406	1.270	0.016	0.050	
Option 1	X	2.000	2.300	0.079	0.091
	Y	2.000	2.300	0.079	0.091
Option 2	X	2.100	2.500	0.083	0.098
	Y	3.000	3.500	0.118	0.138

**8-Lead SOP (Exposed Pad) Plastic Package**

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