

## LM25010/LM25010Q 42V, 1.0A Step-Down Switching Regulator

Check for Samples: [LM25010](#)

### FEATURES

- Wide 6V to 42V Input Voltage Range
- Valley Current Limiting At 1.25A
- Programmable Switching Frequency Up To 1 MHz
- Integrated N-Channel Buck Switch
- Integrated High Voltage Bias Regulator
- No Loop Compensation Required
- Ultra-Fast Transient Response
- Nearly Constant Operating Frequency With Line and Load Variations
- Adjustable Output Voltage
- 2.5V,  $\pm 2\%$  Feedback Reference
- Programmable Soft-Start
- Thermal shutdown
- LM25010Q is AEC-Q100 Grade 1 & 0 qualified

### TYPICAL APPLICATIONS

- Non-Isolated Telecommunications Regulator
- Secondary Side Post Regulator
- Automotive Electronics

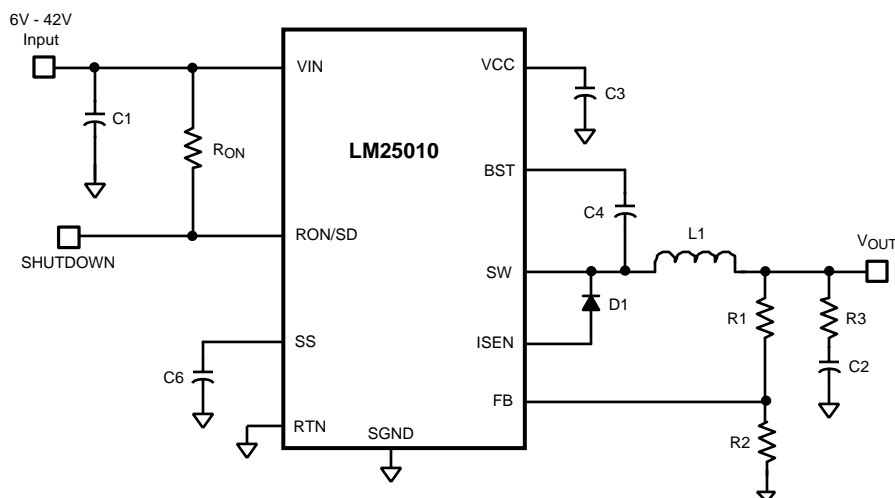
### PACKAGE

- WSON-10 (4 mm x 4 mm)
- HTSSOP-14EP
- Both packages have exposed thermal pad for improved heat dissipation

### DESCRIPTION

The LM25010 features all the functions needed to implement a low cost, efficient, buck regulator capable of supplying in excess of 1A load current. This high voltage regulator integrates an N-Channel Buck Switch, and is available in thermally enhanced WSON-10 and HTSSOP-14EP packages. The constant on-time regulation scheme requires no loop compensation resulting in fast load transient response and simplified circuit implementation. The operating frequency remains constant with line and load variations due to the inverse relationship between the input voltage and the on-time. The valley current limit detection is set at 1.25A. Additional features include: VCC under-voltage lock-out, thermal shutdown, gate drive under-voltage lock-out, and maximum duty cycle limiter.

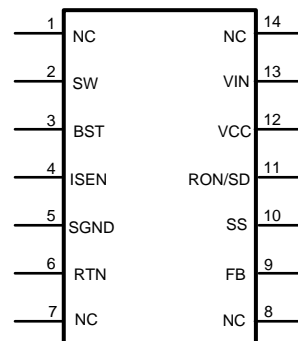
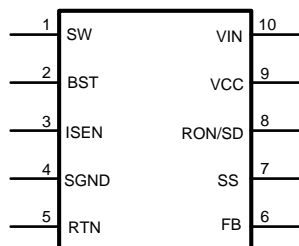
### BASIC STEP-DOWN REGULATOR



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## Connection Diagram



## Pin Descriptions

PIN NUMBER		NAME	DESCRIPTION	APPLICATION INFORMATION
WSON-10	HTSSOP-14			
1	2	SW	Switching node	Internally connected to the buck switch source. Connect to the inductor, free-wheeling diode, and bootstrap capacitor.
2	3	BST	Boost pin for bootstrap capacitor	Connect a capacitor from SW to the BST pin. The capacitor is charged from VCC via an internal diode during the buck switch off-time.
3	4	ISEN	Current sense	During the buck switch off-time, the inductor current flows through the internal sense resistor, and out of the ISEN pin to the free-wheeling diode. The current limit comparator keeps the buck switch off if the ISEN current exceeds 1.25A (typical).
4	5	SGND	Current sense ground	Re-circulating current flows into this pin to the current sense resistor.
5	6	RTN	Circuit ground	Ground return for all internal circuitry other than the current sense resistor.
6	9	FB	Voltage feedback input from the regulated output	Input to both the regulation and over-voltage comparators. The FB pin regulation level is 2.5V.
7	10	SS	Softstart	An internal 11.5 $\mu$ A current source charges the SS pin capacitor to 2.5V to soft-start the reference input of the regulation comparator.
8	11	RON/SD	On-time control and shutdown	An external resistor from VIN to the RON/SD pin sets the buck switch on-time. Grounding this pin shuts down the regulator.
9	12	VCC	Output of the bias regulator	The voltage at VCC is nominally equal to $V_{IN}$ for $V_{IN} < 8.9V$ , and regulated at 7V for $V_{IN} > 8.9V$ . Connect a 0.47 $\mu$ F, or larger capacitor from VCC to ground, as close as possible to the pins. An external voltage can be applied to this pin to reduce internal dissipation if $V_{IN}$ is greater than 8.9V. MOSFET body diodes clamp VCC to VIN if $V_{CC} > V_{IN}$ .
10	13	VIN	Input supply voltage	Nominal input range is 6V to 42V. Input bypass capacitors should be located as close as possible to the VIN and RTN pins.
	1, 7, 8, 14	NC	No connection	No internal connection. Can be connected to ground plane to improve heat dissipation.
		EP	Exposed pad	Exposed metal pad on the underside of the device. It is recommended to connect this pad to the PC board ground plane to aid in heat dissipation.



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 <sup>(1)</sup>

VIN to RTN		–0.3V to 45V
BST to RTN		–0.3V to 59V
SW to RTN (steady state)		–1.5V
BST to VCC		45V
BST to SW		14V
VCC to RTN		–0.3V to 14V
SGND to RTN		–0.3V to 0.3V
SS to RTN		–0.3V to 4V
VIN to SW		45V
All other inputs to RTN		–0.3V to 7V
ESD Rating <sup>(2)</sup>	Human Body Model	2kV
Storage temperature range		–65°C to 150°C
Lead temperature (soldering 4 seconds) <sup>(3)</sup>		260°C

- (1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For guaranteed specifications and test conditions, see the [Electrical Characteristics](#).
- (2) The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin.
- (3) For detailed information on soldering plastic HTSSOP and WSON packages refer to [www.ti.com/packaging](http://www.ti.com/packaging)

## Operating Ratings <sup>(1)</sup>

VIN voltage		6.0V to 42V
Junction temperature	LM25010/LM25010Q1	–40°C to 125°C
	LM25010Q0	–40°C to 150°C

- (1) Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Ratings are conditions under which operation of the device is intended to be functional. For guaranteed specifications and test conditions, see the [Electrical Characteristics](#).

## Electrical Characteristics

Specifications with standard type are for  $T_J = 25^\circ\text{C}$  only; limits in boldface type apply over the full operating junction temperature ( $T_J$ ) range. Minimum and maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at  $T_J = 25^\circ\text{C}$ , and are provided for reference purposes only. Unless otherwise stated, the following conditions apply:  $V_{IN} = 24\text{V}$ ,  $R_{ON} = 200\text{k}\Omega$ . See <sup>(1)</sup>.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
<b>V<sub>CC</sub> Regulator</b>						
V <sub>CC</sub> Reg	V <sub>CC</sub> regulated output		<b>6.6</b>	7	<b>7.4</b>	V
	V <sub>IN</sub> – V <sub>CC</sub>	I <sub>CC</sub> = 0 mA, F <sub>S</sub> ≤ 200 kHz, 6.0V ≤ V <sub>IN</sub> ≤ 8.5V		100		mV
	V <sub>CC</sub> bypass threshold	V <sub>IN</sub> increasing		8.9		V
	V <sub>CC</sub> bypass hysteresis	V <sub>IN</sub> decreasing		260		mV
	V <sub>CC</sub> output impedance (0 mA ≤ I <sub>CC</sub> ≤ 5 mA)	V <sub>IN</sub> = 6.0V		55		Ω
		V <sub>IN</sub> = 8.0V		50		
		V <sub>IN</sub> = 24V		0.21		
	V <sub>CC</sub> current limit (Note 3)	V <sub>IN</sub> = 24V, V <sub>CC</sub> = 0V		15		mA
UVLO <sub>VCC</sub>	V <sub>CC</sub> under-voltage lock-out threshold	V <sub>CC</sub> increasing		5.25		V
	UVLO <sub>VCC</sub> hysteresis	V <sub>CC</sub> decreasing		180		mV
	UVLO <sub>VCC</sub> filter delay	100 mV overdrive		3		μs
	I <sub>IN</sub> operating current	Non-switching, FB = 3V		645	<b>920</b>	μA
	I <sub>IN</sub> shutdown current	R <sub>ON</sub> /SD = 0V		90	<b>170</b>	μA
<b>Switch Characteristics</b>						
R <sub>DS(on)</sub>	Buck switch R <sub>DS(on)</sub> @ f <sub>SW</sub> = 200 mA	T <sub>J</sub> ≤ 125°C T <sub>J</sub> ≤ 150°C		0.35	<b>0.80</b> <b>0.85</b>	Ω
UVLO <sub>GD</sub>	Gate drive UVLO	V <sub>BST</sub> – V <sub>SW</sub> increasing	<b>1.7</b>	3.0	<b>4.0</b>	V
	UVLO <sub>GD</sub> hysteresis			400		mV
<b>SOFT-START Pin</b>						
I <sub>SS</sub>	Internal current source		<b>8.0</b>	11.5	<b>15</b>	μA
<b>Current Limit</b>						
I <sub>LIM</sub>	Threshold	Current out of I <sub>SEN</sub>	<b>1</b>	1.25	<b>1.5</b>	A
	Resistance from I <sub>SEN</sub> to SGND			130		mΩ
	Response time			150		ns
<b>On Timer, RON/SD Pin</b>						
t <sub>ON</sub> – 1	On-time	V <sub>IN</sub> = 10V, R <sub>ON</sub> = 200 kΩ	<b>2.1</b>	2.75	<b>3.4</b>	μs
t <sub>ON</sub> – 2	On-time	V <sub>IN</sub> = 42V, R <sub>ON</sub> = 200 kΩ	<b>500</b>	695	<b>890</b>	ns
	Shutdown threshold	Voltage at RON/SD rising	<b>0.30</b>	0.7	<b>1.05</b>	V
	Threshold hysteresis			40		mV
<b>Off Timer</b>						
t <sub>OFF</sub>	Minimum off-time			260		ns
<b>Regulation and Over-Voltage Comparators (FB Pin)</b>						
V <sub>REF</sub>	FB regulation threshold	T <sub>J</sub> ≤ 125°C T <sub>J</sub> ≤ 150°C	<b>2.445</b> <b>2.435</b>	2.50	<b>2.550</b>	V
	FB over-voltage threshold			2.9		V
	FB bias current			1		nA
<b>Thermal Shutdown</b>						
T <sub>SD</sub>	Thermal shutdown temperature			175		°C
	Thermal shutdown hysteresis			20		°C
<b>Thermal Resistance</b>						
θ <sub>JA</sub>	Junction to ambient, 0 LFPM air flow	DPR0010A Package PWP0014A Package		40 40		°C/W

(1) Typical specifications represent the most likely parametric norm at 25°C operation.

## Electrical Characteristics (continued)

Specifications with standard type are for  $T_J = 25^\circ\text{C}$  only; limits in boldface type apply over the full operating junction temperature ( $T_J$ ) range. Minimum and maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at  $T_J = 25^\circ\text{C}$ , and are provided for reference purposes only. Unless otherwise stated, the following conditions apply:  $V_{IN} = 24\text{V}$ ,  $R_{ON} = 200\text{k}\Omega$ . See <sup>(1)</sup>.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$\theta_{JC}$	Junction to case	DPR0010A Package PWP0014A Package		5.2 5.2		$^\circ\text{C/W}$

## Typical Performance Characteristics

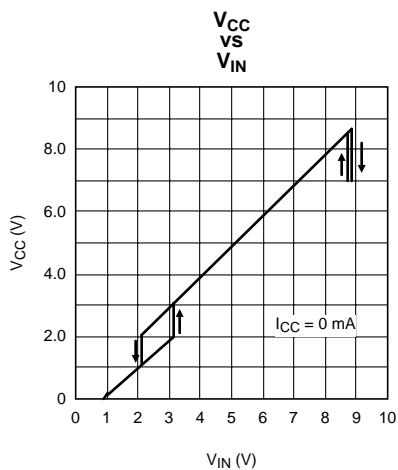


Figure 1.

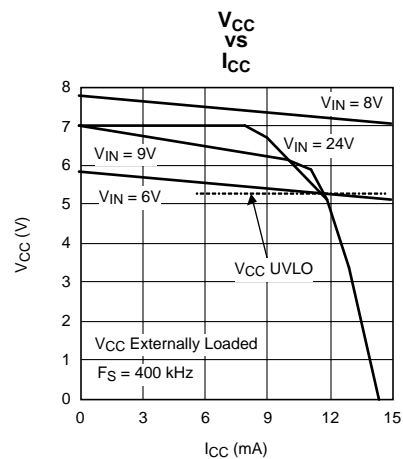


Figure 2.

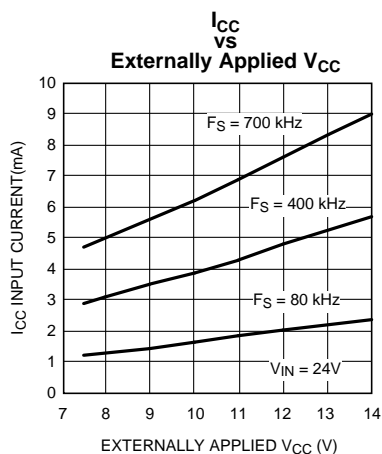


Figure 3.

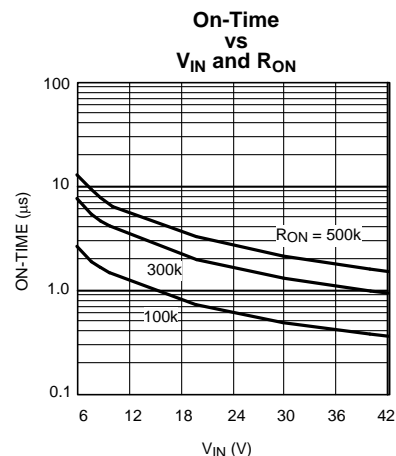


Figure 4.

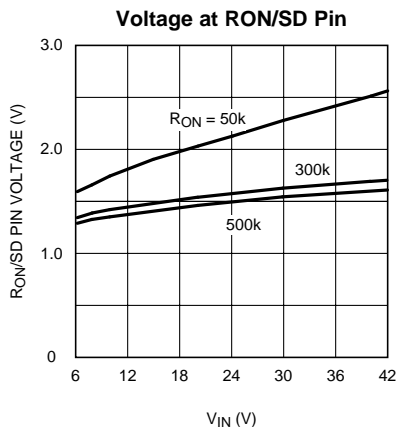


Figure 5.

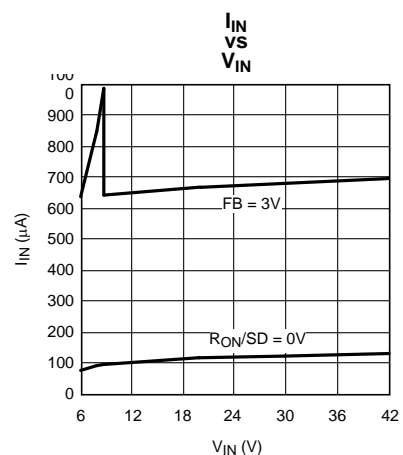
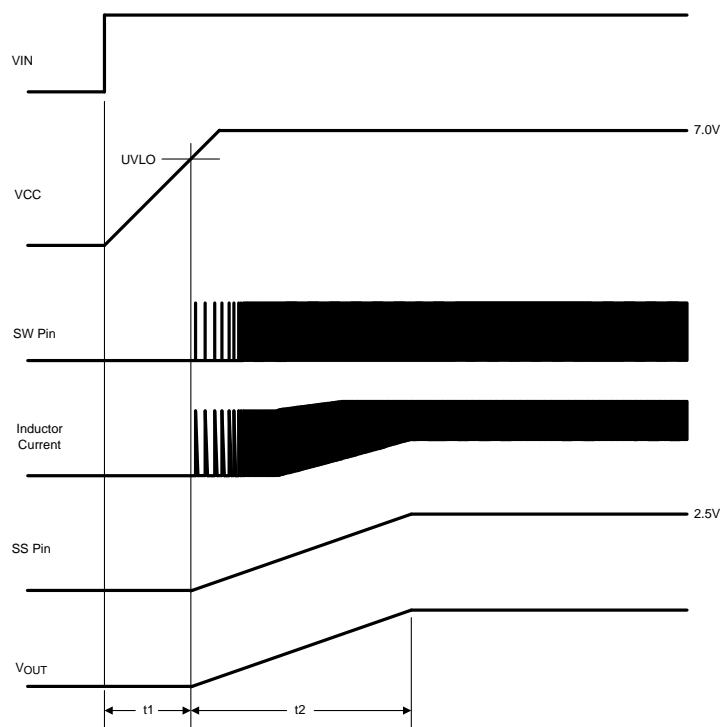
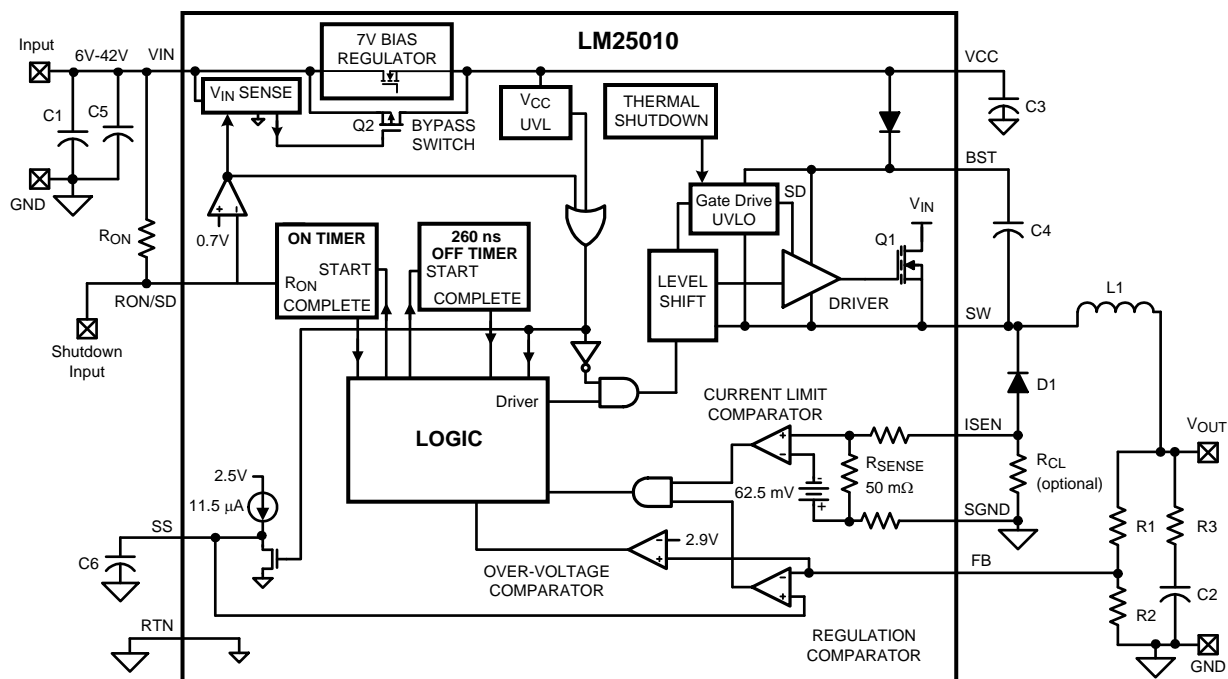


Figure 6.

## Block Diagram



**Figure 7. Startup Sequence**

## Functional Description

The LM25010 Step-Down Switching Regulator features all the functions needed to implement a low cost, efficient buck DC-DC converter capable of supplying in excess of 1A to the load. This high voltage regulator integrates an N-Channel buck switch, with an easy to implement constant on-time controller. It is available in the thermally enhanced WSON-10 and HTSSOP-14EP packages. The regulator compares the feedback voltage to a 2.5V reference to control the buck switch, and provides a switch on-time which varies inversely with VIN. This feature results in the operating frequency remaining relatively constant with load and input voltage variations. The switching frequency can range from less than 100 kHz to 1.0 MHz. The regulator requires no loop compensation resulting in very fast load transient response. The valley current limit circuit holds the buck switch off until the free-wheeling inductor current falls below the current limit threshold, nominally set at 1.25A.

The LM25010 can be applied in numerous applications to efficiently step-down higher DC voltages. Features include: thermal shutdown, VCC under-voltage lock-out, gate drive under-voltage lock-out, and maximum duty cycle limit.

## Control Circuit Overview

The LM25010 employs a control scheme based on a comparator and a one-shot on-timer, with the output voltage feedback (FB) compared to an internal reference (2.5V). If the FB voltage is below the reference the buck switch is turned on for a time period determined by the input voltage and a programming resistor (RON). Following the on-time the switch remains off for a fixed 260 ns off-time, or until the FB voltage falls below the reference, whichever is longer. The buck switch then turns on for another on-time period. Referring to the [Block Diagram](#), the output voltage is set by R1 and R2. The regulated output voltage is calculated as follows:

$$V_{OUT} = 2.5V \times (R1 + R2) / R2 \quad (1)$$

The LM25010 requires a minimum of 25 mV of ripple voltage at the FB pin for stable fixed-frequency operation. If the output capacitor's ESR is insufficient additional series resistance may be required (R3 in the [Block Diagram](#)).

The LM25010 operates in continuous conduction mode at heavy load currents, and discontinuous conduction mode at light load currents. In continuous conduction mode current always flows through the inductor, never decaying to zero during the off-time. In this mode the operating frequency remains relatively constant with load and line variations. The minimum load current for continuous conduction mode is one-half the inductor's ripple current amplitude. The operating frequency in the continuous conduction mode is calculated as follows:

$$F_S = \frac{V_{OUT} \times (V_{IN} - 1.4V)}{1.18 \times 10^{-10} \times (R_{ON} + 1.4 \text{ k}\Omega) \times V_{IN}} \quad (2)$$

The buck switch duty cycle is equal to:

$$DC = \frac{t_{ON}}{t_{ON} + t_{OFF}} = t_{ON} \times F_S = \frac{V_{OUT}}{V_{IN}} \quad (3)$$

Under light load conditions, the LM25010 operates in discontinuous conduction mode, with zero current flowing through the inductor for a portion of the off-time. The operating frequency is always lower than that of the continuous conduction mode, and the switching frequency varies with load current. Conversion efficiency is maintained at a relatively high level at light loads since the switching losses diminish as the power delivered to the load is reduced. The discontinuous mode operating frequency is approximately:

$$F_S = \frac{V_{OUT}^2 \times L1 \times 1.4 \times 10^{20}}{R_L \times R_{ON}^2} \quad (4)$$

where  $R_L$  = the load resistance.

## Start-Up Bias Regulator (VCC)

A high voltage bias regulator is integrated within the LM25010. The input pin (VIN) can be connected directly to line voltages between 6V and 42V. Referring to the [Block Diagram](#) and the graph of VCC vs. VIN, when VIN is between 6V and the bypass threshold (nominally 8.9V), the bypass switch (Q2) is on, and VCC tracks VIN within 100 mV to 150 mV. The bypass switch on-resistance is approximately 50Ω, with inherent current limiting at approximately 100 mA. When VIN is above the bypass threshold, Q2 is turned off, and VCC is regulated at 7V. The VCC regulator output current is limited at approximately 15 mA. When the LM25010 is shutdown using the RON/SD pin, the VCC bypass switch is shut off, regardless of the voltage at VIN.

When  $V_{IN}$  exceeds the bypass threshold, the time required for Q2 to shut off is approximately 2 to 3  $\mu$ s. The capacitor at VCC (C3) must be a minimum of 0.47  $\mu$ F to prevent the voltage at VCC from rising above its absolute maximum rating in response to a step input applied at VIN. C3 must be located as close as possible to the LM25010 pins.

In applications with a relatively high input voltage, power dissipation in the bias regulator is a concern. An auxiliary voltage of between 7.5V and 14V can be diode connected to the VCC pin (D2 in Figure 8) to shut off the VCC regulator, reducing internal power dissipation. The current required into the VCC pin is shown in the Typical Performance Characteristics. Internally a diode connects VCC to VIN requiring that the auxiliary voltage be less than  $V_{IN}$ .

The turn-on sequence is shown in Figure 7. When VCC exceeds the under-voltage lock-out threshold (UVLO) of 5.25V (t1 in Figure 7), the buck switch is enabled, and the SS pin is released to allow the soft-start capacitor (C6) to charge up. The output voltage  $V_{OUT}$  is regulated at a reduced level which increases to the desired value as the soft-start voltage increases (t2 in Figure 7).

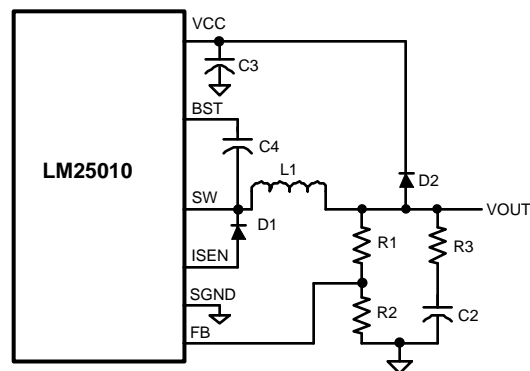


Figure 8. Self Biased Configuration

## Regulation Comparator

The feedback voltage at the FB pin is compared to the voltage at the SS pin (2.5V,  $\pm 2\%$ ). In normal operation an on-time period is initiated when the voltage at FB falls below 2.5V. The buck switch conducts for the on-time programmed by  $R_{ON}$ , causing the FB voltage to rise above 2.5V. After the on-time period the buck switch remains off until the FB voltage falls below 2.5V. Input bias current at the FB pin is less than 5 nA over temperature.

## Over-Voltage Comparator

The feedback voltage at FB is compared to an internal 2.9V reference. If the voltage at FB rises above 2.9V the on-time is immediately terminated. This condition can occur if the input voltage, or the output load, changes suddenly. The buck switch remains off until the voltage at FB falls below 2.5V.

## On-Time Control

The on-time of the internal buck switch is determined by the  $R_{ON}$  resistor and the input voltage ( $V_{IN}$ ), and is calculated as follows:

$$t_{ON} = \frac{1.18 \times 10^{-10} \times (R_{ON} + 1.4k)}{(V_{IN} - 1.4V)} + 67 \text{ ns} \quad (5)$$

The  $R_{ON}$  resistor can be determined from the desired on-time by re-arranging Equation 5 to the following:

$$R_{ON} = \frac{(t_{ON} - 67 \text{ ns}) \times (V_{IN} - 1.4V)}{1.18 \times 10^{-10}} - 1.4 \text{ k}\Omega \quad (6)$$

To set a specific continuous conduction mode switching frequency ( $F_s$ ), the  $R_{ON}$  resistor is determined from the following:

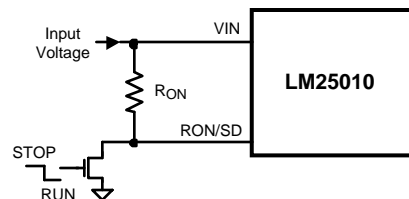
$$R_{ON} = \frac{V_{OUT} \times (V_{IN} - 1.4V)}{V_{IN} \times F_S \times 1.18 \times 10^{-10}} - 1.4 \text{ k}\Omega \quad (7)$$

In high frequency applications the minimum value for  $t_{ON}$  is limited by the maximum duty cycle required for regulation and the minimum off-time of the LM25010 (260 ns,  $\pm 15\%$ ). The fixed off-time limits the maximum duty cycle achievable with a low voltage at  $V_{IN}$ . The minimum allowed on-time to regulate the desired  $V_{OUT}$  at the minimum  $V_{IN}$  is determined from the following:

$$t_{ON(min)} = \frac{V_{OUT} \times 300 \text{ ns}}{(V_{IN(min)} - V_{OUT})} \quad (8)$$

## Shutdown

The LM25010 can be remotely shut down by forcing the RON/SD pin below 0.7V with a switch or open drain device. See [Figure 9](#). In the shutdown mode the SS pin is internally grounded, the on-time one-shot is disabled, the input current at  $V_{IN}$  is reduced, and the  $V_{CC}$  bypass switch is turned off. The  $V_{CC}$  regulator is not disabled in the shutdown mode. Releasing the RON/SD pin allows normal operation to resume. The nominal voltage at RON/SD is shown in the Typical Performance Characteristics. When switching the RON/SD pin, the transition time should be faster than one to two cycles of the regulator's nominal switching frequency.



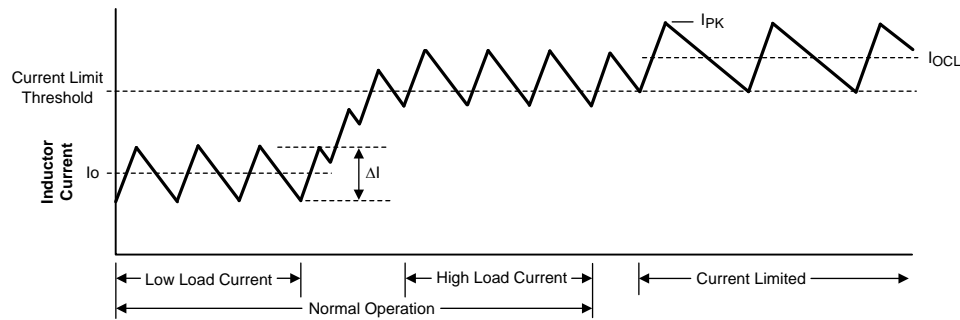
**Figure 9. Shutdown Implementation**

## Current Limit

Current limit detection occurs during the off-time by monitoring the recirculating current through the internal current sense resistor ( $R_{SENSE}$ ). The detection threshold is 1.25A,  $\pm 0.25A$ . Referring to the [Block Diagram](#), if the current into SGND during the off-time exceeds the threshold level the current limit comparator delays the start of the next on-time period. The next on-time starts when the current into SGND is below the threshold **and** the voltage at FB is below 2.5V. [Figure 10](#) illustrates the inductor current waveform during normal operation and during current limit. The output current  $I_O$  is the average of the inductor ripple current waveform. The Low Load Current waveform illustrates continuous conduction mode operation with peak and valley inductor currents below the current limit threshold. When the load current is increased (High Load Current), the ripple waveform maintains the same amplitude and frequency since the current falls below the current limit threshold at the valley of the ripple waveform. Note the average current in the High Load Current portion of [Figure 10](#) is above the current limit threshold. Since the current reduces below the threshold in the normal off-time each cycle, the start of each on-time is not delayed, and the circuit's output voltage is regulated at the correct value. When the load current is further increased such that the lower peak would be above the threshold, the off-time is lengthened to allow the current to decrease to the threshold before the next on-time begins (Current Limited portion of [Figure 10](#)). Both  $V_{OUT}$  and the switching frequency are reduced as the circuit operates in a constant current mode. The load current ( $I_{OCL}$ ) is equal to the current limit threshold plus half the ripple current ( $\Delta I/2$ ). The ripple amplitude ( $\Delta I$ ) is calculated from:

$$\Delta I = \frac{(V_{IN} - V_{OUT}) \times t_{ON}}{L1} \quad (9)$$

The current limit threshold can be increased by connecting an external resistor ( $R_{CL}$ ) between SGND and ISEN.  $R_{CL}$  typically is less than 1 $\Omega$ , and the calculation of its value is explained in the Applications Information section. If the current limit threshold is increased by adding  $R_{CL}$ , the maximum continuous load current should not exceed 1.5A, and the peak current out of the SW pin should not exceed 2A.



**Figure 10. Inductor Current - Current Limit Operation**

## N-Channel Buck Switch and Driver

The LM25010 integrates an N-Channel buck switch and associated floating high voltage gate driver. The peak current through the buck switch should not exceed 2A, and the load current should not exceed 1.5A. The gate driver circuit is powered by the external bootstrap capacitor between BST and SW (C4), which is recharged each off-time from  $V_{CC}$  through the internal high voltage diode. The minimum off-time, nominally 260 ns, ensures sufficient time during each cycle to recharge the bootstrap capacitor. A 0.022  $\mu$ F ceramic capacitor is recommended for C4.

## Soft-Start

The soft-start feature allows the regulator to gradually reach a steady state operating point, thereby reducing startup stresses and current surges. At turn-on, while  $V_{CC}$  is below the under-voltage threshold ( $t_1$  in Figure 7), the SS pin is internally grounded, and  $V_{OUT}$  is held at 0V. When  $V_{CC}$  exceeds the under-voltage threshold (UVLO) an internal 11.5  $\mu$ A current source charges the external capacitor (C6) at the SS pin to 2.5V ( $t_2$  in Figure 7). The increasing SS voltage at the non-inverting input of the regulation comparator gradually increases the output voltage from zero to the desired value. The soft-start feature keeps the load inductor current from reaching the current limit threshold during start-up, thereby reducing inrush currents.

An internal switch grounds the SS pin if  $V_{CC}$  is below the under-voltage lock-out threshold, or if the circuit is shutdown using the RON/SD pin.

## Thermal Shutdown

The LM25010 should be operated below the Maximum Operating Junction Temperature rating. If the junction temperature increases during a fault or abnormal operating condition, the internal Thermal Shutdown circuit activates typically at 175°C. The Thermal Shutdown circuit reduces power dissipation by disabling the buck switch and the on-timer. This feature helps prevent catastrophic failures from accidental device overheating. When the junction temperature reduces below approximately 155°C (20°C typical hysteresis), normal operation resumes.

## APPLICATIONS INFORMATION

### External Components

The procedure for calculating the external components is illustrated with a design example. Referring to the [Block Diagram](#), the circuit is to be configured for the following specifications:

- $V_{OUT} = 5V$
- $V_{IN} = 6V$  to  $40V$
- $F_S = 175\text{ kHz}$
- Minimum load current =  $200\text{ mA}$
- Maximum load current =  $1.0A$
- Softstart time =  $5\text{ ms}$ .

**R1 and R2:** These resistors set the output voltage, and their ratio is calculated from:

$$R1/R2 = (V_{OUT}/2.5V) - 1 \quad (10)$$

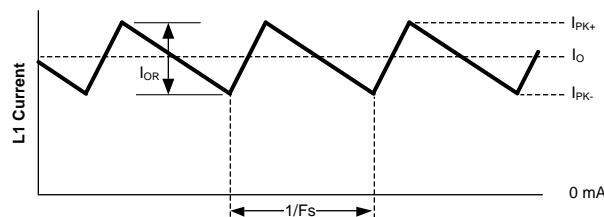
$R1/R2$  calculates to 1.0. The resistors should be chosen from standard value resistors in the range of  $1.0\text{ k}\Omega$  to  $10\text{ k}\Omega$ . A value of  $1.0\text{ k}\Omega$  will be used for R1 and for R2.

**$R_{ON}$ ,  $F_S$ :**  $R_{ON}$  can be chosen using [Equation 7](#) to set the nominal frequency, or from [Equation 6](#) if the on-time at a particular  $V_{IN}$  is important. A higher frequency generally means a smaller inductor and capacitors (value, size and cost), but higher switching losses. A lower frequency means a higher efficiency, but with larger components. Generally, if PC board space is tight, a higher frequency is better. The resulting on-time and frequency have a  $\pm 25\%$  tolerance. Using [Equation 7](#) at a nominal  $V_{IN}$  of  $8V$ ,

$$R_{ON} = \frac{5V \times (8V - 1.4V)}{8V \times 175\text{ kHz} \times 1.18 \times 10^{-10}} - 1.4\text{ k}\Omega = 198\text{ k}\Omega \quad (11)$$

A value of  $200\text{ k}\Omega$  will be used for  $R_{ON}$ , yielding a nominal frequency of  $161\text{ kHz}$  at  $V_{IN} = 6V$ , and  $203\text{ kHz}$  at  $V_{IN} = 40V$ .

**L1:** The guideline for choosing the inductor value in this example is that it must keep the circuit's operation in continuous conduction mode at minimum load current. This is not a strict requirement since the LM25010 regulates correctly when in discontinuous conduction mode, although at a lower frequency. However, to provide an initial value for L1 the above guideline will be used.



**Figure 11. Inductor Current**

To keep the circuit in continuous conduction mode, the maximum allowed ripple current is twice the minimum load current, or  $400\text{ mA}_{P-P}$ . Using this value of ripple current, the inductor (L1) is calculated using the following:

$$L1 = \frac{V_{OUT} \times (V_{IN(max)} - V_{OUT})}{I_{OR} \times F_{S(min)} \times V_{IN(max)}} \quad (12)$$

where  $F_{S(min)}$  is the minimum frequency of  $152\text{ kHz}$  ( $203\text{ kHz} - 25\%$ ) at  $V_{IN(max)}$ .

$$L1 = \frac{5V \times (40V - 5V)}{0.40A \times 152\text{ kHz} \times 40V} = 72\text{ }\mu\text{H} \quad (13)$$

This provides a minimum value for L1 - the next higher standard value (100  $\mu$ H) will be used. To prevent saturation, and possible destructive current levels, L1 must be rated for the peak current which occurs if the current limit and maximum ripple current are reached simultaneously ( $I_{PK}$  in [Figure 10](#)). The maximum ripple amplitude is calculated by re-arranging [Equation 12](#) using  $V_{IN(max)}$ ,  $F_{S(min)}$ , and the minimum inductor value, based on the manufacturer's tolerance. Assume, for this exercise, the inductor's tolerance is  $\pm 20\%$ .

$$I_{OR(max)} = \frac{V_{OUT} \times (V_{IN(max)} - V_{OUT})}{L1_{min} \times F_{S(min)} \times V_{IN(max)}} \quad (14)$$

$$I_{OR(max)} = \frac{5V \times (40V - 5V)}{80 \mu H \times 152 \text{ kHz} \times 40V} = 360 \text{ mAp-p} \quad (15)$$

$$I_{PK} = I_{LIM} + I_{OR(max)} = 1.5A + 0.36A = 1.86A \quad (16)$$

where  $I_{LIM}$  is the maximum guaranteed current limit threshold. At the nominal maximum load current of 1.0A, the peak inductor current is 1.18A.

**R<sub>CL</sub>:** Since it is obvious that the lower peak of the inductor current waveform does not exceed 1.0A at maximum load current (see [Figure 11](#)), it is not necessary to increase the current limit threshold. Therefore  $R_{CL}$  is not needed for this exercise. For applications where the lower peak exceeds 1.0A, see the section entitled Increasing The Current Limit Threshold.

**C1:** This capacitor limits the ripple voltage at VIN resulting from the source impedance of the supply feeding this circuit, and the on/off nature of the switch current into VIN. At maximum load current, when the buck switch turns on, the current into VIN steps up from zero to the lower peak of the inductor current waveform ( $I_{PK-}$  in [Figure 11](#)), ramps up to the peak value ( $I_{PK+}$ ), then drops to zero at turn-off. The average current into VIN during this on-time is the load current. For a worst case calculation, C1 must supply this average current during the maximum on-time. The maximum on-time is calculated at  $V_{IN} = 6V$  using [Equation 5](#), with a 25% tolerance added:

$$t_{ON(max)} = \left[ \frac{1.18 \times 10^{-10} \times (200k + 1.4k)}{6V - 1.4V} + 67 \text{ ns} \right] \times 1.25 = 6.5 \mu s \quad (17)$$

The voltage at VIN should not be allowed to drop below 5.5V in order to maintain  $V_{CC}$  above its UVLO.

$$C1 = \frac{I_O \times t_{ON}}{\Delta V} = \frac{1.0A \times 6.5 \mu s}{0.5V} = 13 \mu F \quad (18)$$

Normally a lower value can be used for C1 since the above calculation is a worst case calculation which assumes the power source has a high source impedance. A quality ceramic capacitor with a low ESR should be used for C1.

**C2 and R3:** Since the LM25010 requires a minimum of 25 mV<sub>P-P</sub> of ripple at the FB pin for proper operation, the required ripple at  $V_{OUT}$  is increased by R1 and R2, and is equal to:

$$V_{RIPPLE} = 25 \text{ mV}_{P-P} \times (R1 + R2)/R2 = 50 \text{ mV}_{P-P} \quad (19)$$

This necessary ripple voltage is created by the inductor ripple current acting on C2's ESR + R3. First, the minimum ripple current, which occurs at minimum  $V_{IN}$ , maximum inductor value, and maximum frequency, is determined.

$$\begin{aligned} I_{OR(min)} &= \frac{V_{OUT} \times (V_{IN(min)} - V_{OUT})}{L1_{max} \times F_{S(max)} \times V_{IN(min)}} \\ &= \frac{5V \times (6V - 5V)}{120 \mu H \times 201 \text{ kHz} \times 6V} = 34.5 \text{ mAp-p} \end{aligned} \quad (20)$$

The minimum ESR for C2 is then equal to:

$$ESR_{(min)} = \frac{50 \text{ mV}}{34.5 \text{ mA}} = 1.45\Omega \quad (21)$$

If the capacitor used for C2 does not have sufficient ESR, R3 is added in series as shown in the [Block Diagram](#). The value chosen for C2 is application dependent, and it is recommended that it be no smaller than 3.3  $\mu$ F. C2 affects the ripple at  $V_{OUT}$ , and transient response. Experimentation is usually necessary to determine the optimum value for C2.

**C3:** The capacitor at the VCC pin provides noise filtering and stability, prevents false triggering of the V<sub>CC</sub> UVLO at the buck switch on/off transitions, and limits the peak voltage at V<sub>CC</sub> when a high voltage with a short rise time is initially applied at V<sub>IN</sub>. C3 should be no smaller than 0.47 µF, and should be a good quality, low ESR, ceramic capacitor, physically close to the IC pins.

**C4:** The recommended value for C4 is 0.022 µF. A high quality ceramic capacitor with low ESR is recommended as C4 supplies the surge current to charge the buck switch gate at each turn-on. A low ESR also ensures a complete recharge during each off-time.

**C5:** This capacitor suppresses transients and ringing due to lead inductance at VIN. A low ESR, 0.1 µF ceramic chip capacitor is recommended, located physically close to the LM25010.

**C6:** The capacitor at the SS pin determines the soft-start time, i.e. the time for the reference voltage at the regulation comparator, and the output voltage, to reach their final value. The capacitor value is determined from the following:

$$C6 = \frac{t_{SS} \times 11.5 \mu A}{2.5V} \quad (22)$$

For a 5 ms softstart time, C6 calculates to 0.022 µF.

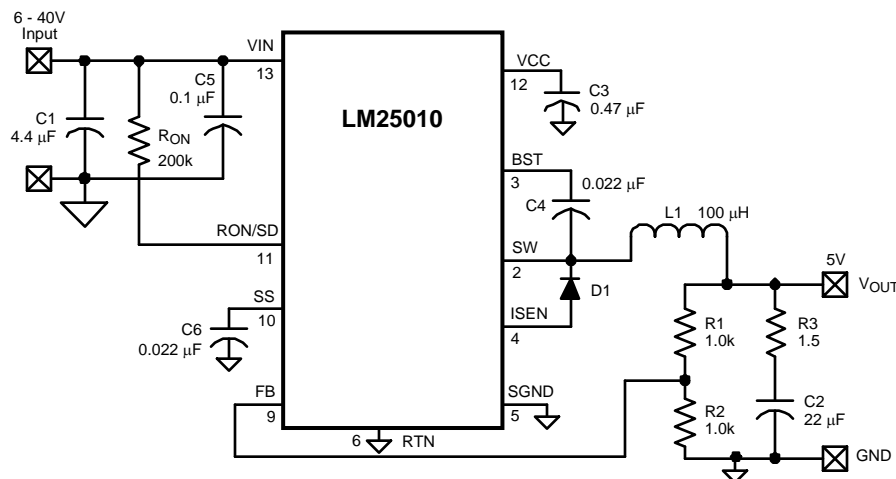
**D1:** A Schottky diode is recommended. Ultra-fast recovery diodes are not recommended as the high speed transitions at the SW pin may inadvertently affect the IC's operation through external or internal EMI. The diode should be rated for the maximum V<sub>IN</sub> (40V), the maximum load current (1A), and the peak current which occurs when current limit and maximum ripple current are reached simultaneously (I<sub>PK</sub> in Figure 10), previously calculated to be 1.86A. The diode's forward voltage drop affects efficiency due to the power dissipated during the off-time. The average power dissipation in D1 is calculated from:

$$P_{D1} = V_F \times I_O \times (1 - D) \quad (23)$$

where I<sub>O</sub> is the load current, and D is the duty cycle.

## Final Circuit

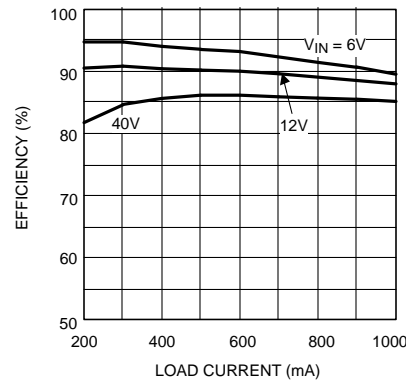
The final circuit is shown in Figure 12, and its performance is shown in Figures 7 and 8. Current limit measured approximately 1.3A.



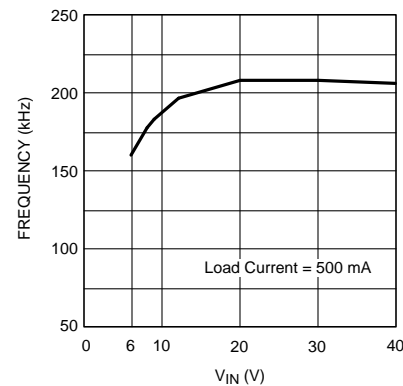
**Figure 12. Example Circuit**

ITEM	DESCRIPTION	VALUE
C1	Ceramic Capacitor	(2) 2.2 µF, 50V
C2	Ceramic Capacitor	22 µF, 16V
C3	Ceramic Capacitor	0.47 µF, 16V
C4, C6	Ceramic Capacitor	0.022 µF, 16V

ITEM	DESCRIPTION	VALUE
C5	Ceramic Capacitor	0.1 $\mu$ F, 50V
D1	Schottky Diode	60V, 2A
L1	Inductor	100 $\mu$ H
R1	Resistor	1.0 k $\Omega$
R2	Resistor	1.0 k $\Omega$
R3	Resistor	1.5 $\Omega$
R <sub>ON</sub>	Resistor	200 k $\Omega$
U1	LM25010	



**Figure 13. Efficiency vs Load Current and V<sub>IN</sub>**  
Circuit of [Figure 12](#)



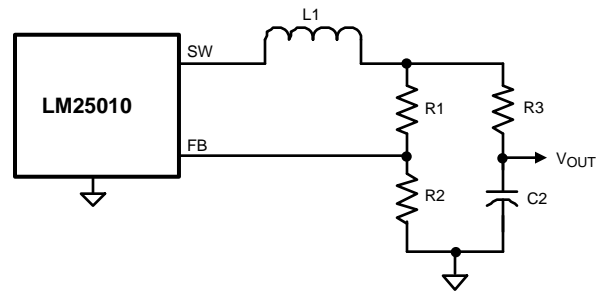
**Figure 14. Frequency vs V<sub>IN</sub>**  
Circuit of [Figure 12](#)

## Minimum Load Current

The LM25010 requires a minimum load current of 500  $\mu$ A. If the load current falls below that level, the bootstrap capacitor (C4) may discharge during the long off-time, and the circuit will either shutdown, or cycle on and off at a low frequency. If the load current is expected to drop below 500  $\mu$ A in the application, R1 and R2 should be chosen low enough in value so they provide the minimum required current at nominal V<sub>OUT</sub>.

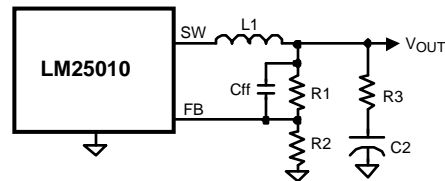
## Low Output Ripple Configurations

For applications where low output voltage ripple is required the output can be taken directly from the low ESR output capacitor (C2) as shown in [Figure 15](#). However, R3 slightly degrades the load regulation. The specific component values, and the application determine if this is suitable.



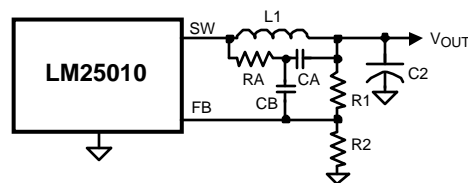
**Figure 15. Low Ripple Output**

Where the circuit of [Figure 15](#) is not suitable, the circuits of [Figure 16](#) or [Figure 17](#) can be used.



**Figure 16. Low Output Ripple Using a Feedforward Capacitor**

In [Figure 16](#),  $C_{ff}$  is added across  $R1$  to AC-couple the ripple at  $V_{OUT}$  directly to the FB pin. This allows the ripple at  $V_{OUT}$  to be reduced, in some cases considerably, by reducing  $R3$ . In the circuit of [Figure 12](#), the ripple at  $V_{OUT}$  ranged from 50 mV<sub>P-P</sub> at  $V_{IN} = 6V$  to 285 mV<sub>P-P</sub> at  $V_{IN} = 40V$ . By adding a 1000 pF capacitor at  $C_{ff}$  and reducing  $R3$  to 0.75Ω, the  $V_{OUT}$  ripple was reduced by 50%, ranging from 25 mV<sub>P-P</sub> to 142 mV<sub>P-P</sub>.



**Figure 17. Low Output Ripple Using Ripple Injection**

To reduce  $V_{OUT}$  ripple further, the circuit of [Figure 17](#) can be used. R3 has been removed, and the output ripple amplitude is determined by C2's ESR and the inductor ripple current. RA and CA are chosen to generate a 40 to 50 mV<sub>P-P</sub> sawtooth at their junction, and that voltage is AC-coupled to the FB pin via CB. In selecting RA and CA,  $V_{OUT}$  is considered a virtual ground as the SW pin switches between  $V_{IN}$  and  $-1V$ . Since the on-time at SW varies inversely with  $V_{IN}$ , the waveform amplitude at the RA/CA junction is relatively constant. R1 and R2 must typically be increased to more than 5k $\Omega$  each to not significantly attenuate the signal provided to FB through CB. Typical values for the additional components are RA = 200k $\Omega$ , CA = 680 pF, and CB = 0.01  $\mu$ F.

### Increasing The Current Limit Threshold

The current limit threshold is nominally 1.25A, with a minimum guaranteed value of 1.0A. If, at maximum load current, the lower peak of the inductor current ( $I_{PK-}$  in [Figure 11](#)) exceeds 1.0A, resistor  $R_{CL}$  must be added between SGND and ISEN to increase the current limit threshold to equal or exceed that lower peak current. This resistor diverts some of the recirculating current from the internal sense resistor so that a higher current level is needed to switch the internal current limit comparator.  $I_{PK-}$  is calculated from:

$$I_{PK-} = I_{O(max)} - \frac{I_{OR(min)}}{2} \quad (24)$$

where  $I_{O(max)}$  is the maximum load current, and  $I_{OR(min)}$  is the minimum ripple current calculated using [Equation 20](#).  $R_{CL}$  is calculated from:

$$R_{CL} = \frac{1.0A \times 0.11\Omega}{I_{PK-} - 1.0A} \quad (25)$$

where 0.11 $\Omega$  is the minimum value of the internal resistance from SGND to ISEN. The next smaller standard value resistor should be used for  $R_{CL}$ . With the addition of  $R_{CL}$ , and when the circuit is in current limit, the upper peak current out of the SW pin ( $I_{PK}$  in [Figure 10](#)) can be as high as:

$$I_{PK} = \frac{1.5A \times (150 \text{ m}\Omega + R_{CL})}{R_{CL}} + I_{OR(MAX)} \quad (26)$$

where  $I_{OR(max)}$  is calculated using [Equation 14](#). The inductor L1 and diode D1 must be rated for this current. If  $I_{PK}$  exceeds 2A, the inductor value must be increased to reduce the ripple amplitude. This will necessitate recalculation of  $I_{OR(min)}$ ,  $I_{PK-}$ , and  $R_{CL}$ .

Increasing the circuit's current limit will increase power dissipation and the junction temperature within the LM25010. See the next section for guidelines on this issue.

### PC Board Layout and Thermal Considerations

The LM25010 regulation, over-voltage, and current limit comparators are very fast, and will respond to short duration noise pulses. Layout considerations are therefore critical for optimum performance. The layout must be as neat and compact as possible, and all the components must be as close as possible to their associated pins. The two major current loops have currents which switch very fast, and so the loops should be as small as possible to minimize conducted and radiated EMI. The first loop is that formed by C1, through the VIN to SW pins, L1, C2, and back to C1. The second loop is that formed by D1, L1, C2, and the SGND and ISEN pins. The ground connection from C2 to C1 should be as short and direct as possible, preferably without going through vias. Directly connect the SGND and RTN pin to each other, and they should be connected as directly as possible to the C1/C2 ground line without going through vias. The power dissipation within the IC can be approximated by determining the total conversion loss ( $P_{IN} - P_{OUT}$ ), and then subtracting the power losses in the free-wheeling diode and the inductor. The power loss in the diode is approximately:

$$P_{D1} = I_O \times V_F \times (1 - D) \quad (27)$$

where  $I_O$  is the load current,  $V_F$  is the diode's forward voltage drop, and D is the duty cycle. The power loss in the inductor is approximately:

$$P_{L1} = I_O^2 \times R_L \times 1.1 \quad (28)$$

where  $R_L$  is the inductor's DC resistance, and the 1.1 factor is an approximation for the AC losses. If it is expected that the internal dissipation of the LM25010 will produce high junction temperatures during normal operation, good use of the PC board's ground plane can help considerably to dissipate heat. The exposed pad on the IC package bottom should be soldered to a ground plane, and that plane should both extend from beneath the IC, and be connected to exposed ground plane on the board's other side using as many vias as

possible. The exposed pad is internally connected to the IC substrate. The use of wide PC board traces at the pins, where possible, can help conduct heat away from the IC. The four NC pins on the HTSSOP package are not electrically connected to any part of the IC, and may be connected to ground plane to help dissipate heat from the package. Judicious positioning of the PC board within the end product, along with the use of any available air flow (forced or natural convection) can help reduce the junction temperature.

## REVISION HISTORY

Changes from Revision C (February 2013) to Revision D	Page
• Changed layout of National Data Sheet to TI format .....	<a href="#">18</a>

## 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
LM25010MH	NRND	HTSSOP	PWP	14	94	TBD	Call TI	Call TI	-40 to 125	L25010 MH	
LM25010MH/NOPB	ACTIVE	HTSSOP	PWP	14	94	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	L25010 MH	<a href="#">Samples</a>
LM25010MHX/NOPB	ACTIVE	HTSSOP	PWP	14	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	L25010 MH	<a href="#">Samples</a>
LM25010Q0MH/NOPB	ACTIVE	HTSSOP	PWP	14	94	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 150	L25010 Q0MH	<a href="#">Samples</a>
LM25010Q0MHX/NOPB	ACTIVE	HTSSOP	PWP	14	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 150	L25010 Q0MH	<a href="#">Samples</a>
LM25010Q1MH/NOPB	ACTIVE	HTSSOP	PWP	14	94	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	L25010 Q1MH	<a href="#">Samples</a>
LM25010Q1MHX/NOPB	ACTIVE	HTSSOP	PWP	14	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	L25010 Q1MH	<a href="#">Samples</a>
LM25010SD/NOPB	ACTIVE	WSO	DPR	10	1000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	-40 to 125	25010SD	<a href="#">Samples</a>
LM25010SDX/NOPB	ACTIVE	WSO	DPR	10	4500	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	-40 to 125	25010SD	<a href="#">Samples</a>

(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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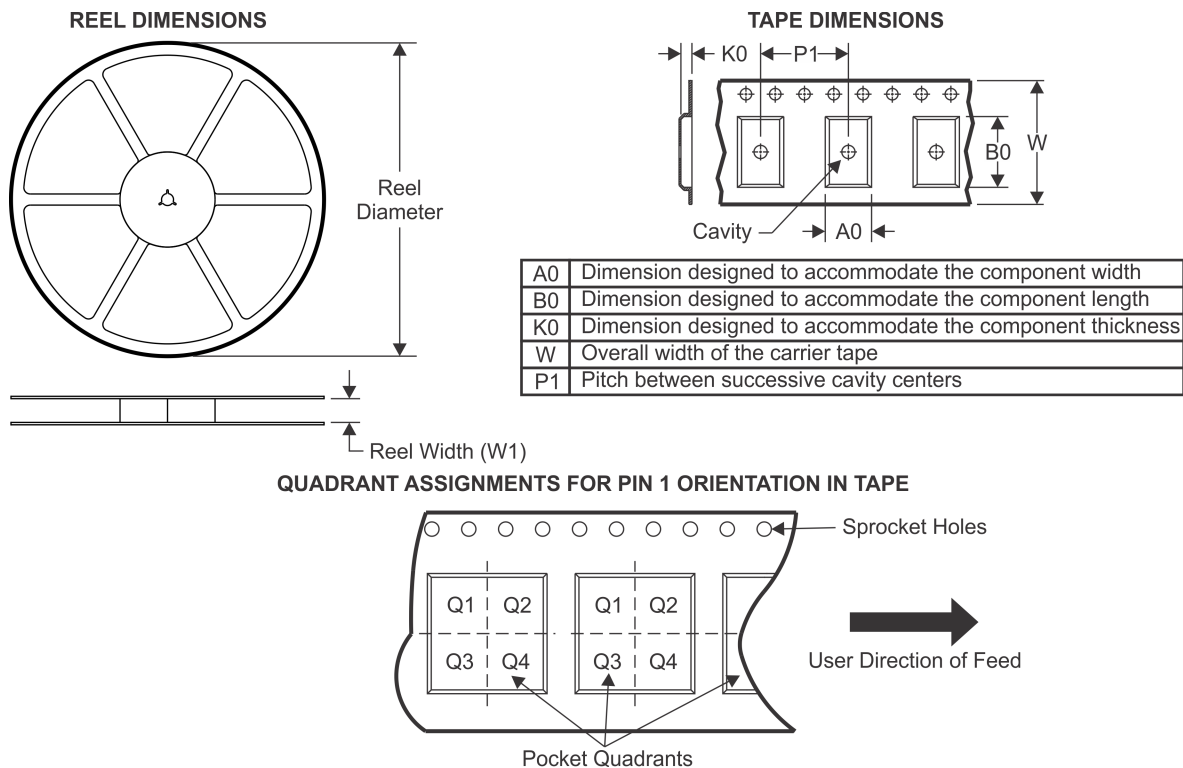
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**OTHER QUALIFIED VERSIONS OF LM25010, LM25010-Q1 :**

- Catalog: [LM25010](#)
- Automotive: [LM25010-Q1](#)

NOTE: Qualified Version Definitions:

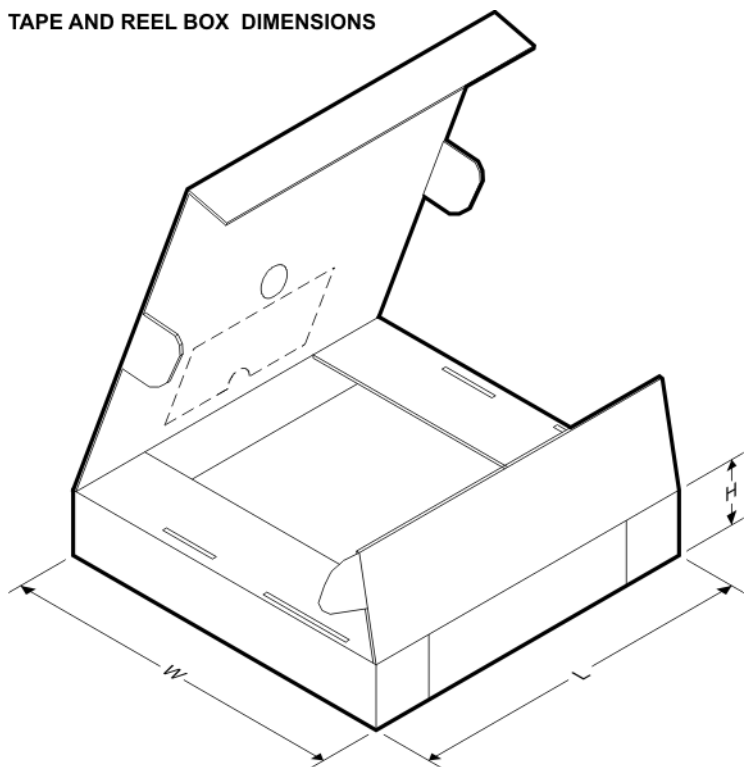
- Catalog - TI's standard catalog product
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

**TAPE AND REEL INFORMATION**


\*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
LM25010MHX/NOPB	HTSSOP	PWP	14	2500	330.0	12.4	6.95	8.3	1.6	8.0	12.0	Q1
LM25010Q0MHX/NOPB	HTSSOP	PWP	14	2500	330.0	12.4	6.95	8.3	1.6	8.0	12.0	Q1
LM25010Q1MHX/NOPB	HTSSOP	PWP	14	2500	330.0	12.4	6.95	8.3	1.6	8.0	12.0	Q1
LM25010SD/NOPB	WSOP	DPR	10	1000	178.0	12.4	4.3	4.3	1.3	8.0	12.0	Q1
LM25010SDX/NOPB	WSOP	DPR	10	4500	330.0	12.4	4.3	4.3	1.3	8.0	12.0	Q1

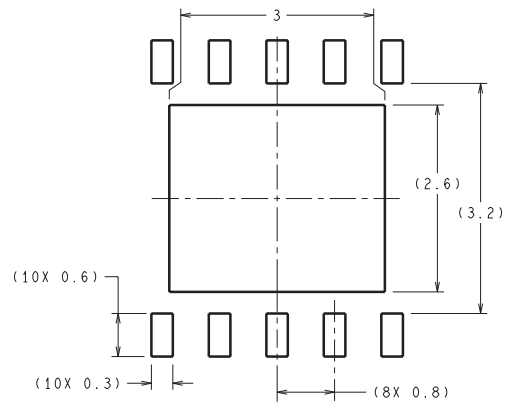
## TAPE AND REEL BOX DIMENSIONS



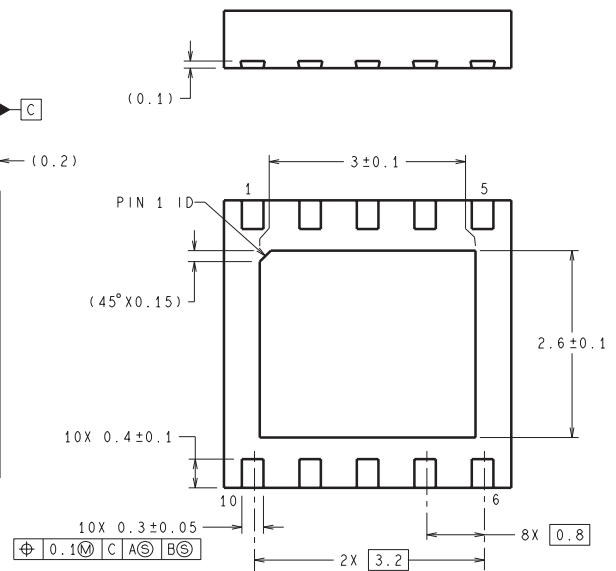
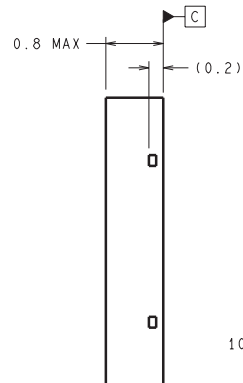
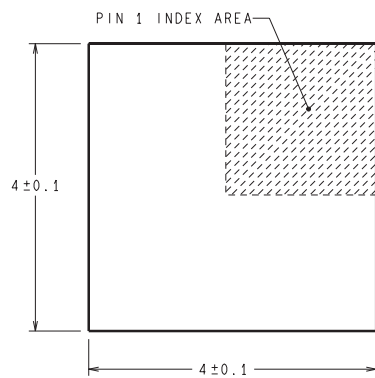
\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM25010MHX/NOPB	HTSSOP	PWP	14	2500	367.0	367.0	35.0
LM25010Q0MHX/NOPB	HTSSOP	PWP	14	2500	367.0	367.0	35.0
LM25010Q1MHX/NOPB	HTSSOP	PWP	14	2500	367.0	367.0	35.0
LM25010SD/NOPB	WSON	DPR	10	1000	210.0	185.0	35.0
LM25010SDX/NOPB	WSON	DPR	10	4500	367.0	367.0	35.0





### RECOMMENDED LAND PATTERN



**DIMENSIONS ARE IN MILLIMETERS**

SDC10A (Rev A)

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