LM2592HV SIMPLE SWITCHER® Power Converter 150 kHz 2A Step-Down Voltage Regulator

Check for Samples: LM2592HV

FEATURES

- **3.3V, 5V, and Adjustable Output Versions**
- **Adjustable Version Output Voltage Range, 1.2V to 57V ±4% Max Over Line and Load Conditions**
- **Ensured 2A Output Load Current**
- **Available in 5-Pin Package**
- **Input Voltage Range up to 60V**
- **150 kHz Fixed Frequency Internal Oscillator**
- **On/Off Control**
- **Low Power Standby Mode, I_Q Typically 90 μA**
- **High Efficiency**
- **Thermal Shutdown and Current Limit Protection**

APPLICATIONS

- **Simple High-Efficiency Step-Down (Buck) Regulator**
- **Efficient Pre-Regulator for Linear Regulators**
- **On-Card Switching Regulators**
- **Positive to Negative Converter**

DESCRIPTION

The LM2592HV series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 2A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, and an adjustable output version.

This series of switching regulators is similar to the LM2593HV, but without some of the supervisory and performance features of the latter.

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

The LM2592HV 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 package with several different lead bend options, and a 5-lead Surface mount package.

Other features include a ensured ±4% tolerance on output voltage under all conditions of input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 90 μA standby current. Self protection features include a two stage current limit for the output switch and an over temperature shutdown for complete protection under fault conditions.

† Patent Number 5,382,918.

TYPICAL APPLICATION

(Fixed Output Voltage Versions)

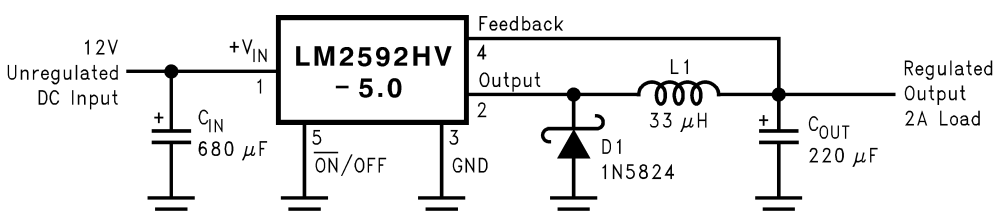

Figure 1.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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All other trademarks are the property of their respective owners.

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ABSOLUTE MAXIMUM RATINGS[1][2][3]

Maximum Supply Voltage (V_{IN})			63V
$\overline{ON}$/OFF Pin Voltage			−0.3 ≤ V ≤ +25V
Feedback Pin Voltage			−0.3 ≤ V ≤ +25V
Output Voltage to Ground (Steady State)			−1V
Power Dissipation			Internally limited
Storage Temperature Range			−65°C to +150°C
ESD Susceptibility	Human Body Model[3]		2 kV
Lead Temperature	KTT Package	Vapor Phase (60 sec.)	+215°C
		Infrared (10 sec.)	+245°C
	NDH Package	Soldering (10 sec.)	+260°C
Maximum Junction Temperature			+150°C

(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 ensure specific performance limits. For ensured specifications and test conditions, see Electrical Characteristics.
(2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/ Distributors for availability and specifications.
(3) The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

OPERATING CONDITIONS

Temperature Range	−40°C ≤ T_J ≤ +125°C
Supply Voltage	4.5V to 60V

ELECTRICAL CHARACTERISTICS LM2592HV-3.3

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range.**

Symbol	Parameter	Conditions	LM2592HV-3.3		Units (Limits)
			Typ[1]	Limit[2]	
SYSTEM PARAMETERS Test Circuit and Layout Guidelines[3]					
V_{OUT}	Output Voltage	4.75V ≤ V_{IN} ≤ 60V, 0.2A ≤ I_{LOAD} ≤ 2A	3.3	 3.168/**3.135** 3.432/**3.465**	V V(min) V(max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 2A	76		

(1) Typical numbers are at 25°C and represent the most likely norm.
(2) All limits ensured 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 ensured via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2592HV is used as shown in the Test Circuit and Layout Guidelines, system performance will be as shown in system parameters section of Electrical Characteristics.

ELECTRICAL CHARACTERISTICS LM2592HV-5.0

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range.**

Symbol	Parameter	Conditions	LM2592HV-5.0		Units (Limits)
			Typ (1)	Limit (2)	
SYSTEM PARAMETERS Test Circuit and Layout Guidelines (3)					
V_{OUT}	Output Voltage	7V ≤ V_{IN} ≤ 60V, 0.2A ≤ I_{LOAD} ≤ 2A	5	 4.800/**4.750** 5.200/**5.250**	V V(min) V(max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 2A	81		%

(1) Typical numbers are at 25°C and represent the most likely norm.
(2) All limits ensured 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 ensured via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2592HV is used as shown in the Test Circuit and Layout Guidelines, system performance will be as shown in system parameters section of Electrical Characteristics.

ELECTRICAL CHARACTERISTICS LM2592HV-ADJ

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range.**

Symbol	Parameter	Conditions	LM2592HV-ADJ		Units (Limits)
			Typ (1)	Limit (2)	
SYSTEM PARAMETERS Test Circuit and Layout Guidelines (3)					
V_{FB}	Feedback Voltage	4.5V ≤ V_{IN} ≤ 60V, 0.2A ≤ I_{LOAD} ≤ 2A V_{OUT} programmed for 3V. Circuit of Test Circuit and Layout Guidelines	1.230	 1.193/**1.180** 1.267/**1.280**	V V(min) V(max)
η	Efficiency	V_{IN} = 12V, V_{OUT} = 3V, I_{LOAD} = 2A	75		%

(1) Typical numbers are at 25°C and represent the most likely norm.
(2) All limits ensured 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 ensured via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2592HV is used as shown in the Test Circuit and Layout Guidelines, system performance will be as shown in system parameters section of Electrical Characteristics.

ELECTRICAL CHARACTERISTICS ALL OUTPUT VOLTAGE VERSIONS

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

Symbol	Parameter	Conditions	LM2592HV-XX		Units (Limits)
			Typ (1)	Limit (2)	
DEVICE PARAMETERS					
I_b	Feedback Bias Current	Adjustable Version Only, V_{FB} = 1.3V	10	50/**100**	nA nA (max)
f_O	Oscillator Frequency	See (3)	150	127/**110** 173/**173**	kHz kHz(min) kHz(max)
V_{SAT}	Saturation Voltage	I_{OUT} = 2A (4) (5)	1.10	1.3/**1.4**	V V(max)
DC	Max Duty Cycle (ON) Min Duty Cycle (OFF)	See (5) (6)	100 0		%
I_{CLIM}	Switch current Limit	Peak Current (4) (5)	3.0	2.4/**2.3** 3.7/**4.0**	A A(min) A(max)
I_L	Output Leakage Current	Output = 0V Output = −1V (4) (6) (7)	5	50 30	μA(max) mA mA(max)
I_Q	Operating Quiescent Current	$\overline{SD}$ /SS Pin Open (6)	5	10	mA mA(max)
I_{STBY}	Standby Quiescent Current	$\overline{SD}$ /SS pin = 0V (7)	90	200/**250**	μA μA(max)
θ_{JC} θ_{JA} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	TO-220 or DDPAK Package, Junction to Case TO-220 Package, Junction to Ambient (8) DDPAK Package, Junction to Ambient (9) DDPAK Package, Junction to Ambient (10) DDPAK Package, Junction to Ambient (11)	2 50 50 30 20		°C/W °C/W °C/W °C/W °C/W
ON/OFF CONTROL Test Circuit and Layout Guidelines					
V_{IH} V_{IL}	$\overline{ON}$ /OFF Pin Logic Input Threshold Voltage	Low (Regulator ON) High (Regulator OFF)	1.3	**0.6** **2.0**	V V(max) V(min)
I_H	$\overline{ON}$ /OFF Pin Input Current	V_{LOGIC} = 2.5V (Regulator OFF)	5	15	μA μA(max)
I_L		V_{LOGIC} = 0.5V (Regulator ON)	0.02	5	μA μA(max)

(1) Typical numbers are at 25°C and represent the most likely norm.
(2) All limits ensured 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 ensured via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(3) The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.
(4) No diode, inductor or capacitor connected to output pin.
(5) Feedback pin removed from output and connected to 0V to force the output transistor switch ON.
(6) Feedback pin removed from output and connected to 12V for the 3.3V, 5V, and the ADJ. version to force the output transistor switch OFF.
(7) V_{IN} = 60V.
(8) Junction to ambient thermal resistance (no external heat sink) for the package mounted TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately 1 in^2.
(9) Junction to ambient thermal resistance with the DDPAK package tab soldered to a single sided printed circuit board with 0.5 in^2 of (1 oz.) copper area.
(10) Junction to ambient thermal resistance with the DDPAK package tab soldered to a single sided printed circuit board with 2.5 in^2 of (1 oz.) copper area.
(11) Junction to ambient thermal resistance with the DDPAK package tab soldered to a double sided printed circuit board with 3 in^2 of (1 oz.) copper area on the LM2592HVS side of the board, and approximately 16 in^2 of copper on the other side of the p-c board. See application hints in this data sheet and the thermal model in **Switchers Made Simple** available at http://www.ti.com/lsds/ti/analog/powermanagement/power_portal.page

TYPICAL PERFORMANCE CHARACTERISTICS

(Circuit of Test Circuit and Layout Guidelines)

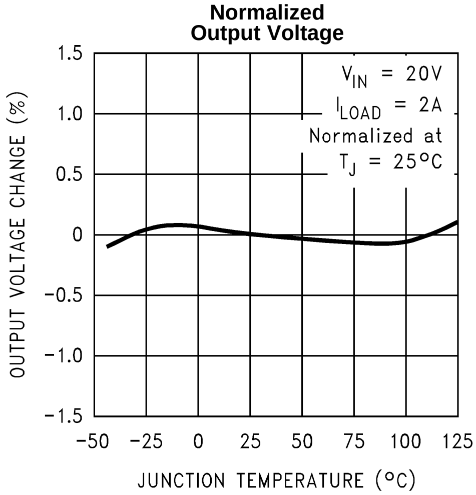


Figure 2.

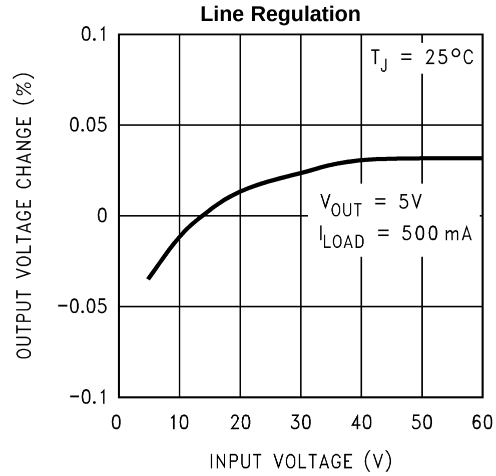


Figure 3.

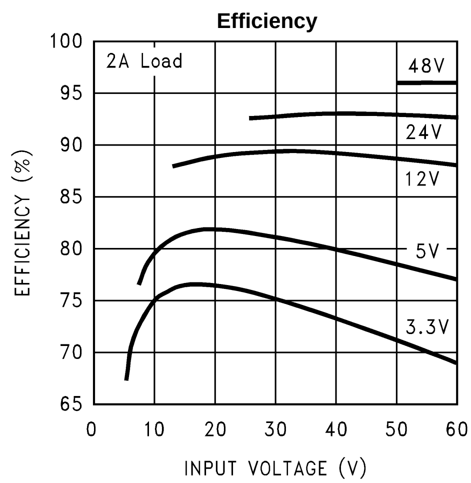


Figure 4.

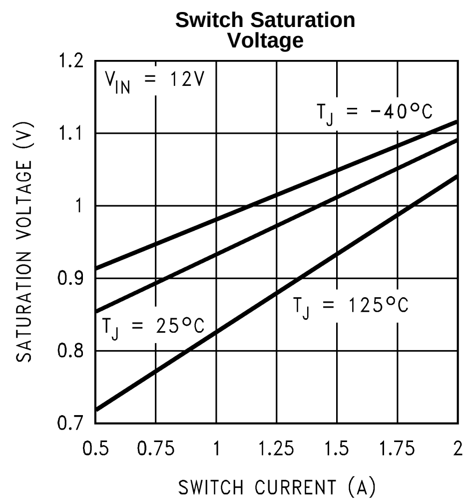


Figure 5.

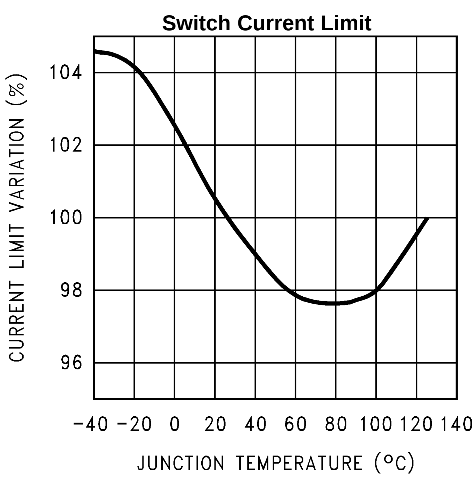


Figure 6.

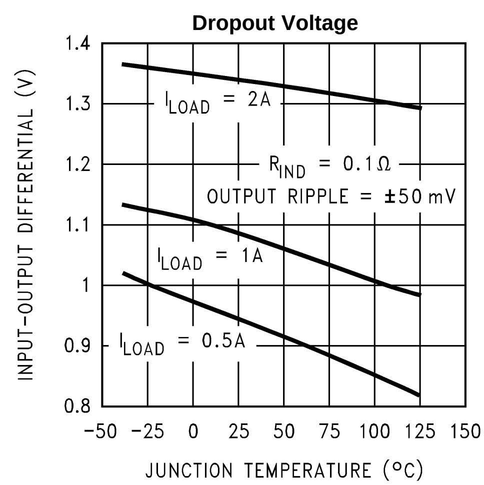


Figure 7.

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

(Circuit of Test Circuit and Layout Guidelines)

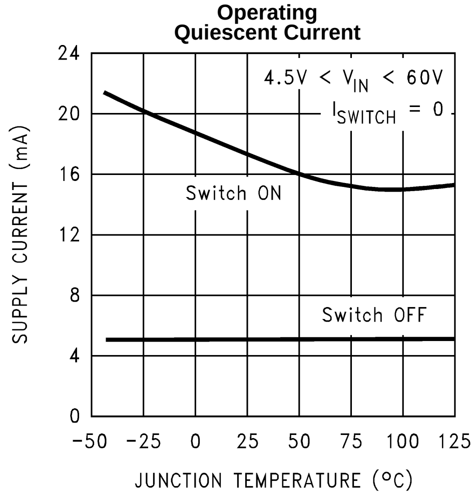


Figure 8.

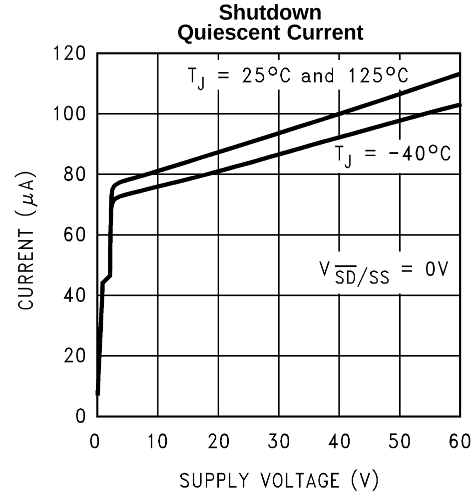


Figure 9.

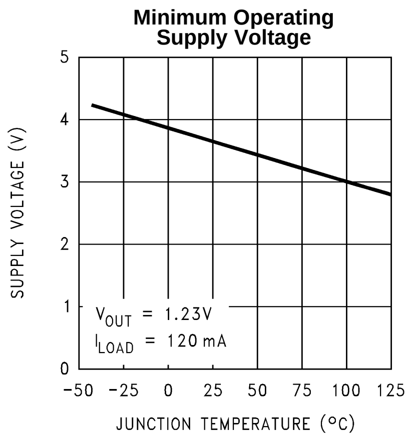


Figure 10.

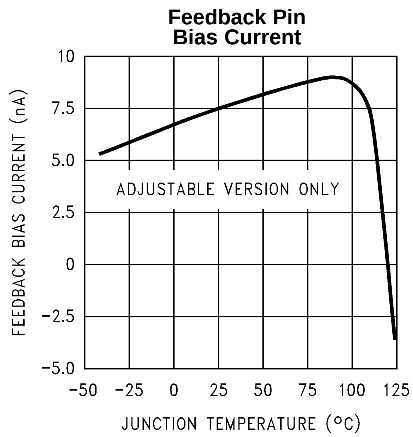


Figure 11.

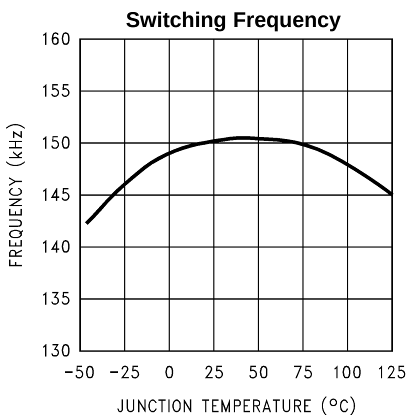


Figure 12.

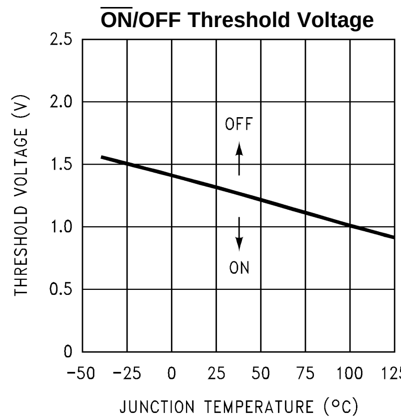


Figure 13.

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

(Circuit of Test Circuit and Layout Guidelines)

ON/OFF Pin Current (Sinking)

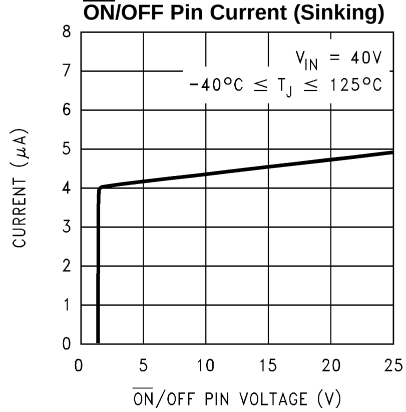


Figure 14.

Internal Gain-Phase Characteristics

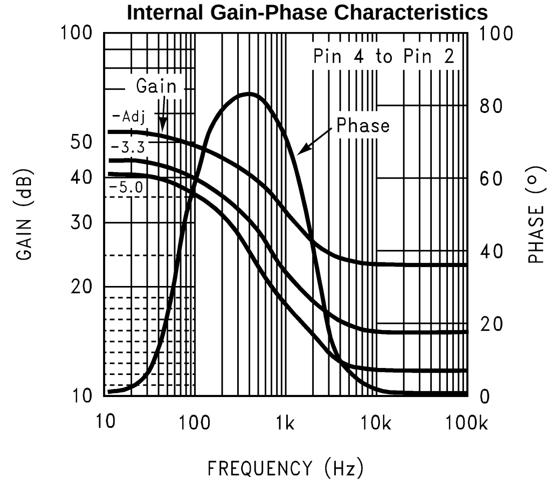
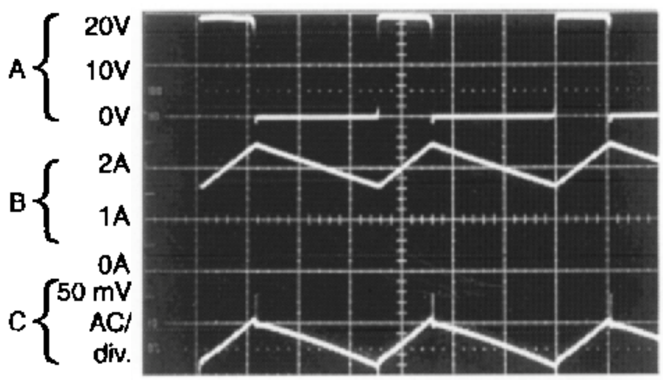


Figure 15.

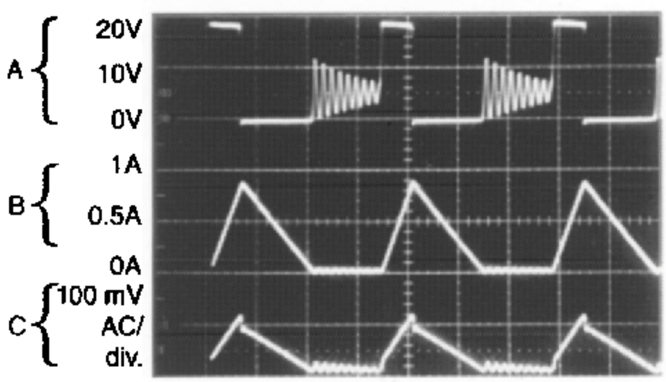
Continuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 2A
L = 32 µH, C_{OUT} = 220 µF, C_{OUT} ESR = 50 mΩ



A: Output Pin Voltage, 10V/div.
B: Inductor Current 1A/div.
C: Output Ripple Voltage, 50 mV/div.

Figure 16. Horizontal Time Base: 2 µs/div.

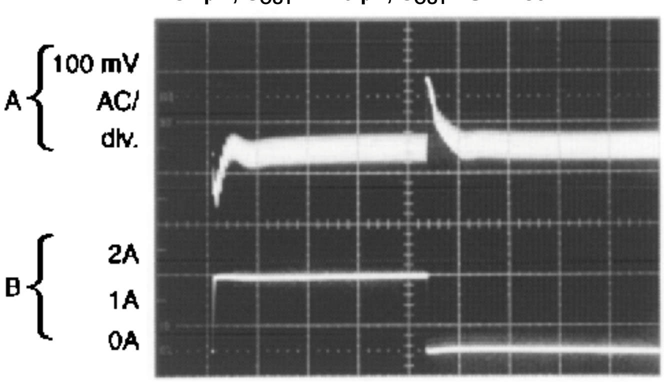
Discontinuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA
L = 10 µH, C_{OUT} = 330 µF, C_{OUT} ESR = 45 mΩ



A: Output Pin Voltage, 10V/div.
B: Inductor Current 0.5A/div.
C: Output Ripple Voltage, 100 mV/div.

Figure 17. Horizontal Time Base: 2 µs/div.

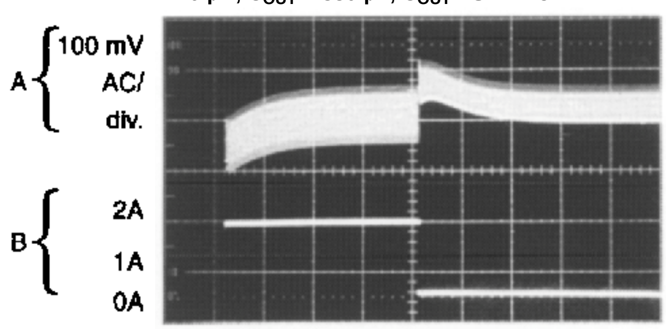
Load Transient Response for Continuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 32 µH, C_{OUT} = 220 µF, C_{OUT} ESR = 50 mΩ



A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse

Figure 18. Horizontal Time Base: 50 µs/div.

Load Transient Response for Discontinuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 10 µH, C_{OUT} = 330 µF, C_{OUT} ESR = 45 mΩ



A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse

Figure 19. Horizontal Time Base: 200 µs/div.

CONNECTION DIAGRAMS

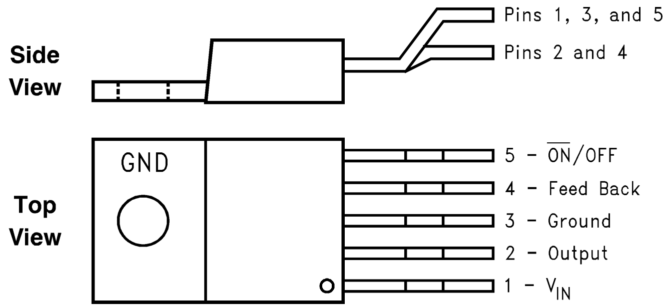


Figure 20. Bent and Staggered Leads, Through Hole Package 5-Lead TO-220 See Package Number NDH

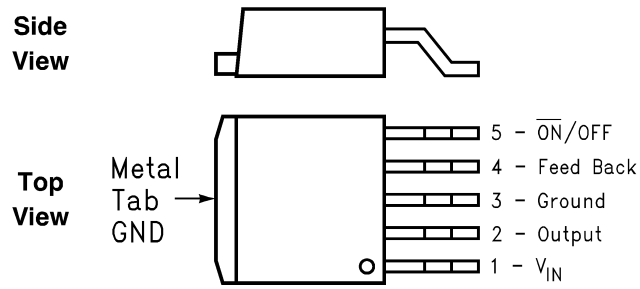
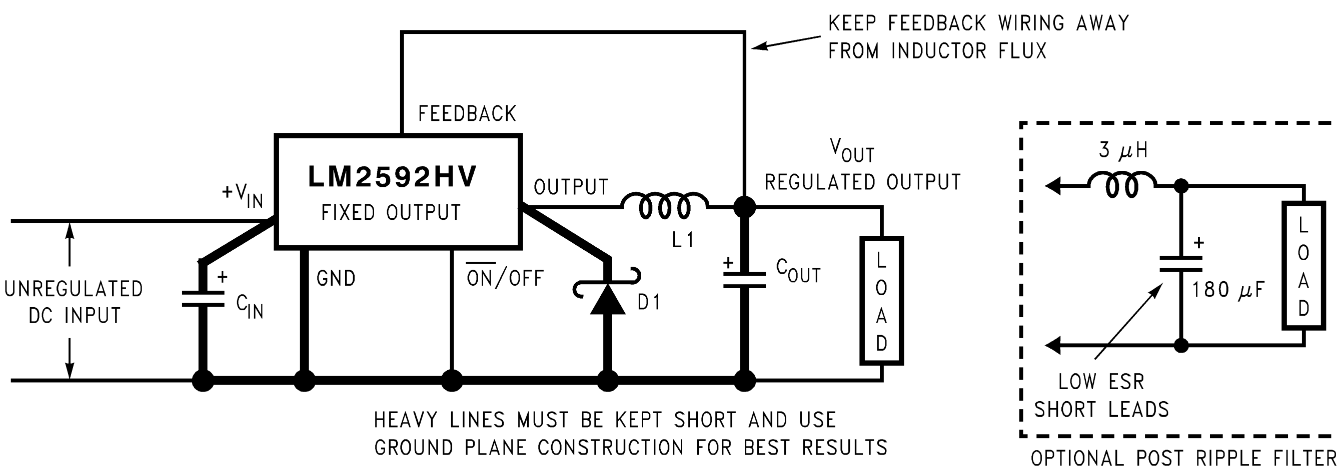


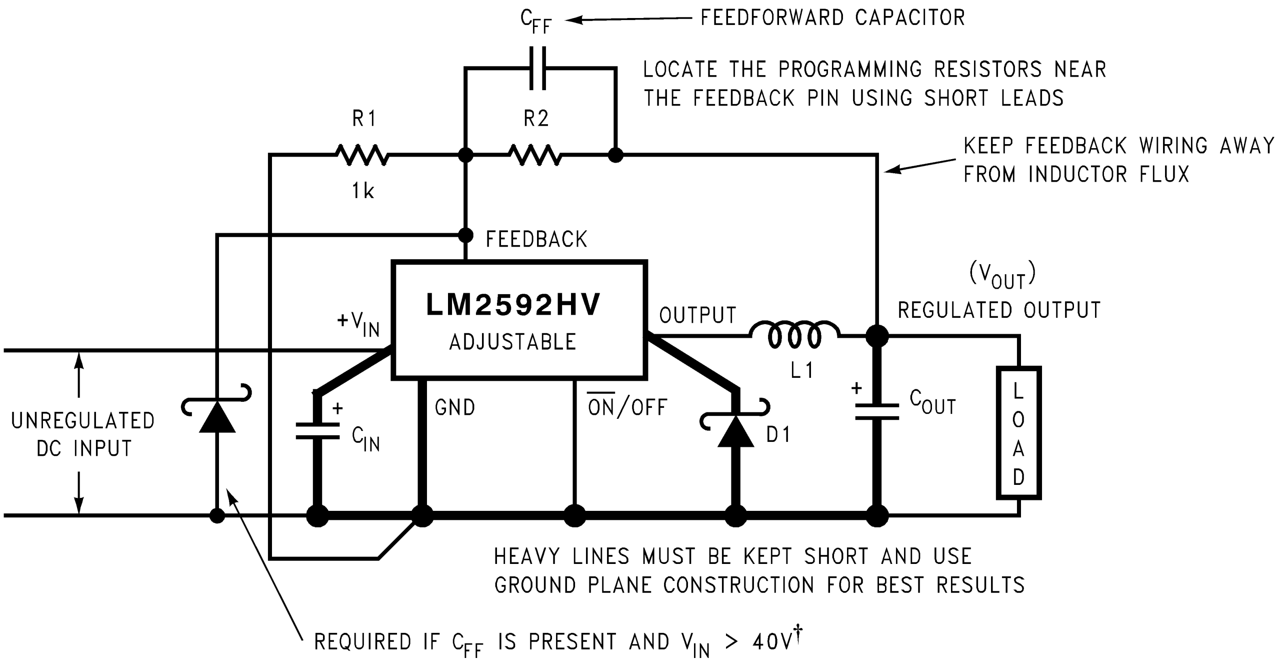
Figure 21. Surface Mount Package 5-Lead DDPAK See Package Number KTT

Test Circuit and Layout Guidelines



Component Values shown are for V_{IN} = 15V,
V_{OUT} = 5V, I_{LOAD} = 2A.
C_{IN} — 470 µF, 50V, Aluminum Electrolytic Nichicon “PM Series”
C_{OUT} — 220 µF, 25V Aluminum Electrolytic, Nichicon “PM Series”
D1 — 3.3A, 60V Schottky Rectifier, 31DQ06 (International Rectifier)
L1 — 33 µH, See INDUCTOR VALUE SELECTION GUIDES

Figure 22. Fixed Output Voltage Versions



Select R_1 to be approximately 1 kΩ, use a 1% resistor for best stability.
Component Values shown are for V_{IN} = 20V,
V_{OUT} = 10V, I_{LOAD} = 2A.
C_{IN}: — 470 µF, 35V, Aluminum Electrolytic Nichicon "PM Series"
C_{OUT}: — 220 µF, 35V Aluminum Electrolytic, Nichicon "PM Series"
D1 — 3.3A, 60V Schottky Rectifier, 31DQ06 (International Rectifier)
L1 — 47 µH, See INDUCTOR VALUE SELECTION GUIDES
R_1 — 1 kΩ, 1%
R_2 — 7.15k, 1%
C_{FF} — 3.3 nF
Typical Values
C_{SS} — 0.1 µF
C_{DELAY} — 0.1 µF
$R_{PULL\ UP}$ — 4.7k (use 22k if V_{OUT} is ≥ 45V)
† Small signal Schottky diode to prevent damage to feedback pin by negative spike when output is shorted (C_{FF} not being able to discharge immediately will drag feedback pin below ground). Required if V_{IN} > 40V

Figure 23. Adjustable Output Voltage Versions

BLOCK DIAGRAM

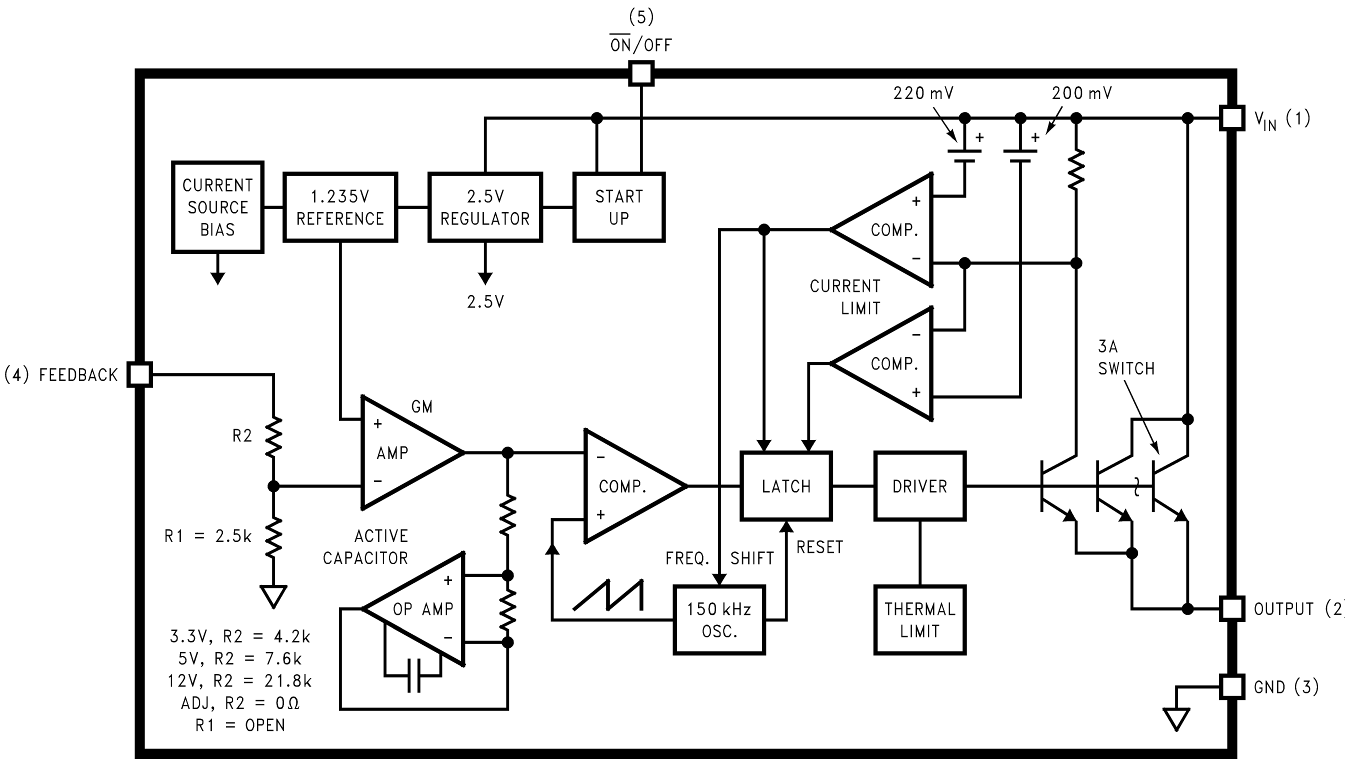


Figure 24.

PIN FUNCTIONS

+V_{IN}(Pin 1) 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.

Output (Pin 2) Internal switch. The voltage at this pin switches between approximately (+V_{IN} − V_{SAT}) and approximately −0.5V, with a duty cycle of V_{OUT}/V_{IN}.

Ground (Pin 3) Circuit ground.

Feedback (Pin 4) Senses the regulated output voltage to complete the feedback loop. This pin is directly connected to the Output for the fixed voltage versions, but is set to 1.23V by means of a resistive divider from the output for the Adjustable version. If a feedforward capacitor is used (Adjustable version), then a negative voltage spike is generated on this pin whenever the output is shorted. This happens because the feedforward capacitor cannot discharge fast enough, and since one end of it is dragged to Ground, the other end goes momentarily negative. To prevent the energy rating of this pin from being exceeded, a small-signal Schottky diode to Ground is recommended for DC input voltages above 40V whenever a feedforward capacitor is present (See Test Circuit and Layout Guidelines). Feedforward capacitor values larger than 0.1 µF are not recommended for the same reason, whatever be the DC input voltage.

$\overline{ON}$ /OFF (Pin 5) The regulator is in shutdown mode, drawing about 90 µA, when this pin is driven to a high level (≥ 2.0V), and is in normal operation when this Pin is left floating or driven to a low level (≤ 0.6V). The typical value of the threshold is 1.3V and the voltage on this pin must not exceed 25V.

INDUCTOR VALUE SELECTION GUIDES

(For Continuous Mode Operation)

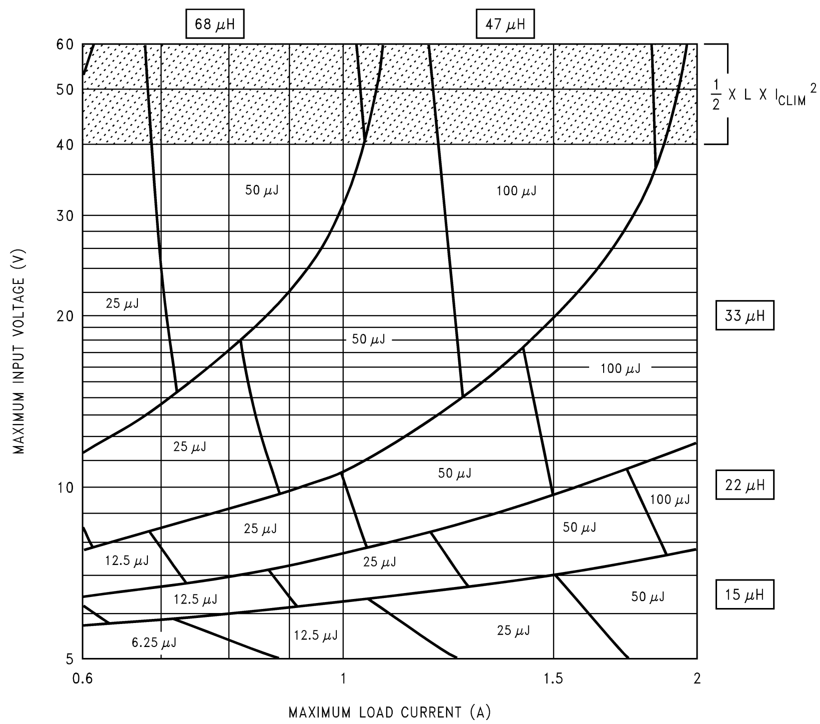


Figure 25. LM2592HV-3.3

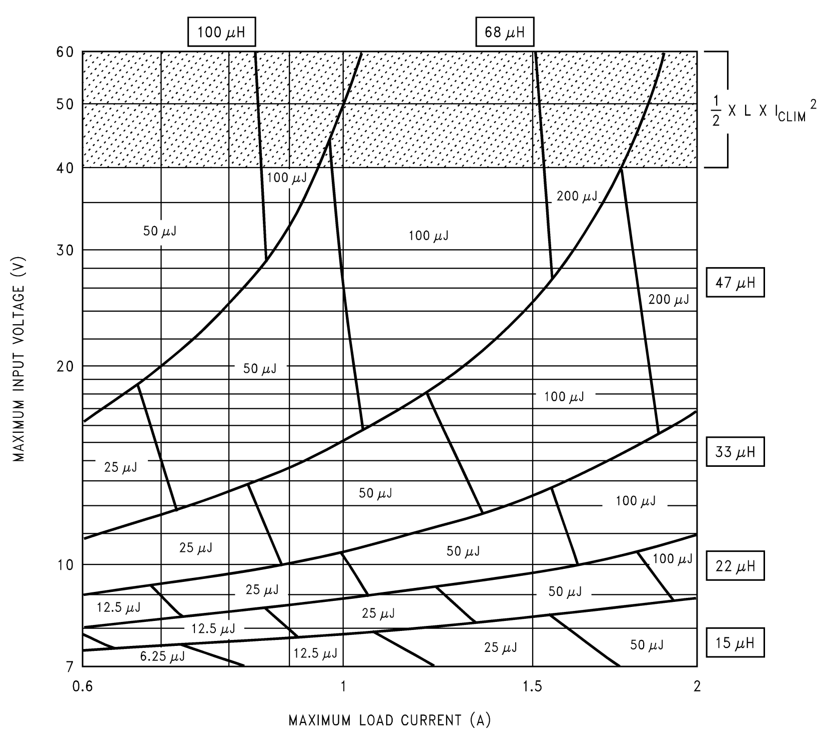


Figure 26. LM2592HV-5.0

(For Continuous Mode Operation)

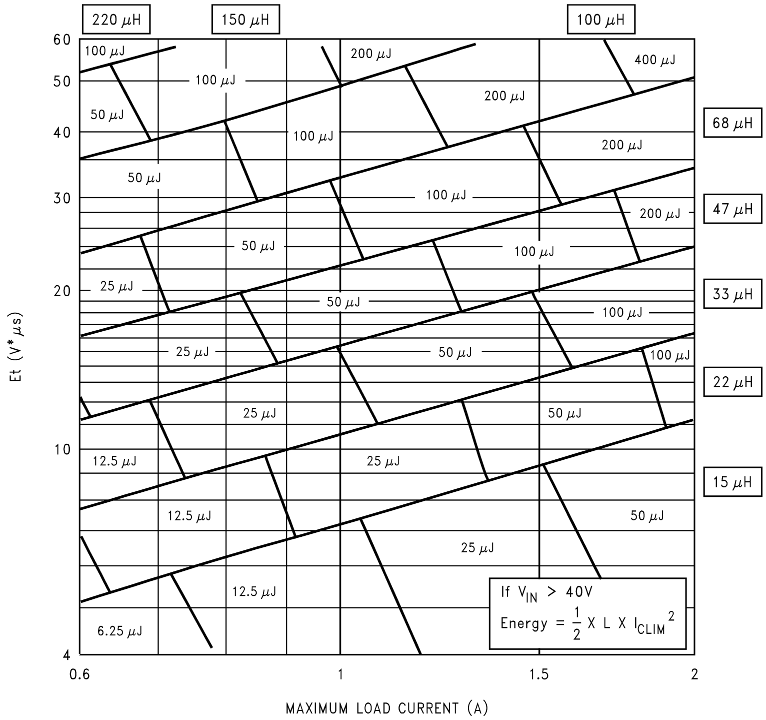


Figure 27. LM2592HV-ADJ

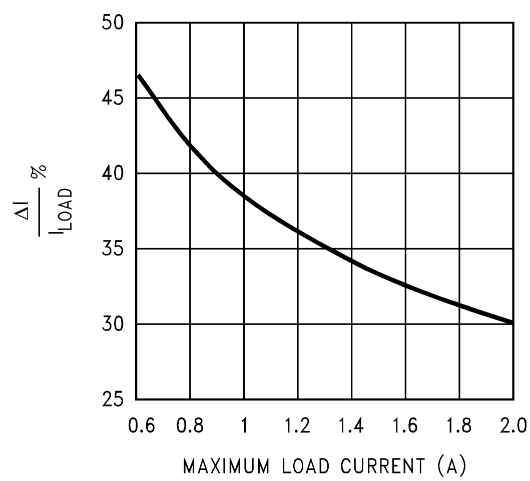


Figure 28. Current Ripple Ratio

Table 1. Contact Information for Suggested Inductor Manufacturers

Coilcraft Inc.	Phone	(USA): 1-800-322-2645
	Web Address	http://www.coilcraft.com
Coilcraft Inc., Europe	Phone	(UK): 1-236-730595
	Web Address	http://www.coilcraft-europe.com
Pulse Engineering Inc.	Phone	(USA): 1-858-674-8100
	Web Address	http://www.pulseeng.com
Pulse Engineering Inc., Europe	Phone	(UK): 1-483-401700
	Web Address	http://www.pulseeng.com
Renco Electronics Inc.	Phone	(USA): 1-321-637-1000
	Web Address	http://www.rencousa.com
Schott Corp.	Phone	(USA): 1-952-475-1173
	Web Address	http://www.shottcorp.com
Cooper Electronic Tech. (Coiltronics)	Phone	(USA): 1-888-414-2645
	Web Address	http://www.cooperet.com

APPLICATION INFORMATION

INDUCTOR SELECTION PROCEDURE

Application Note AN-1197 titled "Selecting Inductors for Buck Converters" provides detailed information on this topic. For a quick-start the designer may refer to the nomographs provided in Figure 25 to Figure 27. To widen the choice of the Designer to a more general selection of available inductors, the nomographs provide the required inductance and also the energy in the core expressed in microjoules (µJ), as an alternative to just prescribing custom parts. The following points need to be highlighted:

1. The Energy values shown on the nomographs apply to steady operation at the corresponding x-coordinate (rated maximum load current). However under start-up, without soft-start, or a short-circuit on the output, the current in the inductor will momentarily/repetitively hit the current limit I_{CLIM} of the device, and this current could be much higher than the rated load, I_{LOAD}. This represents an overload situation, and can cause the Inductor to saturate (if it has been designed only to handle the energy of steady operation). However most types of core structures used for such applications have a large inherent air gap (for example powdered iron types or ferrite rod inductors), and so the inductance does not fall off too sharply under an overload. The device is usually able to protect itself by not allowing the current to ever exceed I_{CLIM}. But if the DC input voltage to the regulator is over 40V, the current can slew up so fast under core saturation, that the device may not be able to act fast enough to restrict the current. The current can then rise without limit till destruction of the device takes place. *Therefore to ensure reliability, it is recommended, that if the DC Input Voltage exceeds 40V, the inductor must ALWAYS be sized to handle an instantaneous current equal to I_{CLIM} without saturating, irrespective of the type of core structure/material*.
2. The Energy under steady operation is:

   $$e = \frac{1}{2} \times L \times I_{PEAK}^2 \ \mu J$$

   where
   - L is in µH
   - and I_{PEAK} is the peak of the inductor current waveform with the regulator delivering I_{LOAD} (1)

   These are the energy values shown in the nomographs. See Example 1.
3. The Energy under overload is:

   $$e_{CLIM} = \frac{1}{2} \times L \times I_{CLIM}^2 \ \mu J \qquad (2)$$

   If V_{IN} > 40V, the inductor should be sized to handle e_{CLIM} instead of the steady energy values. The worst case I_{CLIM} for the LM2592HV is 4A. The Energy rating depends on the Inductance. See Example 2.
4. The nomographs were generated by allowing a greater amount of percentage current ripple in the Inductor as the maximum rated load decreases (see Figure 28). This was done to permit the use of smaller inductors at light loads. Figure 28 however shows only the 'median' value of the current ripple. In reality there may be a great spread around this because the nomographs approximate the exact calculated inductance to standard available values. It is a good idea to refer to AN-1197 for detailed calculations if a certain maximum inductor current ripple is required for various possible reasons. Also consider the rather wide tolerance on the nominal inductance of commercial inductors.
5. Figure 27 shows the inductor selection curves for the Adjustable version. The y-axis is 'Et', in Vµsecs. It is the applied volts across the inductor during the ON time of the switch (V_{IN}-V_{SAT}-V_{OUT}) multiplied by the time for which the switch is on in µsecs. See Example 3.

Example 1: (V_{IN} ≤ 40V) LM2592HV-5.0, V_{IN} = 24V, Output 5V @ 1A

1. A first pass inductor selection is based upon *Inductance and rated max load current*. We choose an inductor with the Inductance value indicated by the nomograph (see Figure 26) and a current rating equal to the maximum load current. We therefore quick-select a 68µH/1A inductor (designed for 150 kHz operation) for this application.

2. We should confirm that it is rated to handle 50 µJ (see Figure 26) by either estimating the peak current or by a detailed calculation as shown in AN-1197, and also that the losses are acceptable.

Example 2: (V_{IN} > 40V) LM2592HV-5.0, V_{IN} = 48V, Output 5V @ 1.5A

1. A first pass inductor selection is based upon *Inductance and the switch currrent limit*. We choose an inductor with the Inductance value indicated by the nomograph (see Figure 26) and a current rating equal to I_{CLIM}. We therefore quick-select a 68µH/4A inductor (designed for 150 kHz operation) for this application.

2. We should confirm that it is rated to handle e_{CLIM} by the procedure shown in AN-1197 and that the losses are acceptable. Here e_{CLIM} is:

$$e_{CLIM} = \frac{1}{2} \times 68 \times 4^2 = 544\ \mu J \tag{3}$$

Example 3: (V_{IN} ≤ 40V) LM2592HV-ADJ, V_{IN} = 20V, Output 10V @ 2A

1. Since input voltage is less than 40V, a first pass inductor selection is based upon Inductance and rated max load current. We choose an inductor with the Inductance value indicated by the nomographFigure 27 and a current rating equal to the maximum load. But we first need to calculate Et for the given application. The Duty cycle is

$$D = \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D}$$

where

- V_D is the drop across the Catch Diode (≅ 0.5V for a Schottky)
- and V_{SAT} the drop across the switch (≅1.5V) (4)

So

$$D = \frac{10 + 0.5}{20 - 1.5 + 0.5} = 0.55 \tag{5}$$

And the switch ON time is:

$$t_{ON} = \frac{D}{f} \times 10^6\ \mu s$$

where

- f is the switching frequency in Hz (6)

So

$$\begin{aligned} Et &= (V_{IN} - V_{SAT} - V_{OUT}) \times t_{ON} \\ &= (20 - 1.5 - 10) \times \frac{0.55}{150000} \times 10^6\ V\mu secs \\ &= 31.3\ V\mu secs \end{aligned} \tag{7}$$

Therefore, looking at Figure 25 we quick-select a 47µH/2A inductor (designed for 150 kHz operation) for this application.

2. We should confirm that it is rated to handle 200 µJ (see Figure 27) by the procedure shown in AN-1197 and that the losses are acceptable. (If the DC Input voltage had been greater than 40V we would need to consider e_{CLIM} as in Example 2).

This completes the simplified inductor selection procedure. For more general applications and better optimization, the designer should refer to AN-1197. Table 1 provides helpful contact information on suggested Inductor manufacturers who may be able to recommend suitable parts, if the requirements are known.

FEEDFORWARD CAPACITOR

(Adjustable Output Voltage Version)

C_{FF} - A Feedforward Capacitor C_{FF}, shown across R2 in Test Circuit and Layout Guidelines is used when the output voltage is greater than 10V or when C_{OUT} has a very low ESR. This capacitor adds lead compensation to the feedback loop and increases the phase margin for better loop stability.

If the output voltage ripple is large (> 5% of the nominal output voltage), this ripple can be coupled to the feedback pin through the feedforward capacitor and cause the error comparator to trigger the error flag. In this situation, adding a resistor, R_{FF}, in series with the feedforward capacitor, approximately 3 times R1, will attenuate the ripple voltage at the feedback pin.

INPUT CAPACITOR

C_{IN} —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 voltage rating of the capacitor and its RMS ripple current capability must never be exceeded.

OUTPUT CAPACITOR

C_{OUT} —An output capacitor is required to filter the output and provide regulator loop stability. Low impedance or low ESR Electrolytic or solid tantalum capacitors designed for switching regulator applications must be used. When selecting an output capacitor, the important capacitor parameters are; the 100 kHz Equivalent Series Resistance (ESR), the RMS ripple current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter. The ESR should generally not be less than 100 mΩ or there will be loop instability. If the ESR is too large, efficiency and output voltage ripple are effected. So ESR must be chosen carefully.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch turns off. This must be a fast diode and must be located close to the LM2592HV using short leads and short printed circuit traces.

Because of their very fast switching speed and low forward voltage drop, Schottky diodes provide the best performance, especially in low output voltage applications (5V and lower). Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. The diode must be chosen for its average/RMS current rating and maximum voltage rating. The voltage rating of the diode must be greater than the DC input voltage (not the output voltage).

DELAYED STARTUP

The circuit in Figure 29 uses the the $\overline{ON}$ /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 $\overline{ON}$ /OFF pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, and resistor R_2 pulls the $\overline{ON}$ /OFF pin low, thus allowing the circuit to start switching. Resistor R_1 is included to limit the maximum voltage applied to the $\overline{ON}$ /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 $\overline{ON}$ /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.

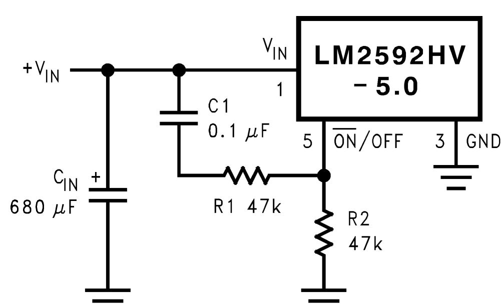


Figure 29. Delayed Startup

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 30, while Figure 31 and Figure 32 applies the same feature to an inverting circuit. The circuit in Figure 31 features a constant threshold voltage for turn on and turn off (zener voltage plus approximately one volt). If hysteresis is needed, the circuit in Figure 32 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 $\overline{ON}$ /OFF pin to the ground pin to stay within the 25V maximum limit of the $\overline{ON}$ /OFF pin.

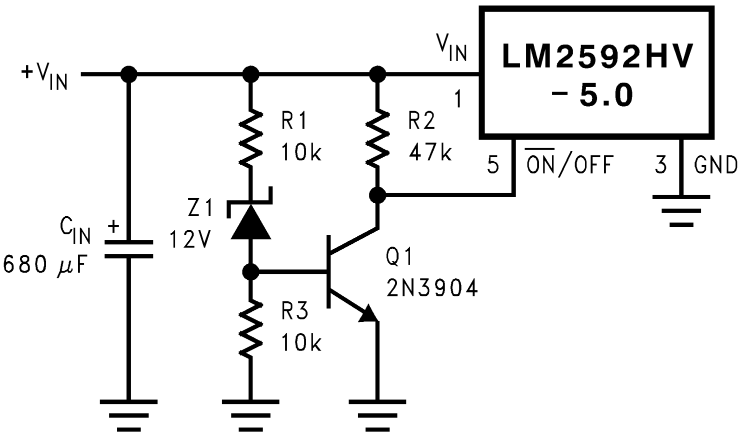
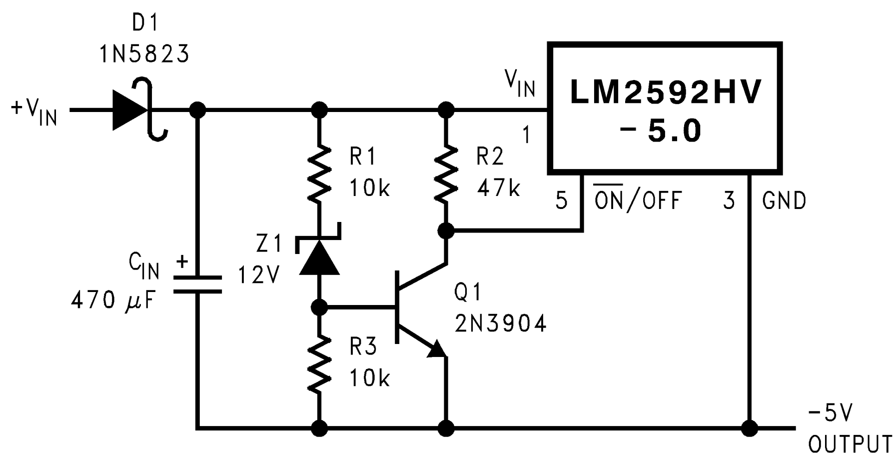


Figure 30. Undervoltage Lockout for Buck Regulator



This circuit has an ON/OFF threshold of approximately 13V.

Figure 31. Undervoltage Lockout for Inverting Regulator

INVERTING REGULATOR

The circuit in Figure 33 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, the regulator senses the inverted output voltage and regulates it.

This example uses the LM2592HV-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.

To determine how much load current is possible before the internal device current limit is reached (and power limiting occurs), the system must be evaluated as a buck-boost configuration rather than as a buck. The peak switch current in Amperes, for such a configuration is given as:

$$I_{PEAK} = I_{LOAD} \times \left(\frac{V_{IN} + V_{OUT}}{V_{IN}}\right) + \frac{V_{IN} \times V_{OUT} \times 10^6}{2 \times L \times f \times (V_{IN}+V_{OUT})}$$

where

- L is in µH
- and f is in Hz
- The maximum possible load current I_{LOAD} is limited by the requirement that $I_{PEAK} \leq I_{CLIM}$ (8)

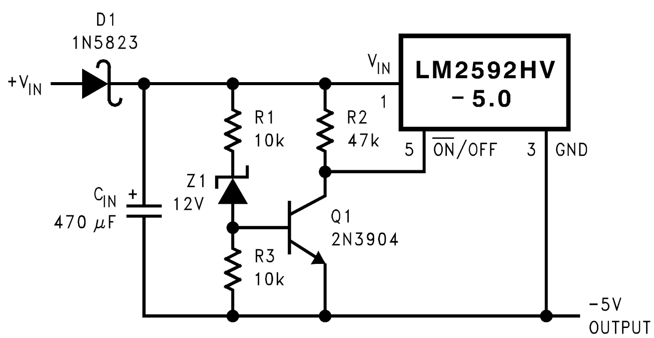
While checking for this, take I_{CLIM} to be the lowest possible current limit value (min across tolerance and temperature is 2.3A for the LM2592HV). Also to account for inductor tolerances, we should take the min value of Inductance for L in the equation (typically 20% less than the nominal value). Further, the above equation disregards the drop across the Switch and the diode. This is equivalent to assuming 100% efficiency, which is never so. Therefore expect I_{PEAK} to be an additional 10-20% higher than calculated from the above equation.

The reader is also referred to Application Note AN-1157 for examples based on positive to negative configuration.

The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 60V. For example, when converting +20V to −12V, the regulator would see 32V between the input pin and ground pin. The LM2592HV has a maximum input voltage spec of 60V.

Additional diodes are required in this regulator configuration. Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closley resemble a buck configuration thus providing good closed loop stability. A Schottky diode is recommended for low input voltages, (because of its lower voltage drop) but for higher input voltages, a fast recovery diode could be used.

Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.

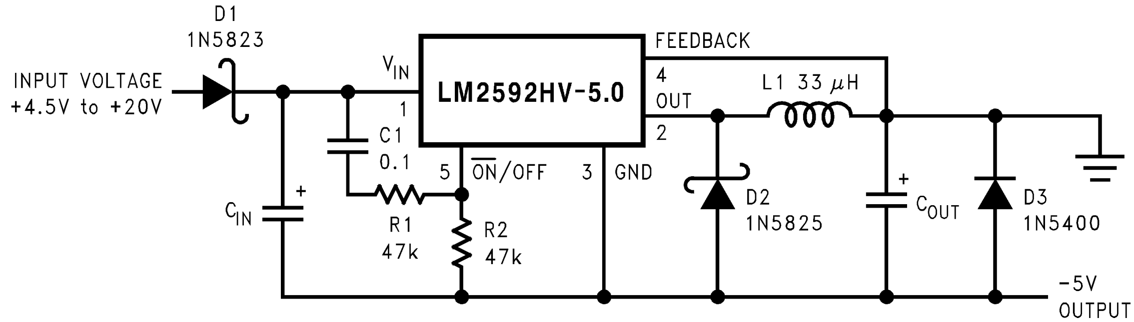


This circuit has hysteresis

Regulator starts switching at V_{IN}= 13V

Regulator stops switching at V_{IN}= 8V

Figure 32. Undervoltage Lockout with Hysteresis for Inverting Regulator



C_{IN} — 68 µF/25V Tant. Sprague 595D

470 µF/50V Elec. Panasonic HFQ

C_{OUT} — 47 µF/20V Tant. Sprague 595D

220 µF/25V Elec. Panasonic HFQ

Figure 33. Inverting −5V Regulator with Delayed Startup

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 µH, 4A inductor is the best choice. Capacitor selection can also be narrowed down to just a few values.

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 LM2592HV current limit (approx 4A) 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 (C1, R_1 and R_2) shown in Figure 33 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.

INVERTING REGULATOR SHUTDOWN METHODS

To use the $\overline{ON}$ /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 34 and Figure 35.

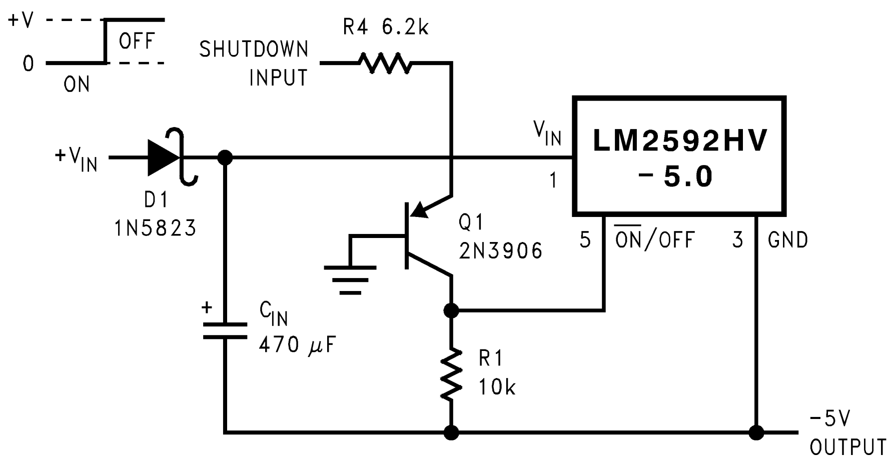


Figure 34. Inverting Regulator Ground Referenced Shutdown

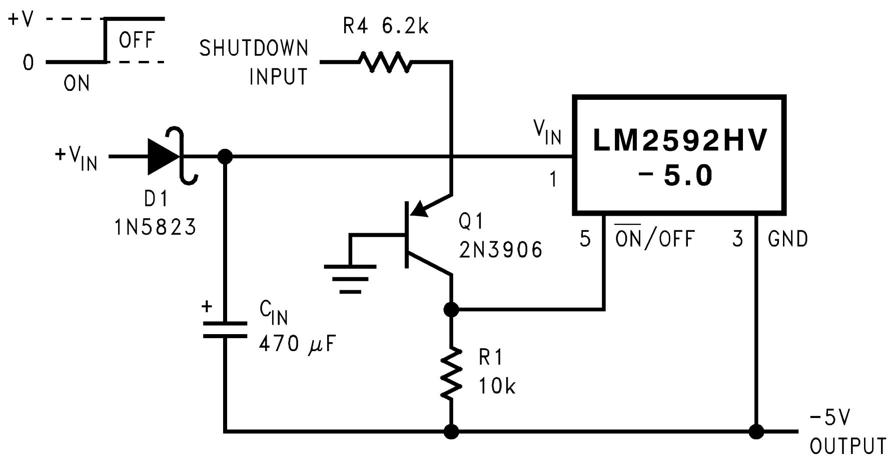


Figure 35. Inverting Regulator Ground Referenced Shutdown using Opto Device

THERMAL CONSIDERATIONS

The LM2592HV is available in two packages, a 5-pin TO-220 (NDH) and a 5-pin surface mount DDPAK (KTT).

The TO-220 package needs a heat sink under most conditions. The size of the heatsink depends on the input voltage, the output voltage, the load current and the ambient temperature. Higher ambient temperatures require more heat sinking.

The DDPAK surface mount package tab is designed to be soldered to the copper on a printed circuit board. The copper and the board are the heat sink for this package and the other heat producing components, such as the catch diode and inductor. The PC board copper area that the package is soldered to should be at least 0.4 in^2, and ideally should have 2 or more square inches of 2 oz. (0.0028) in) copper. Additional copper area improves the thermal characteristics, but with copper areas greater than approximately 6 in^2, only small improvements in heat dissipation are realized. If further thermal improvements are needed, double sided, multilayer PC board with large copper areas and/or airflow are recommended.

The curves shown in Figure 36 show the LM2592HVS (DDPAK package) junction temperature rise above ambient temperature with a 2A load for various input and output voltages. This data was taken with the circuit operating as a buck switching regulator with all components mounted on a PC board to simulate the junction temperature under actual operating conditions. This curve can be used for a quick check for the approximate junction temperature for various conditions, but be aware that there are many factors that can affect the junction temperature. When load currents higher than 2A are used, double sided or multilayer PC boards with large copper areas and/or airflow might be needed, especially for high ambient temperatures and high output voltages.

For the best thermal performance, wide copper traces and generous amounts of printed circuit board copper should be used in the board layout. (One exception to this is the output (switch) pin, which should **not** have large areas of copper.) Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and moving air lowers the thermal resistance even further.

Package thermal resistance and junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers. Some of these factors include board size, shape, thickness, position, location, and even board temperature. Other factors are, trace width, total printed circuit copper area, copper thickness, single- or double-sided, multilayer board and the amount of solder on the board. The effectiveness of the PC board to dissipate heat also depends on the size, quantity and spacing of other components on the board, as well as whether the surrounding air is still or moving. Furthermore, some of these components such as the catch diode will add heat to the PC board and the heat can vary as the input voltage changes. For the inductor, depending on the physical size, type of core material and the DC resistance, it could either act as a heat sink taking heat away from the board, or it could add heat to the board.

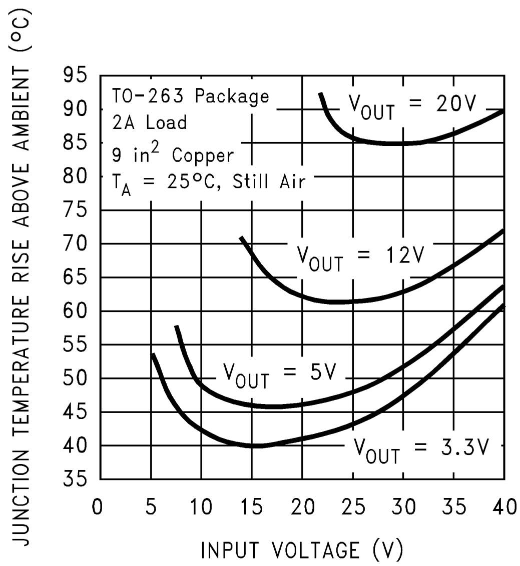


Figure 36. Junction Temperature Rise, DDPAK

Layout Suggestions

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, with reference to Test Circuit and Layout Guidelines, 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.

REVISION HISTORY

Changes from Revision B (April 2013) to Revision C **Page**

- Changed layout of National Data Sheet to TI format 21

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM2592HVS-3.3	NRND	DDPAK/ TO-263	KTT	5	45	TBD	Call TI	Call TI	-40 to 125	LM2592HVS -3.3 P+	
LM2592HVS-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -3.3 P+	Samples
LM2592HVS-5.0	NRND	DDPAK/ TO-263	KTT	5	45	TBD	Call TI	Call TI	-40 to 125	LM2592HVS -5.0 P+	
LM2592HVS-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -5.0 P+	Samples
LM2592HVS-ADJ	NRND	DDPAK/ TO-263	KTT	5	45	TBD	Call TI	Call TI	-40 to 125	LM2592HVS -ADJ P+	
LM2592HVS-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -ADJ P+	Samples
LM2592HVSX-3.3	NRND	DDPAK/ TO-263	KTT	5	500	TBD	Call TI	Call TI	-40 to 125	LM2592HVS -3.3 P+	
LM2592HVSX-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -3.3 P+	Samples
LM2592HVSX-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -5.0 P+	Samples
LM2592HVSX-ADJ	NRND	DDPAK/ TO-263	KTT	5	500	TBD	Call TI	Call TI	-40 to 125	LM2592HVS -ADJ P+	
LM2592HVSX-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM2592HVS -ADJ P+	Samples
LM2592HVT-3.3/NOPB	ACTIVE	TO-220	NDH	5	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM2592HVT -3.3 P+	Samples
LM2592HVT-5.0/NOPB	ACTIVE	TO-220	NDH	5	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM2592HVT -5.0 P+	Samples
LM2592HVT-ADJ	NRND	TO-220	NDH	5	45	TBD	Call TI	Call TI	-40 to 125	LM2592HVT -ADJ P+	
LM2592HVT-ADJ/NOPB	ACTIVE	TO-220	NDH	5	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM2592HVT -ADJ P+	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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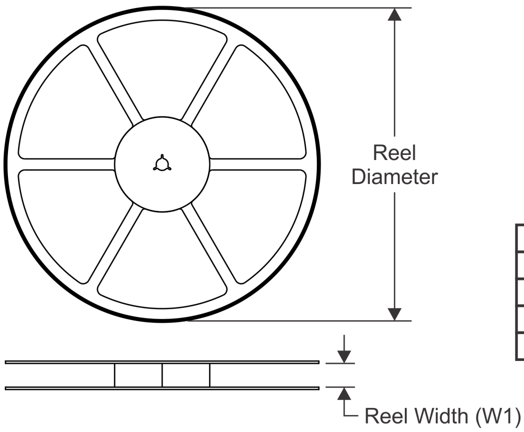
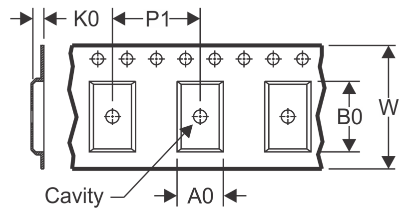
TAPE AND REEL INFORMATION

REEL DIMENSIONS

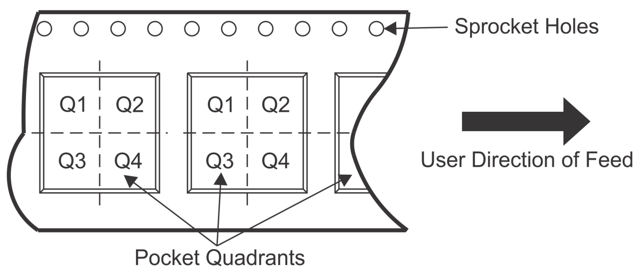


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

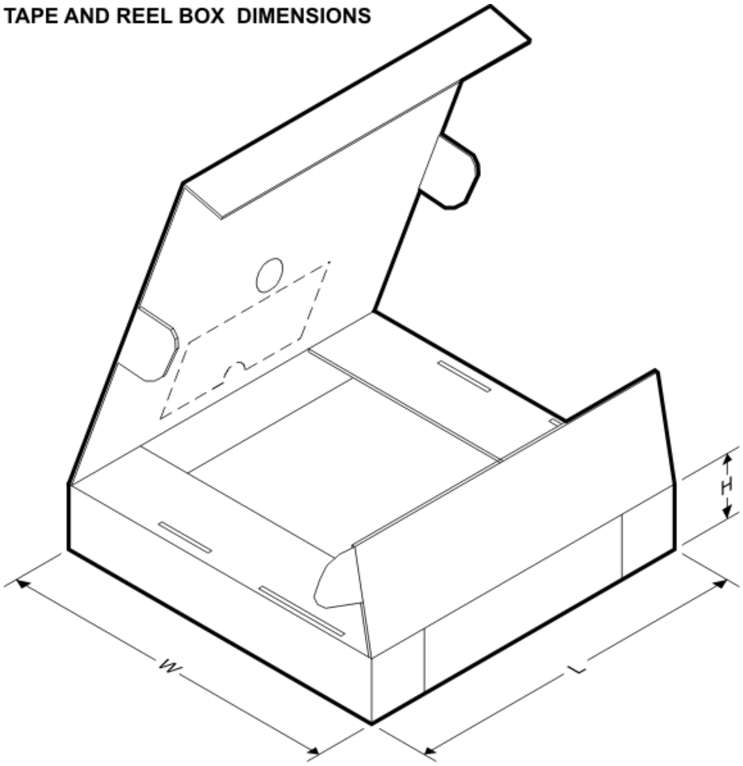
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM2592HVSX-3.3	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2592HVSX-3.3/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2592HVSX-5.0/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2592HVSX-ADJ	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2592HVSX-ADJ/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2

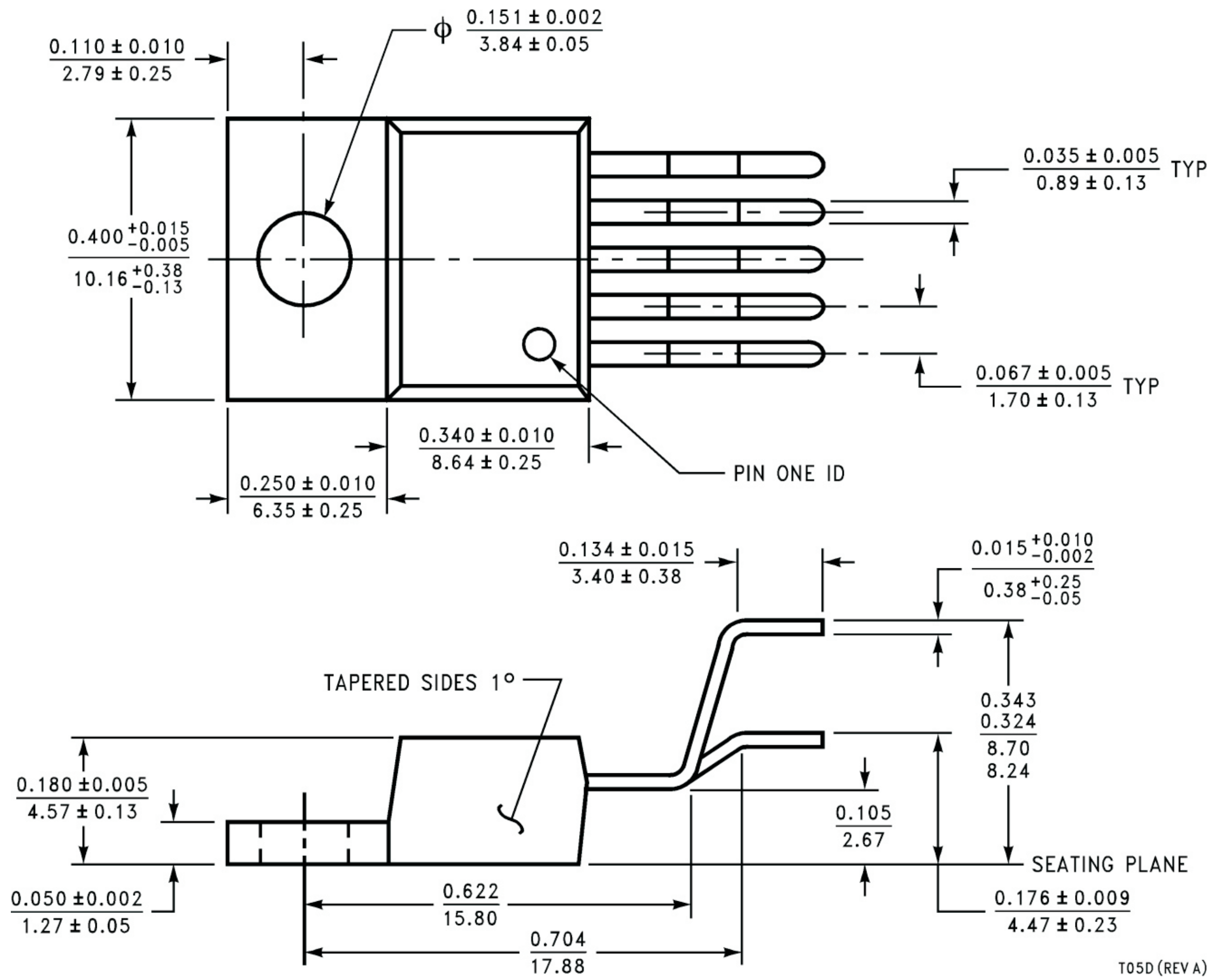
TAPE AND REEL BOX DIMENSIONS



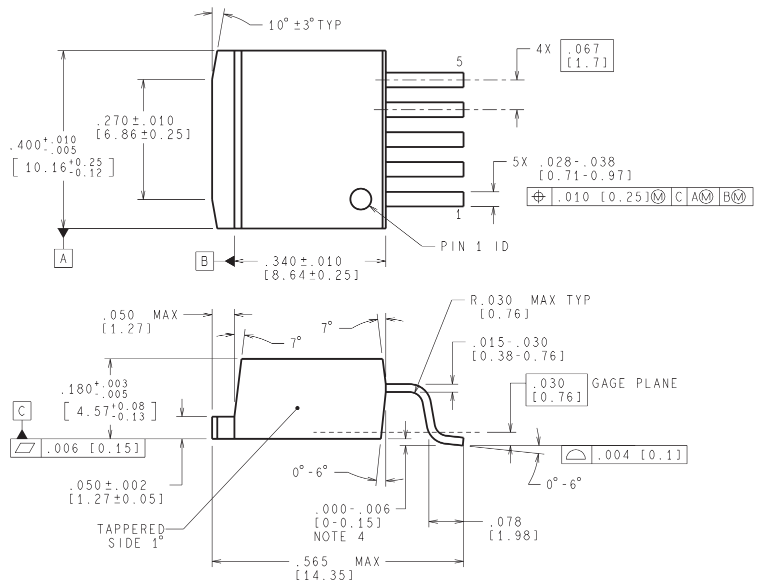
*All dimensions are nominal

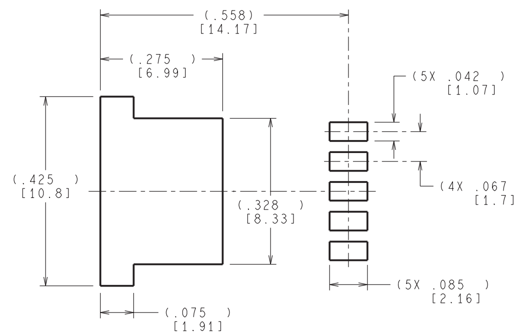
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM2592HVSX-3.3	DDPAK/TO-263	KTT	5	500	367.0	367.0	45.0
LM2592HVSX-3.3/NOPB	DDPAK/TO-263	KTT	5	500	367.0	367.0	45.0
LM2592HVSX-5.0/NOPB	DDPAK/TO-263	KTT	5	500	367.0	367.0	45.0
LM2592HVSX-ADJ	DDPAK/TO-263	KTT	5	500	367.0	367.0	45.0
LM2592HVSX-ADJ/NOPB	DDPAK/TO-263	KTT	5	500	367.0	367.0	45.0

NDH0005D

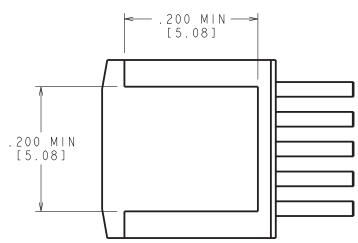

0.110 ± 0.010
2.79 ± 0.25
φ 0.151 ± 0.002
3.84 ± 0.05
0.035 ± 0.005 TYP
0.89 ± 0.13
0.400 +0.015 −0.005
10.16 +0.38 −0.13
0.067 ± 0.005 TYP
1.70 ± 0.13
0.340 ± 0.010
8.64 ± 0.25
PIN ONE ID
0.250 ± 0.010
6.35 ± 0.25
0.134 ± 0.015
3.40 ± 0.38
0.015 +0.010 −0.002
0.38 +0.25 −0.05
TAPERED SIDES 1°
0.343
0.324
8.70
8.24
0.180 ±0.005
4.57 ± 0.13
0.105
2.67
SEATING PLANE
0.050 ±0.002
1.27 ± 0.05
0.622
15.80
0.176 ± 0.009
4.47 ± 0.23
0.704
17.88
T05D (REV A)

KTT0005B





LAND PATTERN RECOMMENDATION



CONTROLLING DIMENSION IS INCH
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TS5B (Rev D)

BOTTOM SIDE OF PACKAGE

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