

FEATURES

- 3.3V, 5.0V, 12V, and Adjustable Output Versions
- Adjustable Version Output Voltage Range, 1.23V to 37V $\pm 4\%$ maximum over line and load conditions
- Guaranteed 3.0A Output Current
- Wide Input Voltage Range: Up to 40V
- Requires Only 4 External Components
- 150kHz Fixed Frequency Internal Oscillator
- TTL Shutdown Capability, Low Power Standby Mode
- High Efficiency
- Uses Readily Available Standard Inductors
- Thermal Shutdown and Current Limit Protection
- Moisture Sensitivity Level 3 for SMD type packages

APPLICATIONS

- Simple High-Efficiency Step-Down (Buck) Regulator
- Efficient Pre-Regulator for Linear Regulators
- On-Card Switching Regulators
- Positive to Negative Converter (Buck-Boost)
- Power Supply for Battery Chargers

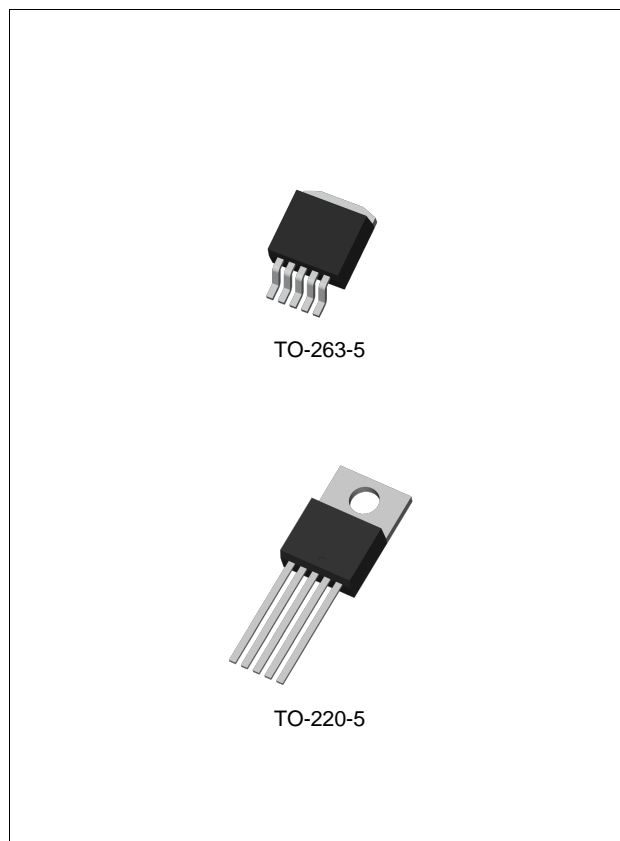
DESCRIPTION

The LM2596G series of regulators are monolithic integrated circuits ideally suited for easy and convenient design of a step-down switching regulator (buck converter). All circuits of this series are capable of driving a 3.0A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5.0V, 12V, and an adjustable output version.

These regulators were designed to minimize the number of external components to simplify the power supply design. Standard series of inductors optimized for use with the LM2596G are offered by several different inductor manufacturers.

The LM2596G series operates at a switching frequency of 150kHz, thus allowing smaller sized filter components than what would be required with lower frequency switching regulators.

LM2596G features include a $\pm 4\%$ tolerance on output voltage within specified input voltages and output load conditions, and $\pm 15\%$ on the oscillator frequency. External shutdown is included. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.



ORDERING INFORMATION

Device	Package
LM2596GR-x.x	TO-263-5L
LM2596GT-x.x	TO-220-5L

x.x: Output Voltage

ABSOLUTE MAXIMUM RATINGS (Note 1)

CHARACTERISTIC	SYMBOL	MIN	MAX	UNIT
Maximum Supply Voltage	V_{IN}	-	45	V
\overline{ON} /OFF Pin Input Voltage	-	-0.3	V_{IN}	V
Output Voltage to Ground	-	-1.0	-	V
Power Dissipation	P_D	-	Internally Limited	W
ESD Rating, HBM	-	2	-	kV
Maximum Junction Temperature	T_J	-	150	°C
Storage Temperature	T_{STG}	-65	150	°C

Note 1. 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 under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING RATINGS (Note 2)

CHARACTERISTIC	SYMBOL	MIN	MAX	UNIT
Supply Voltage	V_{IN}	-	40	V
Operating Junction Temperature	T_J	-40	125	°C

Note 2. The device is not guaranteed to function outside its operating ratings.

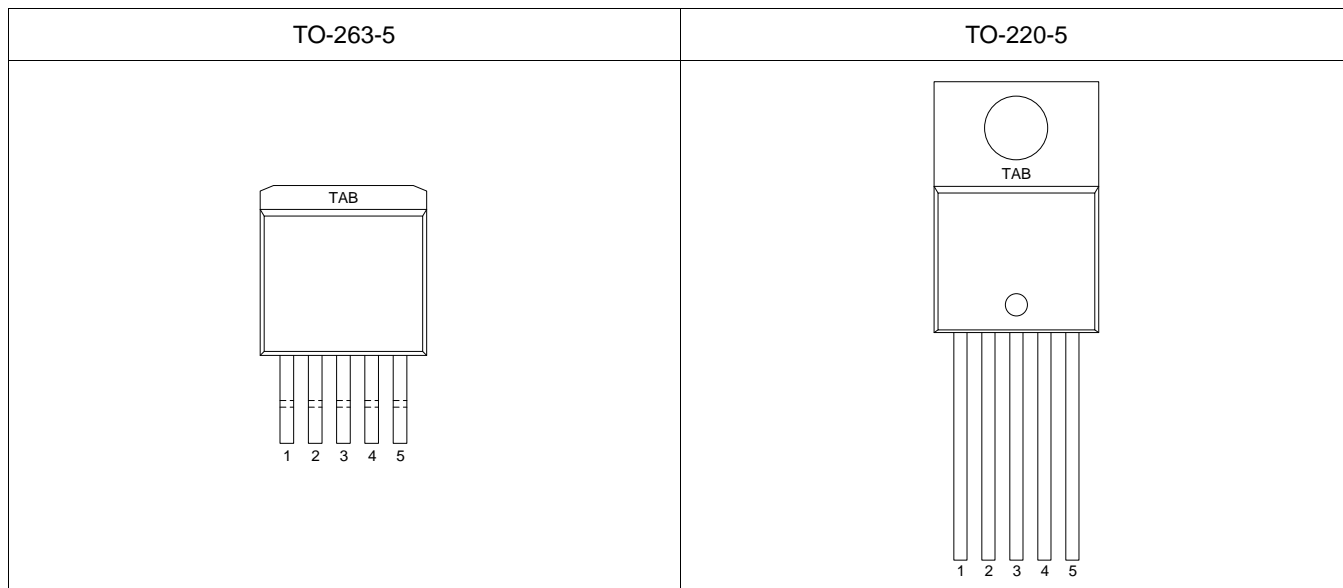
THERMAL INFORMATION

THERMAL METRIC	θ_{JA}	θ_{JC}	UNIT
Thermal Resistance, TO-263-5L	70	5	°C/W
Thermal Resistance, TO-220-5L	65	5	°C/W

ORDERING INFORMATION

VOUT	Package	Order No.	Description	Supplied As	Status
ADJ	TO-263-5L	LM2596GR-ADJ	Adjustable Output	Tape & Reel	Contact Us
	TO-220-5L	LM2596GT-ADJ	Adjustable Output	Tube	Contact Us
3.3V	TO-263-5L	LM2596GR-3.3	3.3V Fixed Output	Tape & Reel	Contact Us
	TO-220-5L	LM2596GT-3.3	3.3V Fixed Output	Tube	Contact Us
5.0V	TO-263-5L	LM2596GR-5.0	5.0V Fixed Output	Tape & Reel	Active
	TO-220-5L	LM2596GT-5.0	5.0V Fixed Output	Tube	Contact Us
12V	TO-263-5L	LM2596GR-12	12V Fixed Output	Tape & Reel	Contact Us
	TO-220-5L	LM2596GT-12	12V Fixed Output	Tube	Contact Us

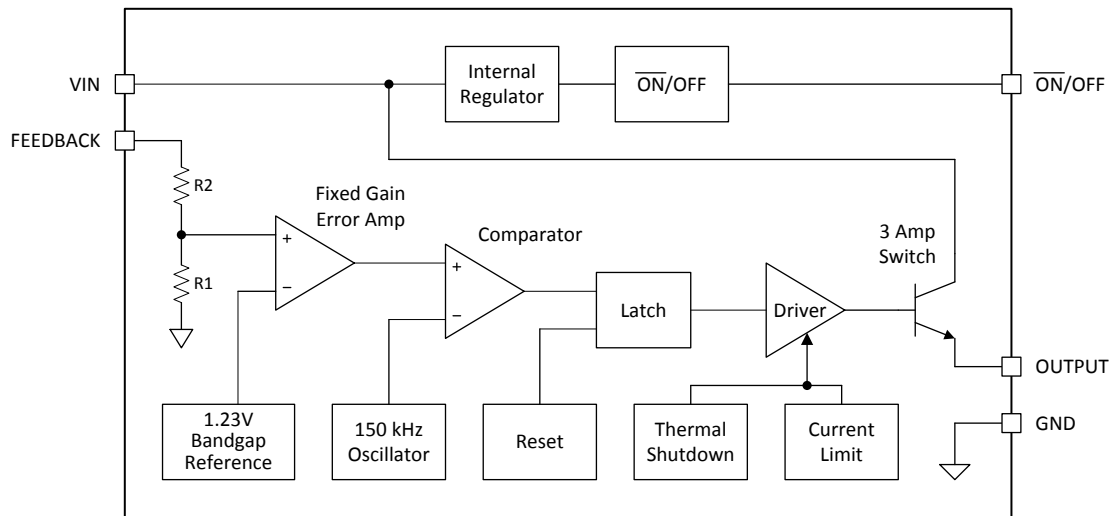
PIN CONFIGURATION



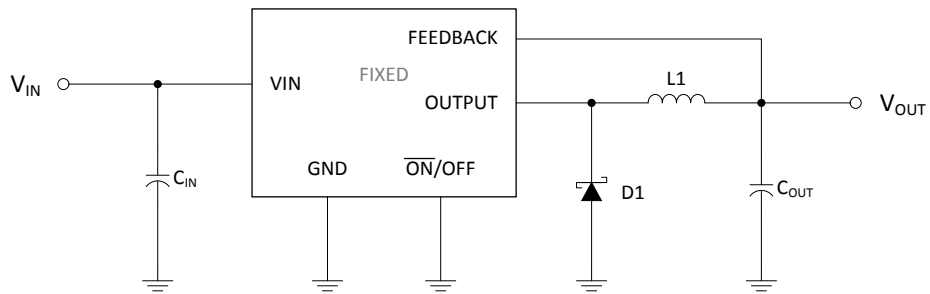
PIN DESCRIPTION

Pin No.		Pin Name	Pin Function
TO-263-5	TO-220-5		
1	1	VIN	Supply input pin to collector pin of power transistor. Connect to power supply and input bypass capacitors C_{IN} . Path from VIN pin to high frequency bypass C_{IN} and GND must be as short as possible to minimize voltage transients.
2	2	OUTPUT	Emitter pin of the power transistor. This is a switching node. Attached this pin to an inductor and the cathode of the external diode. It should be kept in mind that the PCB area connected to this pin should be kept to a minimum in order to minimize coupling to sensitive circuitry.
3	3	GND	Ground pin. Path to C_{IN} must be as short as possible.
4	4	FEEDBACK	Feedback sense input pin. Connect to the midpoint of feedback divider to set V_{OUT} for ADJ version or connect this pin directly to the output capacitor for a fixed output version.
5	5	$\overline{ON/OFF}$	Enable input to the voltage regulator. It allows the switching regulator circuit to be shutdown using logic level signals. Applying level high shuts the regulator off. If the voltage applied to this pin is level low, the regulator will be in the ON condition. Do not leave this pin float.
TAB	TAB	TAB	Connect to GND. Attached to heatsink for thermal relief for TO-220 package or put a copper plane connected to this pin as a thermal relief for TO-263 package.

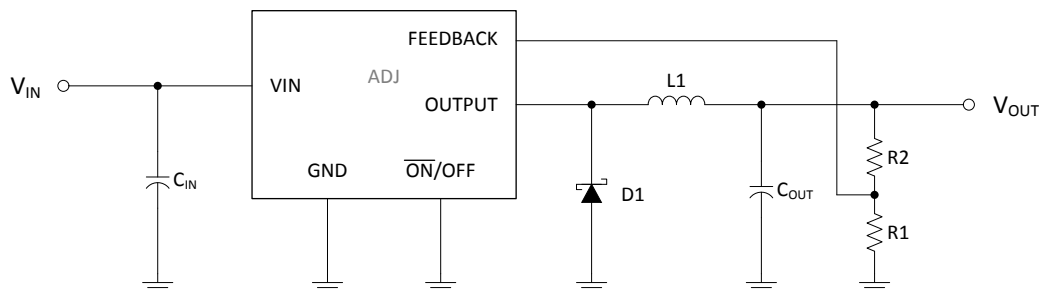
BLOCK DIAGRAM



TYPICAL APPLICATION CIRCUIT



< Fixed Output Voltage Version >



< Adjustable Output Voltage Version >

* External components such as the catch diode (D1), inductor (L1), input and output capacitors and PCB layout can affect switching regulator system performance. For the details, refer to the *Application Information* and *PCB Layout Guidelines*.

ELECTRICAL CHARACTERISTICS

Specification with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full operating temperature range in the *Recommended Operating Ratings*.

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNIT
3.3V Output ^(Note 3)						
Output Voltage	V_{OUT}	$V_{IN} = 12\text{V}, I_{LOAD} = 0.5\text{A}$	3.234	3.3	3.366	V
Output Voltage	V_{OUT}	$6.0\text{V} \leq V_{IN} \leq 40\text{V}, 0.5\text{A} \leq I_{LOAD} \leq 3.0\text{A}$	3.168 3.135	3.3 -	3.432 3.465	V
Efficiency	η	$V_{IN} = 12\text{V}, I_{LOAD} = 3.0\text{A}$	-	73	-	%
5.0V Output ^(Note 3)						
Output Voltage	V_{OUT}	$V_{IN} = 12\text{V}, I_{LOAD} = 0.5\text{A}$	4.900	5.0	5.100	V
Output Voltage	V_{OUT}	$8.0\text{V} \leq V_{IN} \leq 40\text{V}, 0.5\text{A} \leq I_{LOAD} \leq 3.0\text{A}$	4.800 4.750	5.0 -	5.200 5.250	V
Efficiency	η	$V_{IN} = 12\text{V}, I_{LOAD} = 3.0\text{A}$	-	80	-	%
12V Output ^(Note 3)						
Output Voltage	V_{OUT}	$V_{IN} = 25\text{V}, I_{LOAD} = 0.5\text{A}$	11.76	12	12.24	V
Output Voltage	V_{OUT}	$15\text{V} \leq V_{IN} \leq 40\text{V}, 0.5\text{A} \leq I_{LOAD} \leq 3.0\text{A}$	11.52 11.40	12 -	12.48 12.60	V
Efficiency	η	$V_{IN} = 25\text{V}, I_{LOAD} = 3.0\text{A}$	-	90	-	%
Adjustable Output ^(Note 3)						
Feedback Voltage	V_{FB}	$V_{IN} = 12\text{V}, I_{LOAD} = 0.5\text{A}, V_{OUT} = 3.0\text{V}$	1.217	1.23	1.243	V
Feedback Voltage	V_{FB}	$8.0\text{V} \leq V_{IN} \leq 40\text{V}, 0.5\text{A} \leq I_{LOAD} \leq 3.0\text{A},$ $V_{OUT} = 3.0\text{V}$	1.193 1.180	1.23 -	1.267 1.280	V
Efficiency	η	$V_{IN} = 12\text{V}, I_{LOAD} = 3.0\text{A}, V_{OUT} = 3.0\text{V}$	-	73	-	%

Note 3. External components such as catch diode, inductor, input and output capacitors can affect switching regulator system performance.

ELECTRICAL CHARACTERISTICS (continued)

Specification with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full operating temperature range in Recommended Operating Ratings. Unless otherwise specified, $V_{IN} = 12\text{V}$ for the 3.3V, 5.0V, and Adjustable version, and $V_{IN} = 25\text{V}$ for the 12V version. $I_{LOAD} = 500\text{mA}$.

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNIT
All Output Voltage Versions						
Feedback Bias Current	I_B	$V_{OUT} = 3.0\text{V}$ (Adjustable Version Only)	-	15	50	nA
Oscillator Frequency	f_O		127	150	173	kHz
Saturation Voltage	V_{SAT}	$I_{OUT} = 3.0\text{A}$ (Note 4,5)	-	1.26	1.4	V
			-	-	1.5	
Max Duty Cycle (Note 5)	DC	(ON)	-	100	-	%
Current Limit (Note 4,5)	I_{CL}	Peak Current	3.4	4.5	6.0	A
Output Leakage Current (Note 4,5)	I_L	Output = 0V	-	-	25	μA
		Output = -1.0V (Note 7)	-	1.0	10	mA
Quiescent Current (Note 6)	I_Q		-	5.0	10	mA
Standby Quiescent Current	I_{STBY}	$\overline{\text{ON}}/\text{OFF}$ pin = 5.0V (OFF)	-	100	200	μA
$\overline{\text{ON}}/\text{OFF}$ Pin Input Level	V_{IH}	$V_{OUT} = 0\text{V}$	2.0	1.3	-	V
	V_{IL}	$V_{OUT} = \text{Nominal Output Voltage}$	-	1.3	0.6	V
$\overline{\text{ON}}/\text{OFF}$ Pin Input Current	I_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin = 2.5V (OFF)	-	5.0	15	μA
	I_{IL}	$\overline{\text{ON}}/\text{OFF}$ Pin = 0.5V (ON)	-	-	5	μA

Note 4. OUTPUT pin sourcing current. No diode, inductor or capacitor connected to OUTPUT.

Note 5. FEEDBACK pin removed from output and connected to 0V to force the output transistor switch ON.

Note 6. FEEDBACK pin removed from output and connected to +12V for the 3.3V, 5.0V, and Adjustable versions, and 25V for the 12V version, to force the output transistor OFF.

Note 7. $V_{IN} = 40\text{V}$.

TYPICAL OPERATING CHARACTERISTICS

T.B.D.

APPLICATION INFORMATION

OVERVIEW

The LM2596G regulator is an easy-to-use, non-synchronous step-down DC-DC converter with a wide input voltage range up to 40V. It is capable of delivering up to 3.0A DC load current with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5.0V, 12V, and an adjustable output version. The family requires few external components, and the pin arrangement was designed for simple, optimum PCB layout.

INPUT CAPACITOR

To maintain stability, the regulator input pin must be bypassed with at least a 100µF electrolytic capacitor. The capacitor's leads must be kept short, and placed near the regulator.

If the operating temperature range includes temperatures below 25°C, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor increases the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the RMS ripple current rating of the capacitor must be greater than:

$$1.2 \times \left(\frac{t_{ON}}{T} \right) \times I_{LOAD}$$

$$\text{where } \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}} \text{ for a buck regulator}$$

$$\text{and } \frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}} \text{ for a buck-boost regulator}$$

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2596G can be used for both continuous and discontinuous modes of operation.

When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current is approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit is forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 300mA), it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation.

Inductors are available in different styles such as pot core, toroid, E-frame, bobbin core, and so on, as well as different core materials, such as ferrites and powdered iron. The bobbin core is the least expensive type, and consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor; however, because the magnetic flux is not completely contained within the core, the bobbin core generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

An inductor must not operate beyond its maximum-rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly, and the inductor begins to look mainly resistive (the DC resistance of the winding), causing the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this must be considered when selecting an inductor.

The inductor manufacturer's data sheets include an energy limit to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the regulator is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform reaches zero, and the regulator changes to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) is forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor must be placed near the LM2596G using short PCB traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, including: the value, the voltage rating, physical size, and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See *Inductor Ripple Current*.

The lower capacitor values (220 μ F to 1000 μ F) allow typically 50mV to 150mV of output ripple voltage, while larger-value capacitors reduce the ripple to approximately 20mV to 50mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND}) (\text{ESR of } C_{OUT})$$

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called high-frequency, low-inductance, or low-ESR. These reduce the output ripple to 10mV or 20mV. However, when operating in the continuous mode, reducing the ESR below 0.03 Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and must be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The ripple current rating of the capacitor at 150kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode must be placed close to the LM2596G using short leads and short printed-circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-recovery, high-efficiency, or ultra-fast recovery diodes are also suitable, but some types with an abrupt turnoff characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60Hz diodes

(for example, 1N4001 or 1N5400, and so on) are also not suitable. See Table 2 for Schottky and soft fast recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply contains a sawtooth ripple voltage at the regulator frequency, typically about 1% of the output voltages, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by ESR of the output capacitor (See *Inductor Selection*).

The voltage spikes are present because of the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20µH and 100µF) can be added to the output to further reduce the amount of output ripple and transients. A reduction by 10 times in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2596G (fixed voltage versions) FEEDBACK pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2596G to avoid picking up unwanted noise. Avoid using resistors greater than 100kΩ because of the increased change of noise pickup. Adjustable output voltage can be programmed with the following equation:

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

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

where $V_{REF} = 1.23V$, $R1$ between 1.0k and 5.0k

ON/OFF INPUT

The $\overline{ON/OFF}$ pin provides electrical ON and OFF control for the LM2596G.

For normal operation, the $\overline{ON/OFF}$ pin must be grounded or driven with a low-level TTL voltage. When the voltage of the $\overline{ON/OFF}$ pin is below 1.2V, the device starts switching, and the output voltage rises until it reaches the normal regulation voltage.

To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. When the voltage of this pin is higher than 1.4V, the device is in shutdown mode. The typical standby current in this mode is 60µA.

The $\overline{ON/OFF}$ pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{ON/OFF}$ pin must not be left open.

CURRENT LIMIT

The LM2596G device has current limiting to prevent the switch current from exceeding safe values during an accidental overload on the output. This current limit value can be found in *Electrical Characteristics: All Output Voltage Versions* under the heading of I_{CL} .

The LM2596G uses cycle-by-cycle peak current limit for overload protection. This helps to prevent damage to the device and external components. The regulator operates in current limit mode whenever the inductor if the load current is greater than 3A or the converter is starting up. Keep in mind that the maximum available load current

depends on the input voltage, output voltage, and inductor value.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance. For the 5 lead TO-263 and TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

HEAT SINK AND THERMAL CONSIDERATIONS

In many cases, only a small heat sink is required to keep the LM2596G junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (125°C for the LM2596G). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperatures should be selected.
4. LM2596G package thermal resistances θ_{JA} and θ_{JC} .

Total power dissipated by the LM2596G can be estimated as follows:

$$P_D = (V_{IN}) (I_Q) + (V_O / V_{IN}) (I_{LOAD}) (V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in *Typical Operating Characteristics* shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{JC} + \theta_{interface} + \theta_{Heatsink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

PCB LAYOUT

PCB LAYOUT GUIDELINES

As in any switching regulator, the layout of the printed circuit board is very important for the operation of switching power supplies. Switch mode converters are very fast switching devices. Rapidly switching currents associated with wiring inductance, stray capacitance and parasitic inductance of the printed circuit board traces can generate unwanted voltage transients which can generate electromagnetic interferences (EMI) and affect the desired operation. Therefore, appropriate guidelines must be followed to reduce the effects of switching noise.

The most important layout rule is to keep the AC current loops as small as possible. Figure 5 shows the current flow in a buck converter. The top schematic shows a dotted line which represents the current flow during the top-switch ON-state. The middle schematic shows the current flow during the top-switch OFF-state. The bottom schematic shows the currents referred to as AC currents. These AC currents are the most critical because they are changing in a very short time period. The dotted lines of the bottom schematic are the traces to keep as short and wide as possible. This also yields a small loop area reducing the loop inductance.

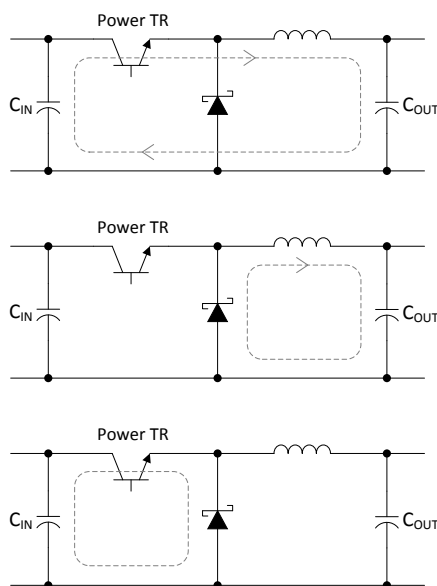


Figure 5. Current Flow in Buck Application

PCB LAYOUT PROCEDURE

General points of PCB layout procedure are as follows:

1. Place the input capacitor and the catch diode on the same PCB surface layer as the IC terminal and as close as possible to IC.
2. Do not omit placing input decoupling/bypass ceramic capacitor (0.1 μ F to 0.47 μ F).
3. Place inductor close to IC but no need to be as close as input capacitor. And do not expand copper area on switching node (OUTPUT) more than needed. The PCB area connected to the OUTPUT of the IC should be kept to a minimum in order to minimize radiation noise from the switching node to sensitive circuitry.
4. Place output capacitor close to inductor.
5. Another sensitive part of the circuit is the feedback. It is important to keep the sensitive feedback wiring short. Route feedback trace away from noise causing sources, such as the inductor and the diode. To assure this, physically locate the programming resistors near to the regulator, when using the adjustable version of the

regulator.

6. Connect thermal vias to a ground plane if available to improve thermal dissipation.

The ground plane area must be sufficient for thermal dissipation purposes. It is recommended to use at least 2oz copper boards to help thermal dissipation and reduce parasitic inductances of board traces.

Review the PCB layout example as shown in Figure 7.

PCB LAYOUT EXAMPLE

Review the PCB layout example as shown in Figure 7.

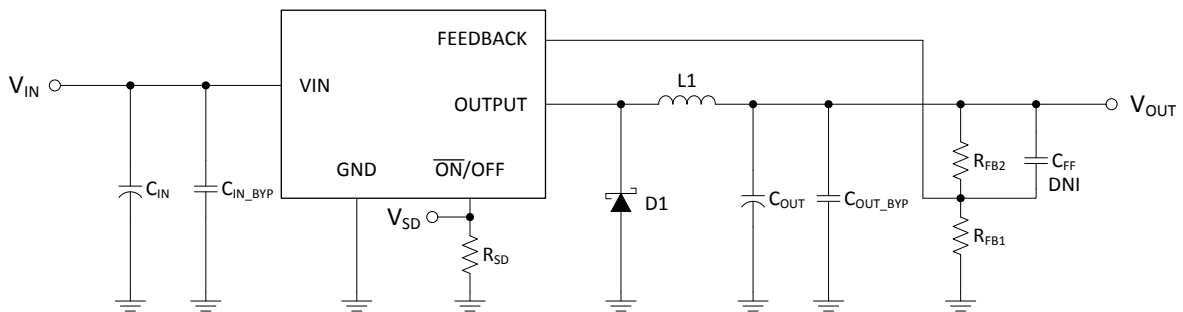


Figure 6. Schematic for PCB Layout Example

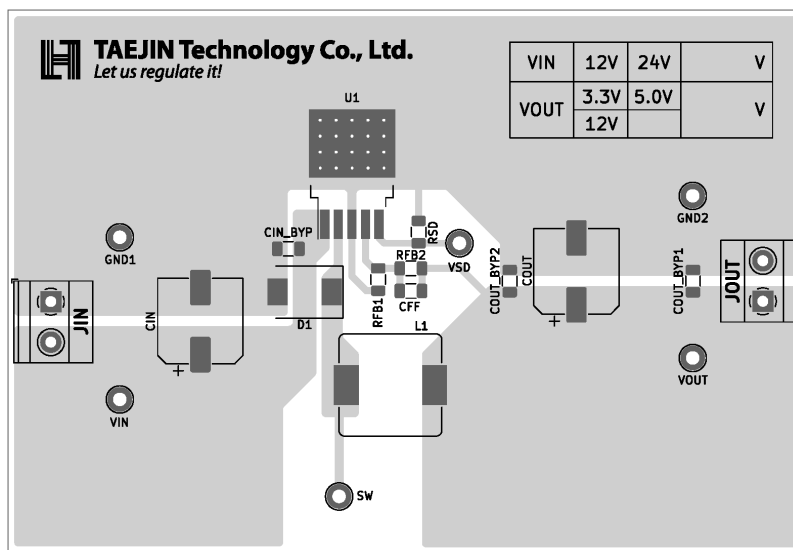


Figure 7. PCB Layout Example

REVISION NOTICE

The description in this datasheet is subject to change without any notice to describe its electrical characteristics properly.