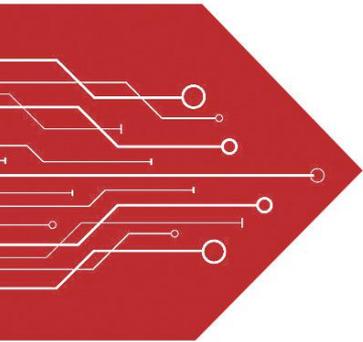
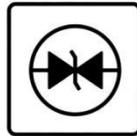


# MSKSEMI

SEMICONDUCTOR



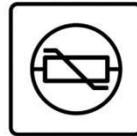
ESD



TVS



TSS



MOV



GDT



PLED

Product data sheet

## 3A Step-Down Voltage Regulator

### General Description

The LM2596 /LM2596HV series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation†, and a fixed-frequency oscillator.

The LM2596 /LM2596HV series operates at a switching frequency of 150 kHz thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Available in a standard 5-lead TO-220 package with several different lead bend options, and a 5-lead TO-262 surface mount package.

A standard series of inductors are available from several different manufacturers optimized for use with the LM2596 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed  $\pm 4\%$  tolerance on output voltage under specified input voltage and output load conditions, and  $\pm 15\%$  on the oscillator frequency. External shutdown is included, featuring typically 80  $\mu\text{A}$  standby current. Self protection features include a two stage frequency reducing current limit for the output switch and an over temperature shutdown for complete protection under fault conditions.

### Features

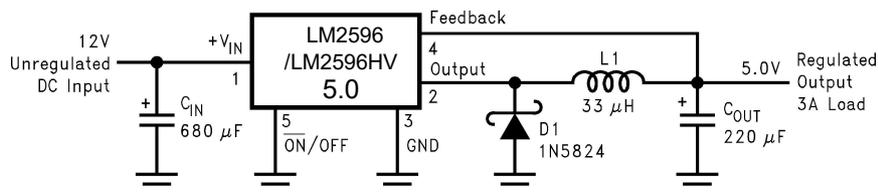
- n 3.3V, 5V, 12V, and adjustable output versions
- n Adjustable version output voltage range, 1.2V to 37V (57V for HV version)  $\pm 4\%$  max over line and load conditions
- n Available in TO-220 and TO-263, TO-220B packages
- n Guaranteed 3A output load current
- n Input voltage range up to 40V
- n Requires only 4 external components
- n Excellent line and load regulation specifications
- n 150 kHz fixed frequency internal oscillator
- n TTL shutdown capability
- n Low power standby mode,  $I_q$  typically 80  $\mu\text{A}$
- n High efficiency
- n Uses readily available standard inductors
- n Thermal shutdown and current limit protection

### Applications

- n Simple high-efficiency step-down (buck) regulator
- n On-card switching regulators
- n Positive to negative converter

**Note:** †Patent Number 5,382,918.

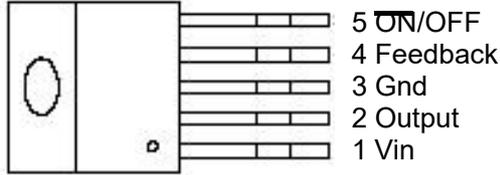
### Typical Application (Fixed Output Voltage Versions)



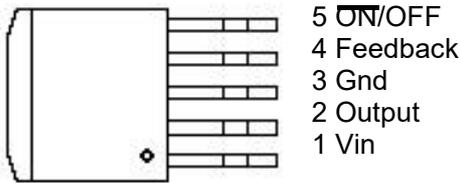
### Package Types



## Pin Assignments



TO220B-5L/TO220-5L



TO263-5L

## Pin Descriptions

| Name     | Description                                    |
|----------|--|
| Vin      | Input supply voltage                           |
| Output   | Switching output                               |
| Gnd      | Ground   |
| Feedback | Output voltage feedback                        |
| ON/OFF   | ON/OFF shutdown<br>Active is "Low" or floating |

## Ordering information

| Temperature Range                                       | Output Voltage, V |                |               |                 | Package Type |
|---|-------------------|----------------|---------------|-----------------|--------------|
|   | 3.3               | 5.0            | 12            | ADJ             |              |
| $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ | LM2596HVS-3.3     | LM2596HVS -5.0 | LM2596HVS -12 | LM2596HVS -ADJ  | TO-263       |
|   | LM2596S -3.3      | LM2596S - 5.0  | LM2596S -12   | LM2596S -ADJ    |              |
|   | LM2596HVT -3.3    | LM2596HVT -5.0 | LM2596HVT -12 | LM2596HVT - ADJ | TO-220       |
|   | LM2596T -3.3      | LM2596T - 5.0  | LM2596T -12   | LM2596T -ADJ    |              |

## Absolute Maximum Ratings

Maximum Supply Voltage

LM2596 45V  
LM2596HV 57V

ON/OFF Pin Input Voltage  $-0.3 \leq V \leq +25\text{V}$

Feedback Pin Voltage  $-0.3 \leq V \leq +25\text{V}$

Output Voltage to Ground (Steady State) -1V

Power Dissipation Internally limited

Storage Temperature Range  $-65^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$

ESD Susceptibility HumanBodyModel 2kV

Lead Temperature

S Package  
Vapor Phase (60 sec.)  $+215^{\circ}\text{C}$   
Infrared (10 sec.)  $+245^{\circ}\text{C}$

T Package (Soldering, 10 sec.)  $+260^{\circ}\text{C}$

Maximum Junction Temperature  $+150^{\circ}\text{C}$

## Operating Conditions

Temperature Range  $-40^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$

Supply Voltage  
LM2596 40V  
LM2596HV 57V

### Electrical Characteristics LM2596- 3.3,LM2596HV -3.3

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over full Operating Temperature Range

| Symbol   | Parameter      | Conditions  | LM2596 -3.3<br>LM2596HV -3.3 |  | Units<br>(Limits)     |
|--|----------------|---|------------------------------|--|-----------------------|
|  |                |   | Typ                          | Limit                                      |                       |
| <b>SYSTEM PARAMETERS</b> (Note 5) Test Circuit <i>Figure 1</i> |                |   |                              |  |                       |
| $V_{OUT}$  | Output Voltage | $4.75\text{V} \leq V_{IN} \leq 40\text{V}$ , $0.2\text{A} \leq I_{LOAD} \leq 3\text{A}$ | 3.3                          | 3.168/ <b>3.135</b><br>3.432/ <b>3.465</b> | V<br>V(min)<br>V(max) |
| $\eta$   | Efficiency     | $V_{IN} = 12\text{V}$ , $I_{LOAD} = 3\text{A}$  | 73                           |  | %                     |

### Electrical Characteristics LM2596-5.0,LM2596HV-5.0

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over full Operating Temperature Range

| Symbol   | Parameter      | Conditions   | LM2596 -5.0<br>LM2596HV -5.0 |  | Units<br>(Limits)     |
|--|----------------|--|------------------------------|--|-----------------------|
|  |                |  | Typ                          | Limit                                      |                       |
| <b>SYSTEM PARAMETERS</b> (Note 5) Test Circuit <i>Figure 1</i> |                |  |                              |  |                       |
| $V_{OUT}$  | Output Voltage | $7\text{V} \leq V_{IN} \leq 40\text{V}$ , $0.2\text{A} \leq I_{LOAD} \leq 3\text{A}$ | 5.0                          | 4.800/ <b>4.750</b><br>5.200/ <b>5.250</b> | V<br>V(min)<br>V(max) |
| $\eta$   | Efficiency     | $V_{IN} = 12\text{V}$ , $I_{LOAD} = 3\text{A}$                                       | 80                           |  | %                     |

### Electrical Characteristics LM2596-12,LM2596HV-12

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over full Operating Temperature Range

| Symbol   | Parameter      | Conditions  | LM2596 -12<br>LM2596HV -12 |  | Units<br>(Limits)     |
|--|----------------|---|----------------------------|--|-----------------------|
|  |                |   | Typ                        | Limit                                      |                       |
| <b>SYSTEM PARAMETERS</b> (Note 5) Test Circuit <i>Figure 1</i> |                |   |                            |  |                       |
| $V_{OUT}$  | Output Voltage | $15\text{V} \leq V_{IN} \leq 40\text{V}$ , $0.2\text{A} \leq I_{LOAD} \leq 3\text{A}$ | 12.0                       | 11.52/ <b>11.40</b><br>12.48/ <b>12.60</b> | V<br>V(min)<br>V(max) |
| $\eta$   | Efficiency     | $V_{IN} = 25\text{V}$ , $I_{LOAD} = 3\text{A}$  | 90                         |  | %                     |

## Electrical Characteristics LM2596-ADJ, LM2596HV-ADJ

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over full Operating Temperature Range

| Symbol   | Parameter        | Conditions  | LM2596 -ADJ<br>LM2596HV -ADJ |  | Units<br>(Limits)     |
|--|------------------|---|------------------------------|--|-----------------------|
|  |                  |   | Typ                          | Limit                                      |                       |
| <b>SYSTEM PARAMETERS</b> (Note 5) Test Circuit <i>Figure 1</i> |                  |   |                              |  |                       |
| $V_{FB}$   | Feedback Voltage | $4.5\text{V} \leq V_{IN} \leq 40\text{V}$ , $0.2\text{A} \leq I_{LOAD} \leq 3\text{A}$<br>$V_{OUT}$ programmed for 3V. Circuit of <i>Figure 1</i> | 1.230                        | 1.193/ <b>1.180</b><br>1.267/ <b>1.280</b> | V<br>V(min)<br>V(max) |
| $\eta$   | Efficiency       | $V_{IN} = 12\text{V}$ , $V_{OUT} = 3\text{V}$ , $I_{LOAD} = 3\text{A}$  | 73                           |  | %                     |

## All Output Voltage Versions Electrical Characteristics

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified,  $V_{IN} = 12\text{V}$  for the 3.3V, 5V, and Adjustable version and  $V_{IN} = 24\text{V}$  for the 12V version.  $I_{LOAD} = 500\text{mA}$

| Symbol                   | Parameter                                   | Conditions                                      | LM2596-XX<br>LM2596HV-XX |                                    | Units<br>(Limits)                    |
|--------------------------|---|---|--------------------------|------------------------------------|--------------------------------------|
|                          |   |   | Typ                      | Limit                              |                                      |
| <b>DEVICE PARAMETERS</b> |   |   |                          |                                    |                                      |
| $I_b$                    | Feedback Bias Current                       | Adjustable Version Only, $V_{FB} = 1.3\text{V}$ | 10                       | 50/ <b>100</b>                     | nA<br>nA (max)                       |
| $f_o$                    | Oscillator Frequency                        | (Note 6)  | 150                      | 127/ <b>110</b><br>173/ <b>173</b> | kHz<br>kHz(min)<br>kHz(max)          |
| $V_{SAT}$                | Saturation Voltage                          | $I_{OUT} = 3\text{A}$ (Notes 7, 8)              | 1.16                     | 1.4/ <b>1.5</b>                    | V<br>V(max)                          |
| DC                       | Max Duty Cycle (ON)<br>Min Duty Cycle (OFF) | (Note 8)<br>(Note 9)                            | 100<br>0                 |                                    | %                                    |
| $I_{CL}$                 | Current Limit                               | Peak Current (Notes 7, 8)                       | 4.5                      | 3.6/ <b>3.4</b><br>6.9/ <b>7.5</b> | A<br>A(min)<br>A(max)                |
| $I_L$                    | Output Leakage Current                      | Output = 0V (Notes 7, 9)                        |                          | 50                                 | $\mu\text{A}$ (max)                  |
|                          |   | Output = -1V (Note 10)                          | 2                        | 30                                 | mA<br>mA(max)                        |
| $I_Q$                    | Quiescent Current                           | (Note 9)  | 5                        | 10                                 | mA<br>mA(max)                        |
|                          |   |   |                          | 80                                 | 200/ <b>250</b>                      |
| $I_{STBY}$               | Standby Quiescent Current                   | ON/OFF pin = 5V (OFF) (Note 10)                 | 80                       | 200/ <b>250</b>                    | $\mu\text{A}$<br>$\mu\text{A}$ (max) |
| $\theta_{JC}$            | Thermal Resistance                          | TO-220 or TO-263 Package, Junction to Case      | 2                        |                                    | $^\circ\text{C}/\text{W}$            |
| $\theta_{JA}$            |   | TO-220 Package, Junction to Ambient (Note 11)   | 50                       |                                    | $^\circ\text{C}/\text{W}$            |
| $\theta_{JA}$            |   | TO-263 Package, Junction to Ambient (Note 12)   | 50                       |                                    | $^\circ\text{C}/\text{W}$            |
| $\theta_{JA}$            |   | TO-263 Package, Junction to Ambient (Note 13)   | 30                       |                                    | $^\circ\text{C}/\text{W}$            |
| $\theta_{JA}$            |   | TO-263 Package, Junction to Ambient (Note 14)   | 20                       |                                    | $^\circ\text{C}/\text{W}$            |

### ON/OFF CONTROL Test Circuit *Figure 1*

|          |  |                      |     |            |             |
|----------|--|----------------------|-----|------------|-------------|
| $V_{IH}$ | ON /OFF Pin Logic Input<br>Threshold Voltage | Low (Regulator ON)   | 1.3 | <b>0.6</b> | V<br>V(max) |
| $V_{IL}$ |  | High (Regulator OFF) |     | <b>2.0</b> | V(min)      |

## All Output Voltage Versions

### Electrical Characteristics (Continued)

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified,  $V_{IN} = 12\text{V}$  for the 3.3V, 5V, and Adjustable version and  $V_{IN} = 24\text{V}$  for the 12V version.  $I_{LOAD} = 500\text{mA}$

| Symbol | Parameter                 | Conditions                                | LM2596 -XX<br>LM2596HV-XX |       | Units<br>(Limits)                   |
|--------|---------------------------|---|---------------------------|-------|-------------------------------------|
|        |                           |   | Typ                       | Limit |                                     |
| $I_H$  | ON /OFF Pin Input Current | $V_{LOGIC} = 2.5\text{V}$ (Regulator OFF) | 5                         | 15    | $\mu\text{A}$<br>$\mu\text{A(max)}$ |
| $I_L$  |                           | $V_{LOGIC} = 0.5\text{V}$ (Regulator ON)  | 0.02                      | 5     | $\mu\text{A}$<br>$\mu\text{A(max)}$ |

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

**Note 2:** The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

**Note 3:** Typical numbers are at  $25^\circ\text{C}$  and represent the most likely norm.

**Note 4:** All limits guaranteed at room temperature (standard type face) and at temperature extremes (bold type face). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).

**Note 5:** External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2596 is used as shown in the *Figure 1* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

**Note 6:** The switching frequency is reduced when the second stage current limit is activated.

**Note 7:** No diode, inductor or capacitor connected to output pin.

**Note 8:** Feedback pin removed from output and connected to 0V to force the output transistor switch ON.

**Note 9:** Feedback pin removed from output and connected to 12V for the 3.3V, 5V, and the ADJ. version, and 15V for the 12V version, to force the output transistor switch OFF.

**Note 10:**  $V_{IN} = 40\text{V}$ .

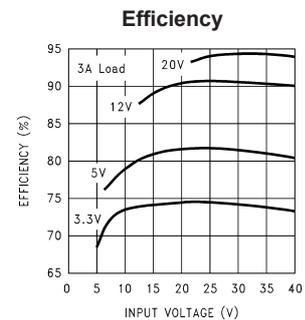
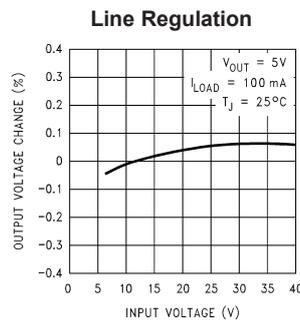
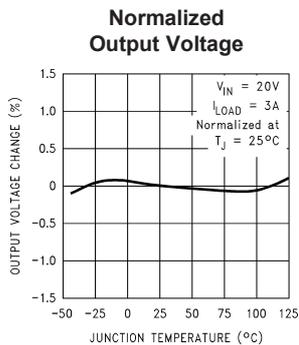
**Note 11:** Junction to ambient thermal resistance (no external heat sink) for the TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately  $1\text{ in}^2$ .

**Note 12:** Junction to ambient thermal resistance with the TO-263 package tab soldered to a single printed circuit board with  $0.5\text{ in}^2$  of (1 oz.) copper area.

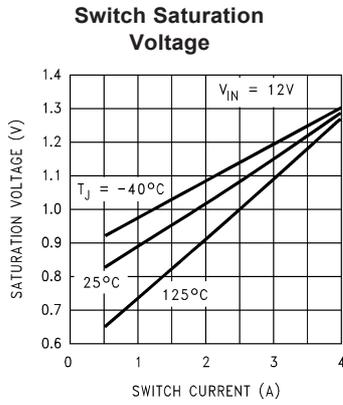
**Note 13:** Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with  $2.5\text{ in}^2$  of (1 oz.) copper area.

**Note 14:** Junction to ambient thermal resistance with the TO-263 package tab soldered to a double sided printed circuit board with  $3\text{ in}^2$  of (1 oz.) copper area on the LM2596S side of the board, and approximately  $16\text{ in}^2$  of copper on the other side of the p-c board. See Application Information in this data sheet and the thermal model in Switchers Made Simple™ version 4.3 software.

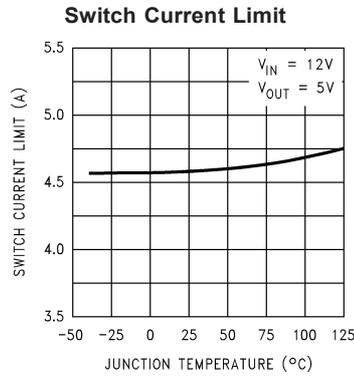
### Typical Performance Characteristics (Circuit of Figure 1)



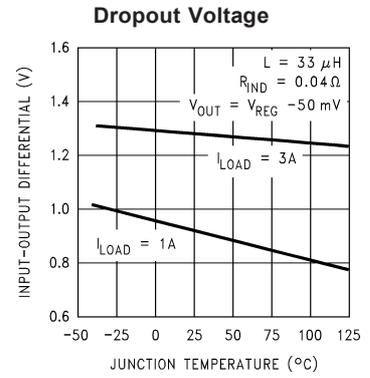
**Typical Performance Characteristics** (Circuit of Figure 1) (Continued)



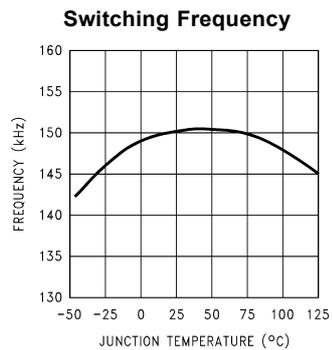
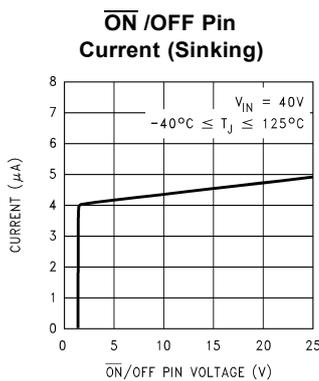
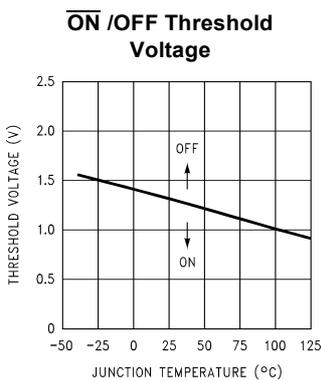
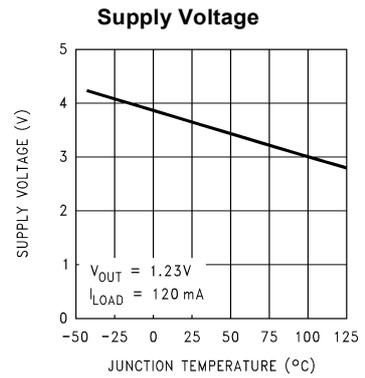
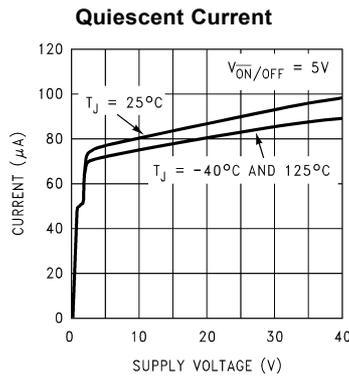
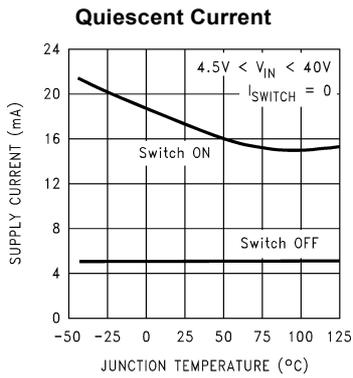
Operating



Shutdown



Minimum Operating



**LM2596/LM2596HV SeriesBuckRegulatorDesignProcedure(FixedOutput)(Continued)**

| Conditions         |                  |                       | Inductor        |              | Output Capacitor            |                           |                        |                            |
|--------------------|------------------|-----------------------|-----------------|--------------|-----------------------------|---------------------------|------------------------|----------------------------|
| Output Voltage (V) | Load Current (A) | Max Input Voltage (V) | Inductance (μH) | Inductor (#) | Through Hole Electrolytic   |                           | Surface Mount Tantalum |                            |
|                    |                  |                       |                 |              | Panasonic HFQ Series (μF/V) | Nichicon PL Series (μF/V) | AVX TPS Series (μF/V)  | Sprague 595D Series (μF/V) |
| 3.3                | 3                | 5                     | 22              | L41          | 470/25                      | 560/16                    | 330/6.3                | 390/6.3                    |
|                    |                  | 7                     | 22              | L41          | 560/35                      | 560/35                    | 330/6.3                | 390/6.3                    |
|                    |                  | 10                    | 22              | L41          | 680/35                      | 680/35                    | 330/6.3                | 390/6.3                    |
|                    |                  | 40                    | 33              | L40          | 560/35                      | 470/35                    | 330/6.3                | 390/6.3                    |
|                    | 2                | 6                     | 22              | L33          | 470/25                      | 470/35                    | 330/6.3                | 390/6.3                    |
|                    |                  | 10                    | 33              | L32          | 330/35                      | 330/35                    | 330/6.3                | 390/6.3                    |
|                    |                  | 40                    | 47              | L39          | 330/35                      | 270/50                    | 220/10                 | 330/10                     |
| 5                  | 3                | 8                     | 22              | L41          | 470/25                      | 560/16                    | 220/10                 | 330/10                     |
|                    |                  | 10                    | 22              | L41          | 560/25                      | 560/25                    | 220/10                 | 330/10                     |
|                    |                  | 15                    | 33              | L40          | 330/35                      | 330/35                    | 220/10                 | 330/10                     |
|                    |                  | 40                    | 47              | L39          | 330/35                      | 270/35                    | 220/10                 | 330/10                     |
|                    | 2                | 9                     | 22              | L33          | 470/25                      | 560/16                    | 220/10                 | 330/10                     |
|                    |                  | 20                    | 68              | L38          | 180/35                      | 180/35                    | 100/10                 | 270/10                     |
|                    |                  | 40                    | 68              | L38          | 180/35                      | 180/35                    | 100/10                 | 270/10                     |
| 12                 | 3                | 15                    | 22              | L41          | 470/25                      | 470/25                    | 100/16                 | 180/16                     |
|                    |                  | 18                    | 33              | L40          | 330/25                      | 330/25                    | 100/16                 | 180/16                     |
|                    |                  | 30                    | 68              | L44          | 180/25                      | 180/25                    | 100/16                 | 120/20                     |
|                    |                  | 40                    | 68              | L44          | 180/35                      | 180/35                    | 100/16                 | 120/20                     |
|                    | 2                | 15                    | 33              | L32          | 330/25                      | 330/25                    | 100/16                 | 180/16                     |
|                    |                  | 20                    | 68              | L38          | 180/25                      | 180/25                    | 100/16                 | 120/20                     |
|                    |                  | 40                    | 150             | L42          | 82/25                       | 82/25                     | 68/20                  | 68/25                      |

FIGURE 2. LM2596 Fixed Voltage Quick Design Component Selection Table

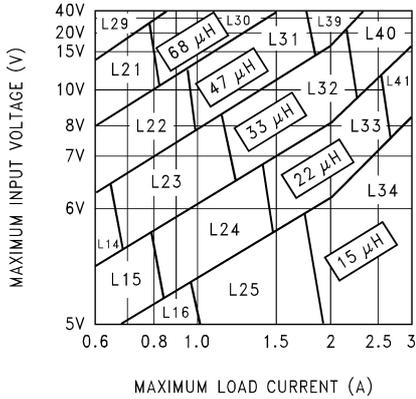
**LM2596/LM2596HV SeriesBuckRegulatorDesignProcedure(AdjustableOutput)**

| Output Voltage (V) | Through Hole Output Capacitor |                           |                       | Surface Mount Output Capacitor |                            |                       |
|--------------------|-------------------------------|---------------------------|-----------------------|--------------------------------|----------------------------|-----------------------|
|                    | Panasonic HFQ Series (μF/V)   | Nichicon PL Series (μF/V) | Feedforward Capacitor | AVX TPS Series (μF/V)          | Sprague 595D Series (μF/V) | Feedforward Capacitor |
| 2                  | 820/35                        | 820/35                    | 33 nF                 | 330/6.3                        | 470/4                      | 33 nF                 |
| 4                  | 560/35                        | 470/35                    | 10 nF                 | 330/6.3                        | 390/6.3                    | 10 nF                 |
| 6                  | 470/25                        | 470/25                    | 3.3 nF                | 220/10                         | 330/10                     | 3.3 nF                |
| 9                  | 330/25                        | 330/25                    | 1.5 nF                | 100/16                         | 180/16                     | 1.5 nF                |
| 12                 | 330/25                        | 330/25                    | 1 nF                  | 100/16                         | 180/16                     | 1 nF                  |
| 15                 | 220/35                        | 220/35                    | 680 pF                | 68/20                          | 120/20                     | 680 pF                |
| 24                 | 220/35                        | 150/35                    | 560 pF                | 33/25                          | 33/25                      | 220 pF                |
| 28                 | 100/50                        | 100/50                    | 390 pF                | 10/35                          | 15/50                      | 220 pF                |

FIGURE 3. Output Capacitor and Feedforward Capacitor Selection Table

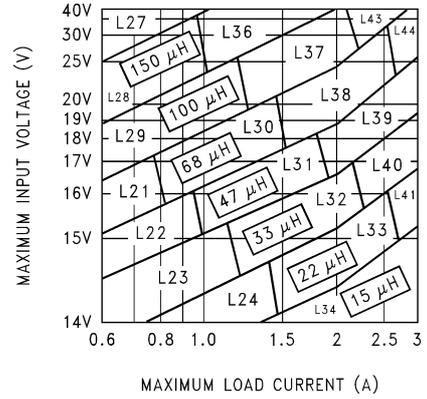
## LM2596/LM2596HV Series Buck Regulator Design Procedure

### INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)



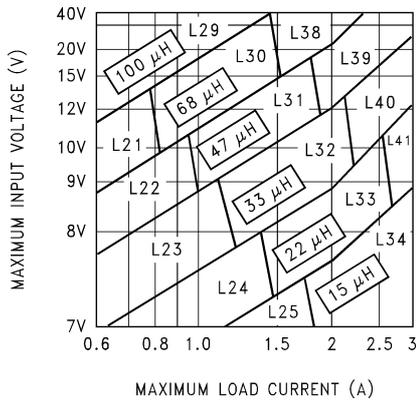
01258324

FIGURE 4. LM2596/LM2596HV-3.3



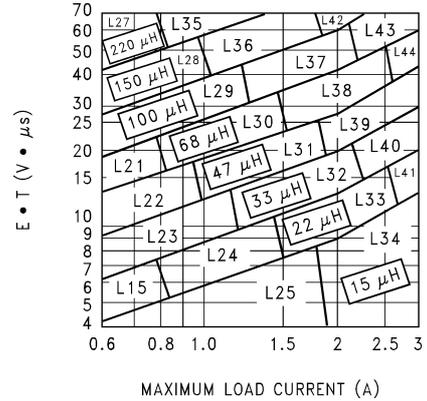
01258326

FIGURE 6. LM2596/LM2596HV-12



01258325

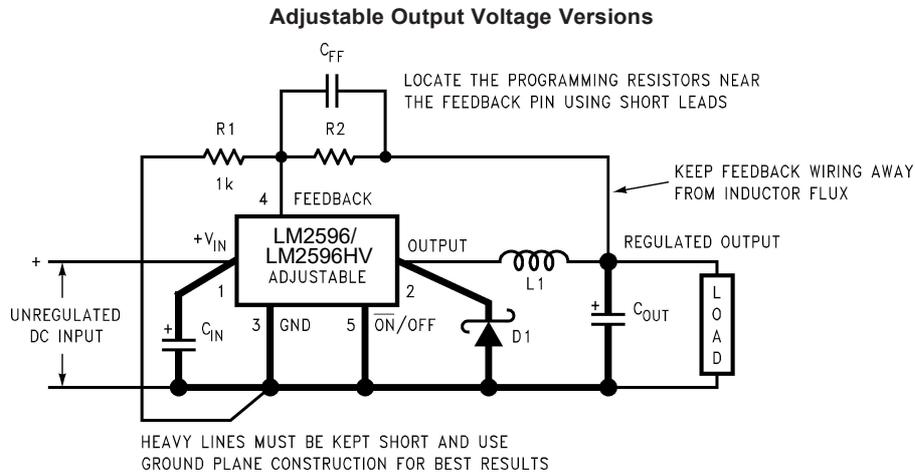
FIGURE 5. LM2596/LM2596HV-5.0



01258327

FIGURE 7. LM2596/LM2596HV-ADJ

**Test Circuit and Layout Guidelines** (Continued)



$$V_{OUT} = V_{REF} \left( 1 + \frac{R_2}{R_1} \right)$$

where  $V_{REF} = 1.23V$

$$R_2 = R_1 \left( \frac{V_{OUT}}{V_{REF}} - 1 \right)$$

Select  $R_1$  to be approximately 1 k $\Omega$ , use a 1% resistor for best stability.

$C_{IN}$  — 470  $\mu F$ , 50V, Aluminum Electrolytic Nichicon "PL Series"

$C_{OUT}$  — 220  $\mu F$ , 35V Aluminum Electrolytic, Nichicon "PL Series"

D1 — 5A, 40V Schottky Rectifier, 1N5825

L1 — 68  $\mu H$ , L38

R1 — 1 k $\Omega$ , 1%

$C_{FF}$  — See Application Information Section

**FIGURE 1. Standard Test Circuits and Layout Guides**

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance can generate voltage transients which can cause problems. For minimal inductance and ground loops, the wires indicated by **heavy lines should be wide printed circuit traces and should be kept as short as possible.** For best results, external components should be located as close to the switcher IC as possible using ground plane construction or single point grounding.

If **open core inductors are used**, special care must be taken as to the location and positioning of this type of inductor. Allowing the inductor flux to intersect sensitive feedback, IC groundpath and  $C_{OUT}$  wiring can cause problems.

When using the adjustable version, special care must be taken as to the location of the feedback resistors and the associated wiring. Physically locate both resistors near the IC, and route the wiring away from the inductor, especially an open core type of inductor. (See application section for more information.)

## LM2596 /LM2596HV Series Buck Regulator Design Procedure (Adjustable Output)

| PROCEDURE (Adjustable Output Voltage Version)  | EXAMPLE (Adjustable Output Voltage Version)  |
|--|--|
| <p><b>Given:</b><br/> <math>V_{OUT}</math> = Regulated Output Voltage<br/> <math>V_{IN(max)}</math> = Maximum Input Voltage<br/> <math>I_{LOAD(max)}</math> = Maximum Load Current<br/> <math>F</math> = Switching Frequency (<i>Fixed at a nominal 150 kHz</i>).</p> <p><b>1. Programming Output Voltage</b> (Selecting <math>R_1</math> and <math>R_2</math>, as shown in <i>Figure 1</i> )<br/>           Use the following formula to select the appropriate resistor values.</p> $V_{OUT} = V_{REF} \left( 1 + \frac{R_2}{R_1} \right) \text{ where } V_{REF} = 1.23V$ <p>Select a value for <math>R_1</math> between <math>240\Omega</math> and <math>1.5\text{ k}\Omega</math>. The lower resistor values minimize noise pickup in the sensitive feedback pin. (For the lowest temperature coefficient and the best stability with time, use 1% metal film resistors.)</p> $R_2 = R_1 \left( \frac{V_{OUT}}{V_{REF}} - 1 \right)$ <p><b>2. Inductor Selection (L1)</b><br/> <b>A.</b> Calculate the inductor Volt • microsecond constant <math>E \cdot T</math> (<math>V \cdot \mu s</math>), from the following formula:</p> $E \cdot T = (V_{IN} - V_{OUT} - V_{SAT}) \cdot \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D} \cdot \frac{1000}{150\text{ kHz}} (V \cdot \mu s)$ <p>where <math>V_{SAT}</math> = internal switch saturation voltage = <math>1.16V</math><br/>           and <math>V_D</math> = diode forward voltage drop = <math>0.5V</math></p> <p><b>B.</b> Use the <math>E \cdot T</math> value from the previous formula and match it with the <math>E \cdot T</math> number on the vertical axis of the Inductor Value Selection Guide shown in <i>Figure 7</i>.</p> <p><b>C.</b> on the horizontal axis, select the maximum load current.</p> <p><b>D.</b> Identify the inductance region intersected by the <math>E \cdot T</math> value and the Maximum Load Current value. Each region is identified by an inductance value and an inductor code (LXX).</p> <p><b>E.</b> Select an appropriate inductor from the four manufacturer's part numbers listed in <i>Figure 8</i>.</p> | <p><b>Given:</b><br/> <math>V_{OUT} = 20V</math><br/> <math>V_{IN(max)} = 28V</math><br/> <math>I_{LOAD(max)} = 3A</math><br/> <math>F</math> = Switching Frequency (<i>Fixed at a nominal 150 kHz</i>).</p> <p><b>1. Programming Output Voltage</b> (Selecting <math>R_1</math> and <math>R_2</math>, as shown in <i>Figure 1</i> )<br/>           Select <math>R_1</math> to be <math>1\text{ k}\Omega</math>, 1%. Solve for <math>R_2</math>.</p> $R_2 = R_1 \left( \frac{V_{OUT}}{V_{REF}} - 1 \right) = 1k \left( \frac{20V}{1.23V} - 1 \right)$ <p><math>R_2 = 1k (16.26 - 1) = 15.26k</math>, closest 1% value is <math>15.4\text{ k}\Omega</math>.<br/> <math>R_2 = 15.4\text{ k}\Omega</math>.</p> <p><b>2. Inductor Selection (L1)</b><br/> <b>A.</b> Calculate the inductor Volt • microsecond constant (<math>E \cdot T</math>),</p> $E \cdot T = (28 - 20 - 1.16) \cdot \frac{20 + 0.5}{28 - 1.16 + 0.5} \cdot \frac{1000}{150} (V \cdot \mu s)$ $E \cdot T = (6.84) \cdot \frac{20.5}{27.34} \cdot 6.67 (V \cdot \mu s) = 34.2 (V \cdot \mu s)$ <p><b>B.</b> <math>E \cdot T = 34.2 (V \cdot \mu s)</math><br/> <b>C.</b> <math>I_{LOAD(max)} = 3A</math><br/> <b>D.</b> From the inductor value selection guide shown in <i>Figure 7</i>, the inductance region intersected by the <math>34 (V \cdot \mu s)</math> horizontal</p> <p>L39.<br/> <b>E.</b> From the table in <i>Figure 8</i>, locate line L39, and select an</p> <p>bers.</p> |

**Block Diagram**

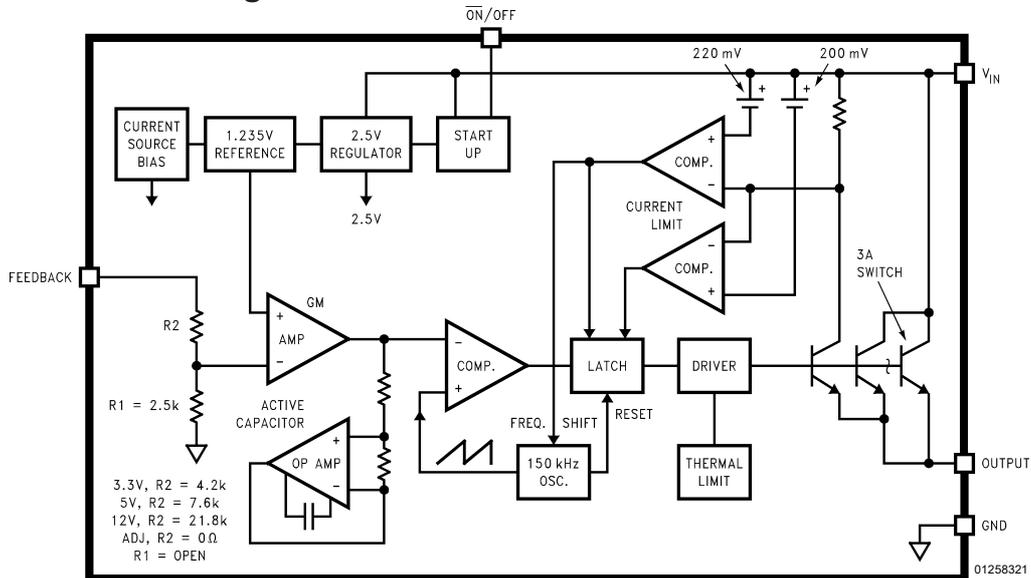


FIGURE 12.

**Application Information**

**PIN FUNCTIONS**

**+VIN** — This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents needed by the regulator.

**Ground** — Circuit ground.

**Output** — Internal switch. The voltage at this pin switches between (+VIN - VSAT) and approximately -0.5V, with a duty cycle of approximately VOUT/VIN. To minimize coupling to sensitive circuitry, the PC board copper area connected to this pin should be kept to a minimum.

**Feedback** — Senses the regulated output voltage to complete the feedback loop.

**ON /OFF** — Allows the switching regulator circuit to be shut down using logic level signals thus dropping the total input supply current to approximately 80 μA. Pulling this pin below a threshold voltage of approximately 1.3V turns the regulator on, and pulling this pin above 1.3V (up to a maximum of 25V) shuts the regulator down. If this shutdown feature is not needed, the ON /OFF pin can be wired to the ground pin or it can be left open, in either case the regulator will be in the ON condition.

**EXTERNAL COMPONENTS**

**INPUT CAPACITOR**

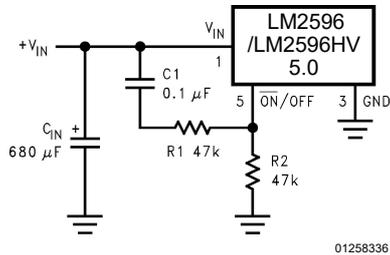
**CIN** — A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin. It must be located near the regulator using short leads. This capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous current needed each time the switch turns on.

The important parameters for the Input capacitor are the voltage rating and the RMS current rating. Because of the

relatively high RMS currents flowing in a buck regulator's input capacitor, this capacitor should be chosen for its RMS current rating rather than its capacitance or voltage ratings, although the capacitance value and voltage rating are directly related to the RMS current rating.

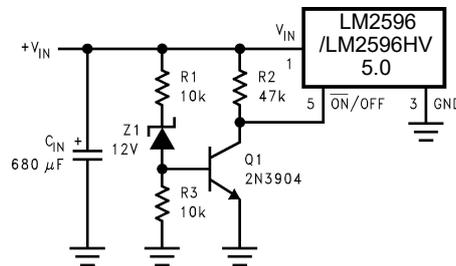
The RMS current rating of a capacitor could be viewed as a capacitor's power rating. The RMS current flowing through the capacitors internal ESR produces power which causes the internal temperature of the capacitor to rise. The RMS current rating of a capacitor is determined by the amount of current required to raise the internal temperature approximately 10°C above an ambient temperature of 105°C. The ability of the capacitor to dissipate this heat to the surrounding air will determine the amount of current the capacitor can safely sustain. Capacitors that are physically large and have a large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating.

**Application Information** (Continued)



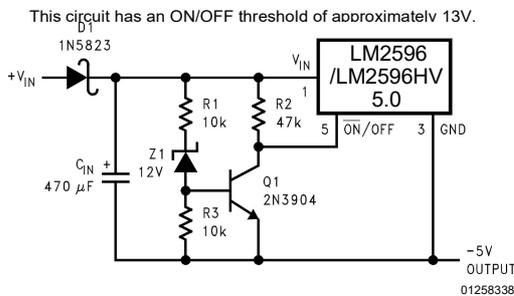
01258336

**FIGURE 21. Delayed Startup**



01258337

**FIGURE 22. Undervoltage Lockout for Buck Regulator**



01258338

**for Inverting Regulator**

**FIGURE 23. Undervoltage Lockout**

**DELAYED STARTUP**

The circuit in *Figure 21* uses the the  $\overline{\text{ON}}/\text{OFF}$  pin to provide a time delay between the time the input voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start up is shown). As the input voltage rises, the charging of capacitor C1 pulls the  $\overline{\text{ON}}/\text{OFF}$  pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, and resistor R2 pulls the  $\overline{\text{ON}}/\text{OFF}$  pin low, thus allowing the circuit to start switching. Resistor R1 is included to limit the maximum voltage applied to the  $\overline{\text{ON}}/\text{OFF}$  pin (maximum of 25V), reduces power supply noise sensitivity, and also limits the capacitor, C1, discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the  $\overline{\text{ON}}/\text{OFF}$  pin and cause problems.

This delayed startup feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

**UNDERVOLTAGE LOCKOUT**

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. An undervoltage lockout feature applied to a buck regulator is shown in *Figure 22*, while *Figure 23* and *24* applies the same feature to an inverting circuit. The circuit in *Figure 23* fea-

tures a constant threshold voltage for turn on and turn off (zener voltage plus approximately one volt). If hysteresis is needed, the circuit in *Figure 24* has a turn ON voltage which is different than the turn OFF voltage. The amount of hysteresis is approximately equal to the value of the output voltage. If zener voltages greater than 25V are used, an additional 47 kΩ resistor is needed from the  $\overline{\text{ON}}/\text{OFF}$  pin to the ground pin to stay within the 25V maximum limit of the  $\overline{\text{ON}}/\text{OFF}$  pin.

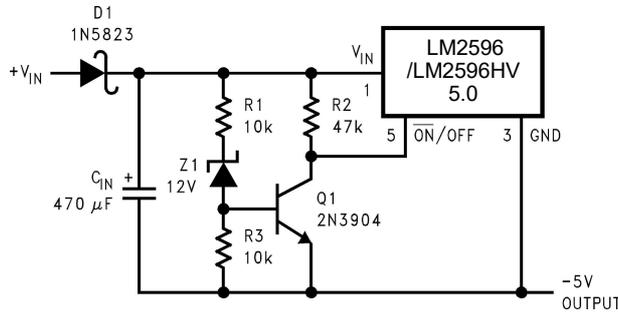
**INVERTING REGULATOR**

The circuit in *Figure 25* converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the regulator's ground pin to the negative output voltage, then grounding the feedback pin,

This example uses the LM2596/LM2596HV-5.0 to generate a -5V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version.

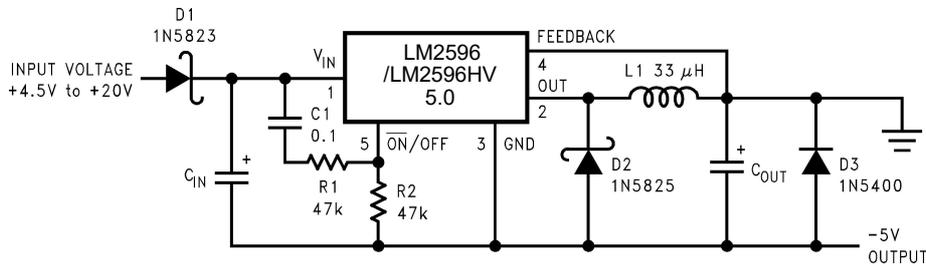
Since this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. The curve shown in *Figure 26* provides a guide as to the amount of output load current possible for the different input and output voltage conditions.

**Application Information** (Continued)



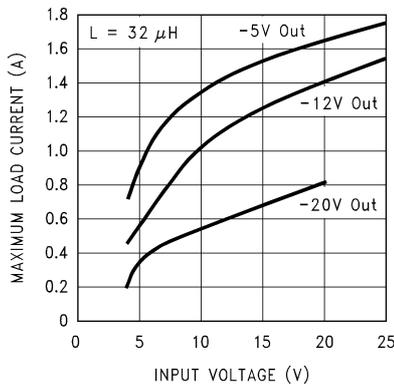
This circuit has hysteresis. Regulator starts switching at  $V_{IN} = 13V$ . Regulator stops switching at  $V_{IN} = 8V$ .

**FIGURE 24. Undervoltage Lockout with Hysteresis for Inverting Regulator**



$C_{IN}$  — 68  $\mu F/25V$  Tant. Sprague 595D  
470  $\mu F/50V$  Elec. Panasonic HFQ  
 $C_{OUT}$  — 47  $\mu F/20V$  Tant. Sprague 595D  
220  $\mu F/25V$  Elec. Panasonic HFQ

**FIGURE 25. Inverting -5V Regulator with Delayed Startup**



**FIGURE 26. Inverting Regulator Typical Load Current**

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 33  $\mu H$ , 3.5A inductor is the best choice. Capacitor selection can also

be narrowed down to just a few values. Using the values shown in *Figure 25* will provide good results in the majority of inverting designs.

This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the LM2596 /LM2596HV current limit (approx 4.5A) are needed for at least 2 ms or more, until the output reaches its nominal output voltage.

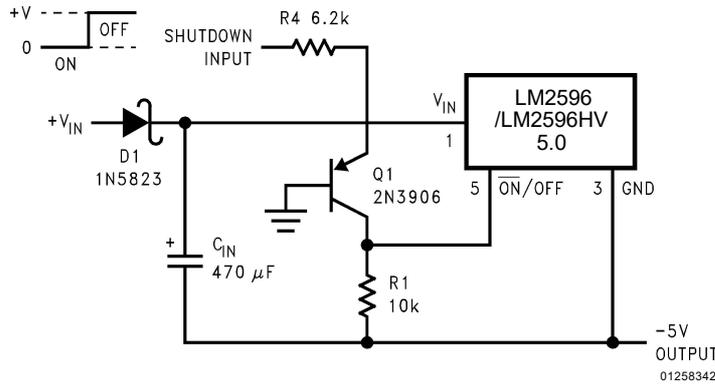
The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, may not work correctly. Because of the relatively high startup currents required by the inverting topology the delayed startup feature ( $C_1$ ,  $R_1$  and  $R_2$ ) shown in *Figure 25* is recommended. By delaying the regulator startup, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current needed for startup is now supplied by the input capacitor ( $C_{IN}$ ). For severe start up conditions, the input capacitor can be made much larger than normal.

**Application Information** (Continued)

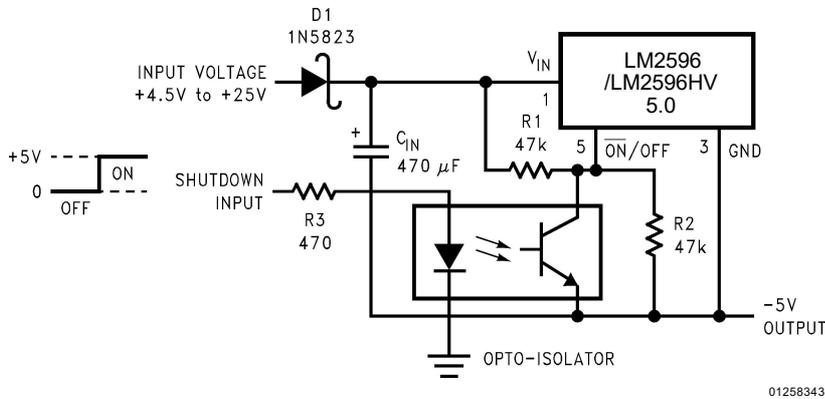
**INVERTING REGULATOR SHUTDOWN METHODS**

To use the  $\overline{\text{ON}}$  /OFF pin in a standard buck configuration is simple, pull it below 1.3V (@25°C, referenced to ground) to turn regulator ON, pull it above 1.3V to shut the regulator

OFF. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in *Figure 27* and *28*.

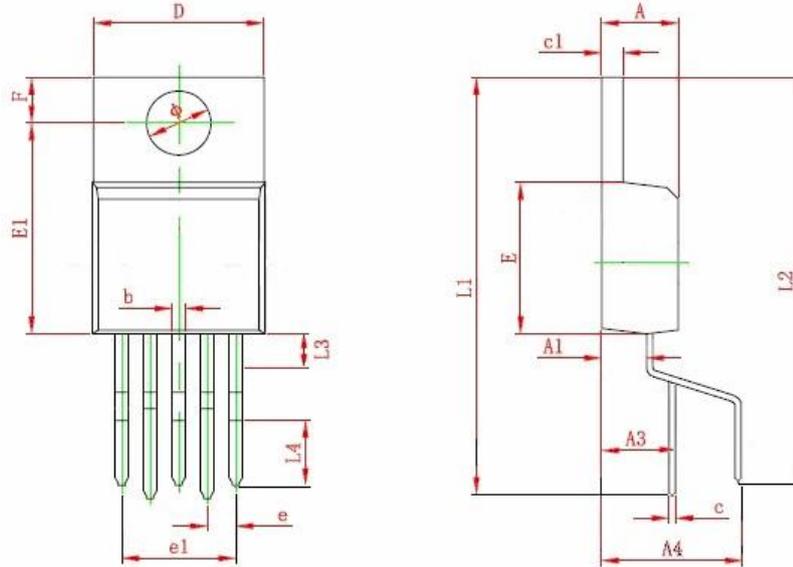


**FIGURE 27. Inverting Regulator Ground Referenced Shutdown**



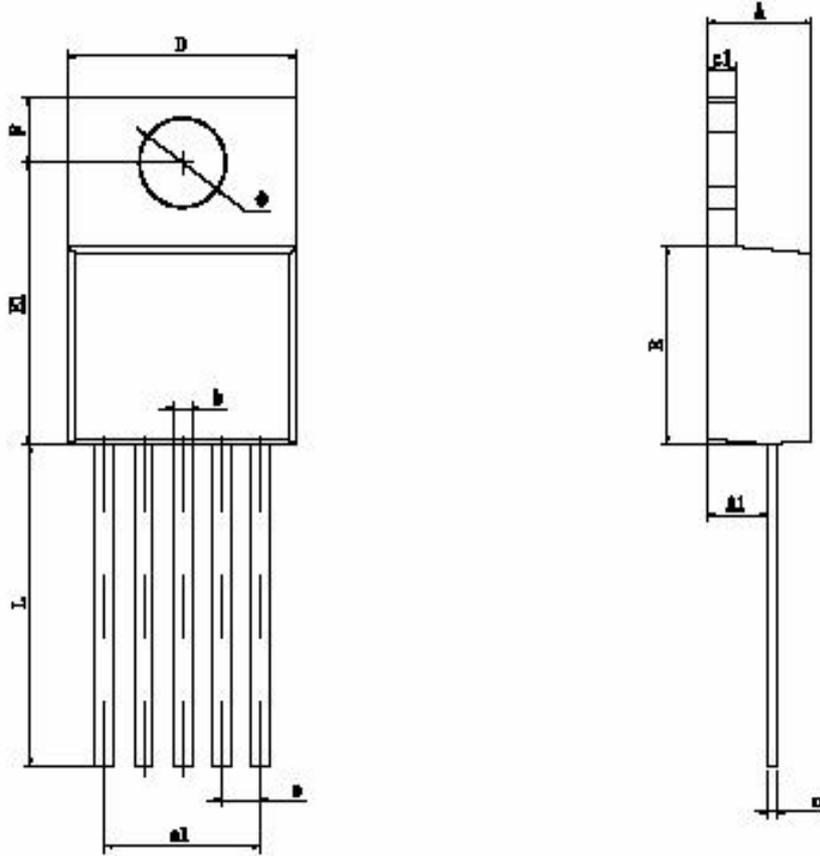
**FIGURE 28. Inverting Regulator Ground Referenced Shutdown using Opto Device**

**PACKAGES DIMENSION : TO220B-5L**



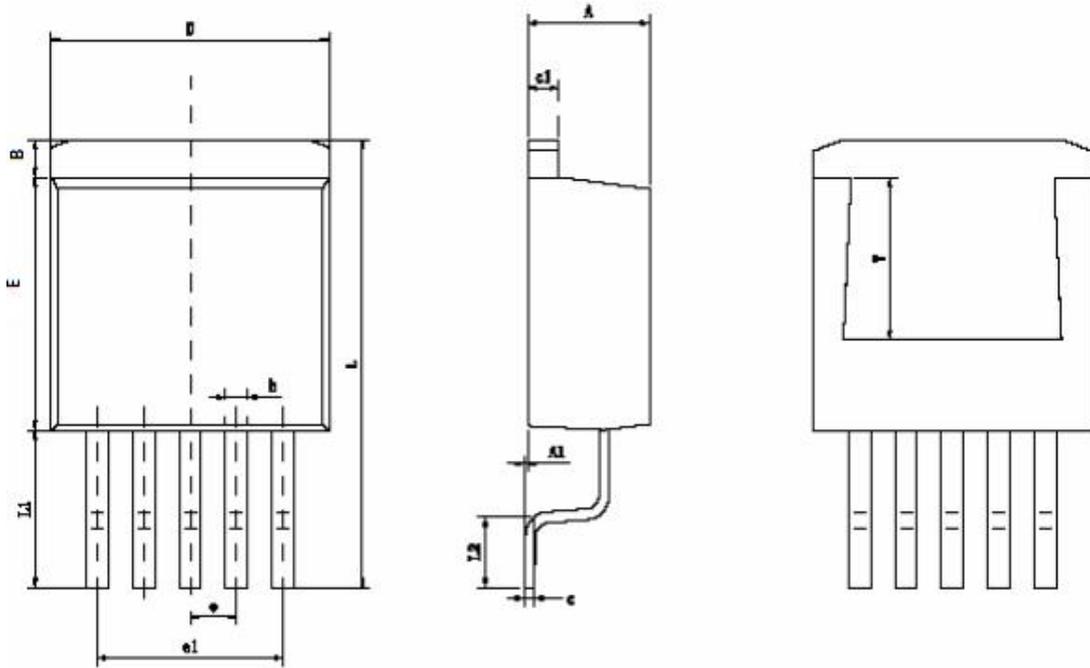
| Symbol | Dimensions In Millimeters |        | Dimensions In Inches |       |
|--------|---------------------------|--------|----------------------|-------|
|        | Min                       | Max    | Min                  | Max   |
| A      | 4.470                     | 4.670  | 0.176                | 0.184 |
| A1     | 2.520                     | 2.820  | 0.099                | 0.111 |
| A3     | 4.450                     | 4.850  | 0.175                | 0.191 |
| A4     | 8.350                     | 8.750  | 0.329                | 0.345 |
| b      | 0.710                     | 0.910  | 0.028                | 0.036 |
| c      | 0.310                     | 0.530  | 0.012                | 0.021 |
| c1     | 1.170                     | 1.370  | 0.046                | 0.054 |
| D      | 10.010                    | 10.310 | 0.394                | 0.406 |
| E      | 8.900                     | 9.300  | 0.350                | 0.366 |
| E1     | 12.460                    | 12.860 | 0.491                | 0.506 |
| e      | 1.700TYP                  |        | 0.220TYP             |       |
| e1     | 6.700                     | 6.900  | 0.264                | 0.272 |
| F      | 2.590                     | 2.890  | 0.102                | 0.114 |
| L1     | 26.800                    | 27.400 | 1.055                | 1.079 |
| L2     | 24.800                    | 25.200 | 0.976                | 0.992 |
| L3     | 1.000                     | 2.000  | 0.039                | 0.079 |
| L4     | 6.000                     | 6.400  | 0.236                | 0.252 |
| R      | 0.950                     | 1.050  | 0.037                | 0.041 |
| Φ      | 3.790                     | 3.890  | 0.149                | 0.153 |

**PACKAGES DIMENSION : TO220-5L**



| Symbol | Dimensions In Millimeters |        | Dimensions In Inches |       |
|--------|---------------------------|--------|----------------------|-------|
|        | Min                       | Max    | Min                  | Max   |
| A      | 4.470                     | 4.670  | 0.176                | 0.184 |
| A1     | 2.520                     | 2.820  | 0.099                | 0.111 |
| b      | 0.710                     | 0.910  | 0.028                | 0.036 |
| c      | 0.310                     | 0.530  | 0.012                | 0.021 |
| c1     | 1.170                     | 1.370  | 0.046                | 0.054 |
| D      | 9.850                     | 10.150 | 0.388                | 0.400 |
| E      | 8.200                     | 8.600  | 0.323                | 0.339 |
| E1     | 11.760                    | 12.160 | 0.463                | 0.479 |
| e      | 1.700TYP                  |        | 0.067TYP             |       |
| e1     | 6.700                     | 6.900  | 0.264                | 0.272 |
| F      | 2.590                     | 2.890  | 0.102                | 0.114 |
| L      | 13.500                    | 13.900 | 0.531                | 0.547 |
| $\Phi$ | 3.790                     | 3.890  | 0.149                | 0.153 |

**PACKAGES DIMENSION : TO263-5**



| Symbol | Dimensions In Millimeters |        | Dimensions In Inches |       |
|--------|---------------------------|--------|----------------------|-------|
|        | Min                       | Max    | Min                  | Max   |
| A      | 4.470                     | 4.670  | 0.176                | 0.184 |
| A1     | 0.000                     | 0.150  | 0.000                | 0.006 |
| B      | 1.560                     | 1.760  | 0.061                | 0.069 |
| b      | 0.710                     | 0.910  | 0.028                | 0.036 |
| c      | 0.310                     | 0.530  | 0.012                | 0.021 |
| c1     | 1.170                     | 1.370  | 0.046                | 0.054 |
| D      | 9.880                     | 10.180 | 0.389                | 0.401 |
| E      | 8.200                     | 8.600  | 0.323                | 0.339 |
| e      | 1.700TYP                  |        | 0.067TYP             |       |
| e1     | 6.700                     | 6.900  | 0.264                | 0.272 |
| L      | 15.140                    | 15.540 | 0.596                | 0.612 |
| L1     | 5.080                     | 5.480  | 0.200                | 0.216 |
| L2     | 2.340                     | 2.740  | 0.092                | 0.108 |
| V      | 5.600REF                  |        | 0.220REF             |       |

## Attention

- Any and all MSKSEMI Semiconductor products described or contained herein do not have specifications that can handle applications that require extremely high levels of reliability, such as life-support systems, aircraft's control systems, or other applications whose failure can be reasonably expected to result in serious physical and/or material damage. Consult with your MSKSEMI Semiconductor representative nearest you before using any MSKSEMI Semiconductor products described or contained herein in such applications.
- MSKSEMI Semiconductor assumes no responsibility for equipment failures that result from using products at values that exceed, even momentarily, rated values (such as maximum ratings, operating condition ranges, or other parameters) listed in products specifications of any and all MSKSEMI Semiconductor products described or contained herein.
- Specifications of any and all MSKSEMI Semiconductor products described or contained herein stipulate the performance, characteristics, and functions of the described products in the independent state, and are not guarantees of the performance, characteristics, and functions of the described products as mounted in the customer's products or equipment. To verify symptoms and states that cannot be evaluated in an independent device, the customer should always evaluate and test devices mounted in the customer's products or equipment.
- MSKSEMI Semiconductor strives to supply high-quality high-reliability products. However, any and all semiconductor products fail with some probability. It is possible that these probabilistic failures could give rise to accidents or events that could endanger human lives, that could give rise to smoke or fire, or that could cause damage to other property. When designing equipment, adopt safety measures so that these kinds of accidents or events cannot occur. Such measures include but are not limited to protective circuits and error prevention circuits for safe design, redundant design, and structural design.
- In the event that any or all MSKSEMI Semiconductor products (including technical data, services) described or contained herein are controlled under any of applicable local export control laws and regulations, such products must not be exported without obtaining the export license from the authorities concerned in accordance with the above law.
- No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying and recording, or any information storage or retrieval system, or otherwise, without the prior written permission of MSKSEMI Semiconductor.
- Information (including circuit diagrams and circuit parameters) herein is for example only ; it is not guaranteed for volume production. MSKSEMI Semiconductor believes information herein is accurate and reliable, but no guarantees are made or implied regarding its use or any infringement of intellectual property rights or other rights of third parties.
- Any and all information described or contained herein are subject to change without notice due to product/technology improvement, etc. When designing equipment, refer to the "Delivery Specification" for the MSKSEMI Semiconductor product that you intend to use.