National Semiconductor

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LM5008

High Voltage (100V) Step Down Switching Regulator

General Description

The LM5008 Step Down Switching Regulator features all of the functions needed to implement a low cost, efficient, Buck bias regulator. This high voltage regulator contains an 100 V N-Channel Buck Switch. The device is easy to implement and is provided in the MSOP-8 and the thermally enhanced LLP-8 packages. The regulator is based on a hysteretic control scheme using an ON time inversely proportional to V_{IN}. This feature allows the operating frequency to remain relatively constant. The hysteretic control requires no loop compensation. An intelligent current limit is implemented with forced OFF time, which is inversely proportional to Vout. This scheme ensures short circuit protection while providing minimum foldback. Other protection features include: Thermal Shutdown, V_{CC} under-voltage lockout, Gate drive under-voltage lockout, and Max Duty Cycle limiter

Features

- Integrated 100V, N-Channel buck switch
- Internal V_{CC} regulator
- No loop compensation required
- Ultra-Fast transient response
- On time varies inversely with line voltage
- Operating frequency remains constant with varying line voltage and load current
- Adjustable output voltage
- Highly efficient operation
- Precision internal reference
- Low bias current
- Intelligent current limit protection
- Thermal shutdown

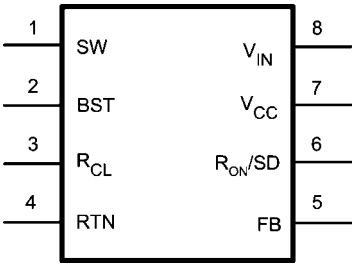
Typical Applications

- Non-Isolated Telecommunication Buck Regulator
- Secondary High Voltage Post Regulator
- +42V Automotive Systems

Package

- MSOP - 8
- LLP - 8 (4mm x 4mm)

Connection Diagram



8-Lead MSOP, LLP

Ordering Information

Order Number	Package Type	NSC Package Drawing	Supplied As
LM5008MM	MSOP-8	MUA08A	1000 Units on Tape and Reel
LM5008MMX			3500 Units on Tape and Reel
LM5008SD	LLP-8	SDC08A	1000 Units on Tape and Reel
LM5008SDX			4500 Units on Tape and Reel
LM5008SDC		SDC08B	1000 Units on Tape and Reel
LM5008SDCX			4500 Units on Tape and Reel

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Typical Application Circuit and Block Diagram

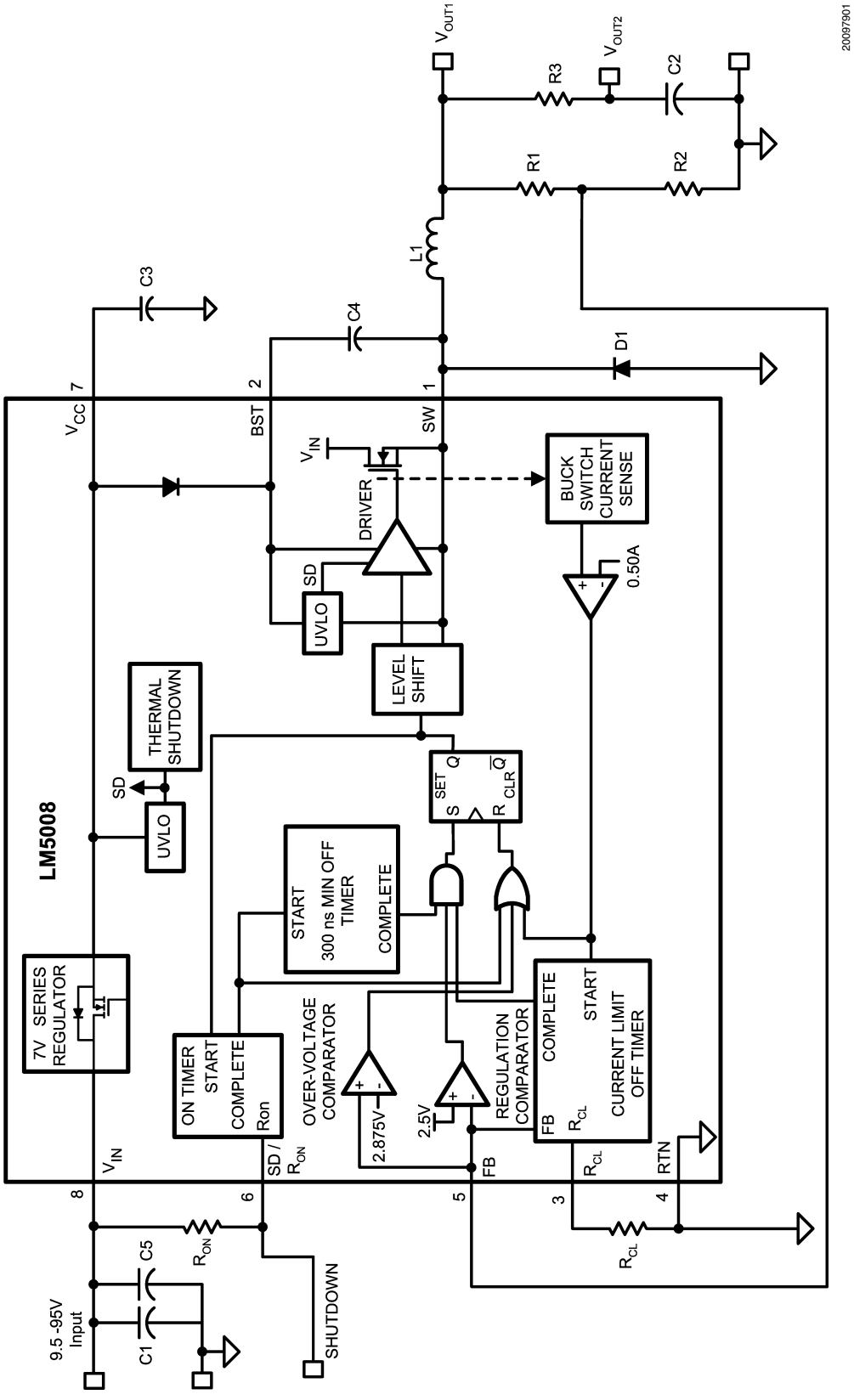


FIGURE 1.

Pin Descriptions

Pin	Name	Description	Application Information
1	SW	Switching Node	Power switching node. Connect to the output inductor, re-circulating diode, and bootstrap capacitor.
2	BST	Boost Pin (Boot–strap capacitor input)	An external capacitor is required between the BST and the SW pins. A 0.01µF ceramic capacitor is recommended. An internal diode charges the capacitor from V_{CC}.
3	R_{CL}	Current Limit OFF time set pin Toff = 10^{-5} / (0.285 + (FB / 6.35 x 10^{-6} x R_{CL}))	A resistor between this pin and RTN sets the off-time when current limit is detected. The off-time is preset to 35µs if FB = 0V.
4	RTN	Ground pin	Ground for the entire circuit.
5	FB	Feedback input from Regulated Output	This pin is connected to the inverting input of the internal regulation comparator. The regulation threshold is 2.5V.
6	R_{ON}/SD	On time set pin Ton = 1.25 x 10^{-10} R_{ON} / V_{IN}	A resistor between this pin and V_{IN} sets the switch on time as a function of V_{IN}. The minimum recommended on time is 400ns at the maximum input voltage. This pin can be used for remote shutdown.
7	V_{CC}	Output from the internal high voltage series pass regulator. Regulated at 7.0V.	If an auxiliary voltage is available to raise the voltage on this pin, above the regulation setpoint (7V), the internal series pass regulator will shutdown, reducing the IC power dissipation. Do not exceed 14V. This voltage provides gate drive power for the internal Buck switch. An internal diode is provided between this pin and the BST pin. A local 0.1µF decoupling capacitor is recommended. Series pass regulator is current limited to 10mA.
8	V_{IN}	Input voltage	Recommended operating range: 9.5V to 95V.
	EP	Exposed Pad	The exposed pad has no electrical contact. Connect to system ground plane for reduced thermal resistance.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V_{IN} to GND	-0.3V to 100V
BST to GND	-0.3V to 114V
SW to GND (Steady State)	-1V
ESD Rating (Note 5)	
Human Body Model	2kV
BST to V_{CC}	100V
BST to SW	14V
V_{CC} to GND	14V
All Other Inputs to GND	-0.3 to 7V
Lead Temperature (Soldering 4 sec)	260°C
Storage Temperature Range	-55°C to +150°C

Operating Ratings (Note 1)

V_{IN}	9.5V to 95V
Operating Junction Temperature	–40°C to + 125°C

Electrical Characteristics

Specifications with standard typeface are for T_J = 25°C, and those with **boldface** type apply over full **Operating Junction Temperature range**. V_{IN} = 48V, unless otherwise stated (Note 3).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} Supply						
V_{CC} Reg	V_{CC} Regulator Output		**6.6**	7	**7.4**	V
	V_{CC} Current Limit	(Note 4)		9.5		mA
	V_{CC} undervoltage Lockout Voltage (V_{CC} increasing)			6.3		V
	V_{CC} Undervoltage Hysteresis			200		mV
	V_{CC} UVLO Delay (filter)	100mV overdrive		10		µs
	I_{IN} Operating Current	Non-Switching, FB = 3V		485	**675**	µA
	I_{IN} Shutdown Current	R_{ON}/SD = 0V		76	**150**	µA
Switch Characteristics						
	Buck Switch Rds(on)	I_{TEST} = 200mA, (Note 6)		1.15	**2.47**	Ω
	Gate Drive UVLO	V_{BST} – V_{SW} Rising	**3.4**	4.5	**5.5**	V
	Gate Drive UVLO Hysteresis			430		mV
Current Limit						
	Current Limit Threshold		**0.41**	0.51	**0.61**	A
	Current Limit Response Time	I_{switch} Overdrive = 0.1A Time to Switch Off		400		ns
	OFF time generator (test 1)	FB=0V, R_{CL} = 100K		35		µs
	OFF time generator (test 2)	FB=2.3V, R_{CL} = 100K		2.56		µs
On Time Generator						
	T_{ON} - 1	Vin = 10V Ron = 200K	**2.15**	2.77	**3.5**	µs
	T_{ON} - 2	Vin = 95V Ron = 200K	**200**	300	**420**	ns
	Remote Shutdown Threshold	Rising	**0.40**	0.70	**1.05**	V
	Remote Shutdown Hysteresis			35		mV

Symbol	Parameter	Conditions	Min	Typ	Max	Units
Minimum Off Time						
	Minimum Off Timer	FB = 0V		300		ns
Regulation and OV Comparators						
	FB Reference Threshold	Internal reference Trip point for switch ON	**2.445**	2.5	**2.550**	V
	FB Over-Voltage Threshold	Trip point for switch OFF		2.875		V
	FB Bias Current			100		nA
Thermal Shutdown						
Tsd	Thermal Shutdown Temp.			165		°C
	Thermal Shutdown Hysteresis			25		°C
Thermal Resistance						
θ_{JA}	Junction to Ambient	MUA Package		200		°C/W
		SDC Package		40		°C/W

Note 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.

Note 2: For detailed information on soldering plastic MSOP and LLP packages, refer to the Packaging Data Book available from National Semiconductor Corporation.

Note 3: All limits are guaranteed. All electrical characteristics having room temperature limits are tested during production with $T_A = T_J = 25°C$. All hot and cold limits are guaranteed by correlating the electrical characteristics to process and temperature variations and applying statistical process control.

Note 4: The V_{CC} output is intended as a self bias for the internal gate drive power and control circuits. Device thermal limitations limit external loading.

Note 5: The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin.

Note 6: For devices procured in the LLP-8 package the Rds(on) limits are guaranteed by design characterization data only.

Typical Performance Characteristics

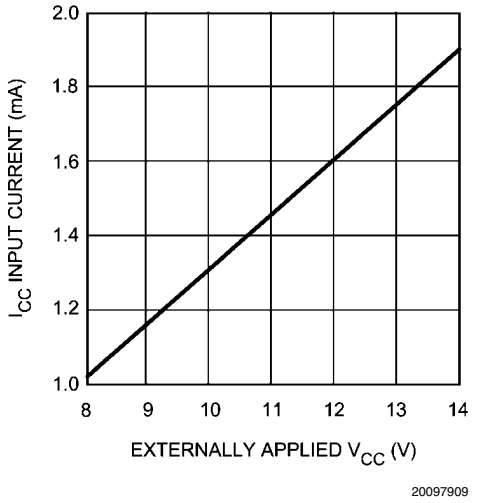


FIGURE 2. I_{CC} Current vs Applied V_{CC} Voltage

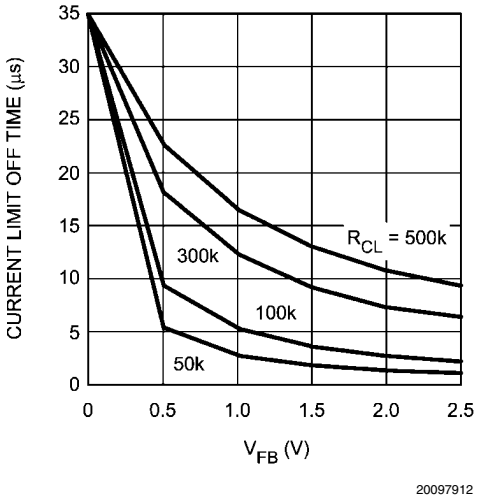


FIGURE 5. Current Limit Off-Time vs V_{FB} and R_{CL}

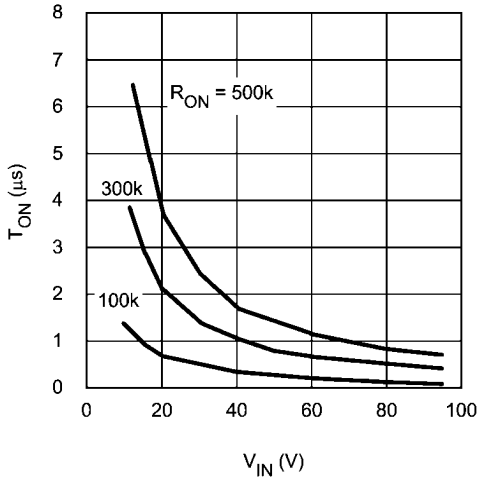


FIGURE 3. ON-Time vs Input Voltage and R_{ON}

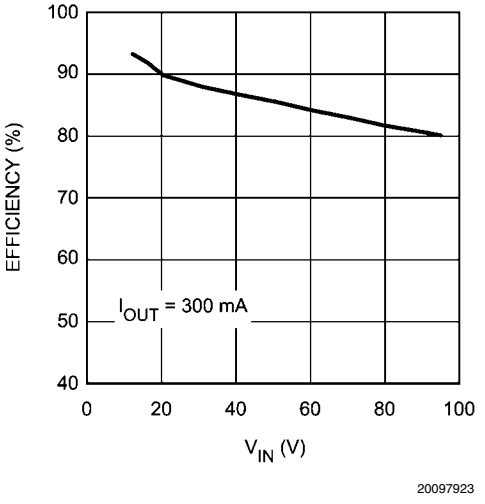


FIGURE 6. Efficiency vs V_{IN} (Circuit of *Figure 13*)

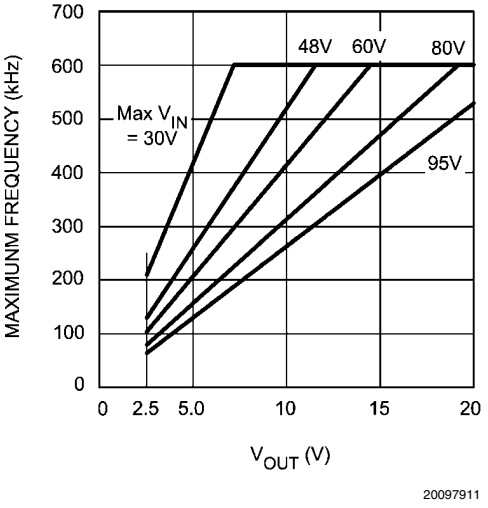


FIGURE 4. Maximum Frequency vs V_{OUT} and V_{IN}

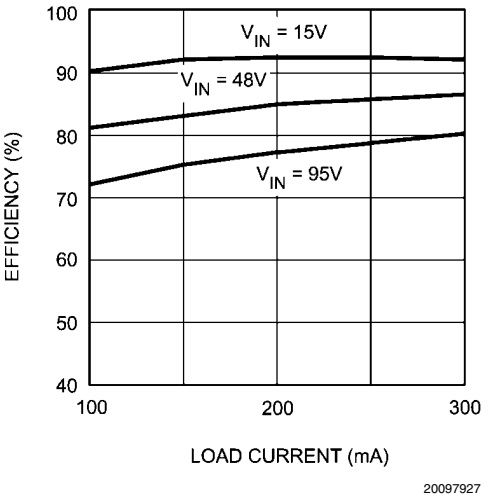


FIGURE 7. Efficiency vs Load Current vs V_{IN} (Circuit of *Figure 13*)

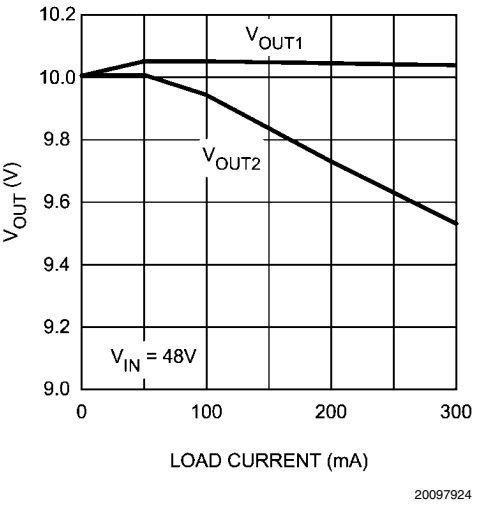


FIGURE 8. Output Voltage vs Load Current (Circuit of *Figure 13*)

Functional Description

The LM5008 Step Down Switching Regulator features all the functions needed to implement a low cost, efficient, Buck bias power converter. This high voltage regulator contains a 100 V N-Channel Buck Switch, is easy to implement and is provided in the MSOP-8 and the thermally enhanced LLP-8 packages. The regulator is based on a hysteretic control scheme using an on-time inversely proportional to V_{IN}. The hysteretic control requires no loop compensation. Current limit is implemented with forced off-time, which is inversely proportional to V_{OUT}. This scheme ensures short circuit protection while providing minimum foldback. The Functional Block Diagram of the LM5008 is shown in *Figure 1*.

The LM5008 can be applied in numerous applications to efficiently regulate down higher voltages. This regulator is well suited for 48 Volt Telecom and the new 42V Automotive power bus ranges. Protection features include: Thermal Shutdown, V_{CC} under-voltage lockout, Gate drive under-voltage lockout, Max Duty Cycle limit timer and the intelligent current limit off timer.

Hysteretic Control Circuit Overview

The LM5008 is a Buck DC-DC regulator that uses a control scheme in which the on-time varies inversely with line voltage (V_{IN}). Control is based on a comparator and the on-time one-shot, with the output voltage feedback (FB) compared to an internal reference (2.5V). If the FB level is below the reference the buck switch is turned on for a fixed time determined by the line voltage and a programming resistor (R_{ON}). Following the ON period the switch will remain off for at least the minimum off-timer period of 300ns. If FB is still below the reference at that time the switch will turn on again for another on-time period. This will continue until regulation is achieved.

The LM5008 operates in discontinuous conduction mode at light load currents, and continuous conduction mode at heavy load current. In discontinuous conduction mode, current through the output inductor starts at zero and ramps up to a peak during the on-time, then ramps back to zero before the end of the off-time. The next on-time period starts when the voltage at FB falls below the internal reference - until then the inductor current remains zero. In this mode the operating frequency is lower than in continuous conduction mode, and varies with load current. Therefore at light loads the conversion efficiency is maintained, since the switching losses reduce with the reduction in load and frequency. The discontinuous operating frequency can be calculated as follows:

$$F = \frac{V_{OUT}^2 \times L \times 1.28 \times 10^{20}}{R_L \times (R_{ON})^2}$$

where R_L = the load resistance

In continuous conduction mode, current flows continuously through the inductor and never ramps down to zero. In this mode the operating frequency is greater than the discontinuous mode frequency and remains relatively constant with load and line variations. The approximate continuous mode operating frequency can be calculated as follows:

$$F = \frac{V_{OUT}}{1.25 \times 10^{-10} \times R_{ON}} \quad (1)$$

The output voltage (V_{OUT}) can be programmed by two external resistors as shown in *Figure 1*. The regulation point can be calculated as follows:

$$\mathbf{V_{OUT} = 2.5 \times (R1 + R2) / R2}$$

All hysteretic regulators regulate the output voltage based on ripple voltage at the feedback input, requiring a minimum amount of ESR for the output capacitor C2. A minimum of 25mV to 50mV of ripple voltage at the feedback pin (FB) is required for the LM5008. In cases where the capacitor ESR is too small, additional series resistance may be required (R3 in *Figure 1*).

For applications where lower output voltage ripple is required the output can be taken directly from a low ESR output capacitor, as shown in *Figure 9*. However, R3 slightly degrades the load regulation.

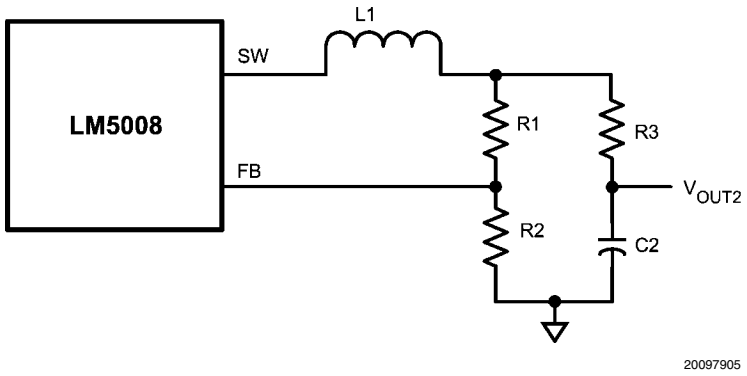


FIGURE 9. Low Ripple Output Configuration

High Voltage Start-Up Regulator

The LM5008 contains an internal high voltage startup regulator. The input pin (V_{IN}) can be connected directly to the line voltages up to 95 Volts, with transient capability to 100 volts. The regulator is internally current limited to 9.5mA at V_{CC}. Upon power up, the regulator sources current into the external capacitor at V_{CC} (C3). When the voltage on the V_{CC} pin reaches the under-voltage lockout threshold of 6.3V, the buck switch is enabled.

In applications involving a high value for V_{IN}, where power dissipation in the V_{CC} regulator is a concern, an auxiliary voltage can be diode connected to the V_{CC} pin. Setting the auxiliary voltage to 8.0 -14V will shut off the internal regulator, reducing internal power dissipation. See *Figure 10*. The current required into the V_{CC} pin is shown in *Figure 2*.

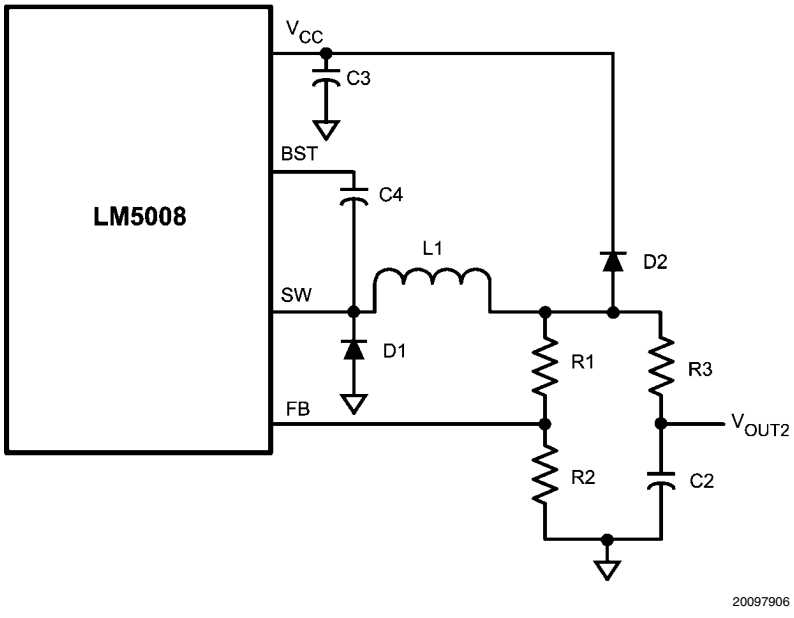


FIGURE 10. Self Biased Configuration

Regulation Comparator

The feedback voltage at FB is compared to an internal 2.5V reference. In normal operation (the output voltage is regulated), an on-time period is initiated when the voltage at FB falls below 2.5V. The buck switch will stay on for the on-time, causing the FB voltage to rise above 2.5V. After the on-time period, the buck switch will stay off until the FB voltage again falls below 2.5V. During start-up, the FB voltage will be below 2.5V at the end of each on-time, resulting in the minimum off-time of 300 ns. Bias current at the FB pin is nominally 100 nA.

Over-Voltage Comparator

The feedback voltage at FB is compared to an internal 2.875V reference. If the voltage at FB rises above 2.875V the on-time pulse is immediately terminated. This condition can occur if the input voltage, or the output load, change suddenly. The buck switch will not turn on again until the voltage at FB falls below 2.5V.

On-Time Generator and Shutdown

The on-time for the LM5008 is determined by the R_{ON} resistor, and is inversely proportional to the input voltage (Vin), resulting in a nearly constant frequency as Vin is varied over its range. The on-time equation for the LM5008 is:

$$T_{ON} = 1.25 \times 10^{-10} \times R_{ON} / V_{IN} \quad (2)$$

See *Figure 3*. R_{ON} should be selected for a minimum on-time (at maximum V_{IN}) greater than 400 ns, for proper current limit operation. This requirement limits the maximum frequency for each application, depending on V_{IN} and V_{OUT}. See *Figure 4*.

The LM5008 can be remotely disabled by taking the R_{ON}/SD pin to ground. See *Figure 11*. The voltage at the R_{ON}/SD pin is between 1.5 and 3.0 volts, depending on Vin and the value of the R_{ON} resistor.

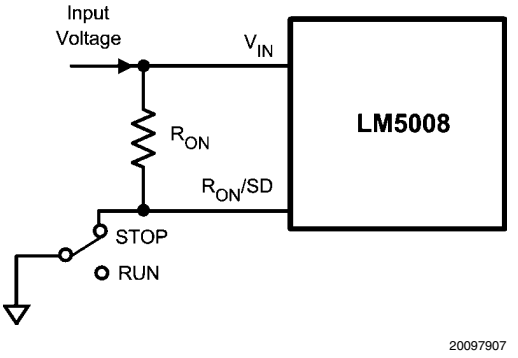


FIGURE 11. Shutdown Implementation

Current Limit

The LM5008 contains an intelligent current limit OFF timer. If the current in the Buck switch exceeds 0.5A the present cycle is immediately terminated, and a non-resetable OFF timer is initiated. The length of off-time is controlled by an external resistor (R_{CL}) and the FB voltage (see *Figure 5*). When FB = 0V, a maximum off-time is required, and the time is preset to 35µs. This condition occurs when the output is shorted, and during the initial part of start-up. This amount of time ensures safe short circuit operation up to the maximum input voltage of 95V. In cases of overload where the FB voltage is above zero volts (not a short circuit) the current limit off-time will be less than 35µs. Reducing the off-time during less severe overloads reduces the amount of foldback, recovery time, and the start-up time. The off-time is calculated from the following equation:

$$T_{OFF} = 10^{-5} / (0.285 + (V_{FB} / 6.35 \times 10^{-6} \times R_{CL})) \quad (3)$$

The current limit sensing circuit is blanked for the first 50-70ns of each on-time so it is not falsely tripped by the current surge which occurs at turn-on. The current surge is required by the re-circulating diode (D1) for its turn-off recovery.

N - Channel Buck Switch and Driver

The LM5008 integrates an N-Channel Buck switch and associated floating high voltage gate driver. The gate driver circuit works in conjunction with an external bootstrap capacitor and an internal high voltage diode. A 0.01µF ceramic capacitor (C4) connected between the BST pin and SW pin provides the voltage to the driver during the on-time.

During each off-time, the SW pin is at approximately 0V, and the bootstrap capacitor charges from Vcc through the internal diode. The minimum OFF timer, set to 300ns, ensures a minimum time each cycle to recharge the bootstrap capacitor.

An external re-circulating diode (D1) carries the inductor current after the internal Buck switch turns off. This diode must be of the Ultra-fast or Schottky type to minimize turn-on losses and current over-shoot.

Thermal Protection

The LM5008 should be operated so the junction temperature does not exceed 125°C during normal operation. An internal Thermal Shutdown circuit is provided to protect the LM5008 in the event of a higher than normal junction temperature. When activated, typically at 165°C, the controller is forced into a low power reset state, disabling the buck switch and the V_{CC} regulator. This feature prevents catastrophic failures from accidental device overheating. When the junction temperature reduces below 140°C (typical hysteresis = 25°C), the Vcc regulator is enabled, and normal operation is resumed.

Applications Information

SELECTION OF EXTERNAL COMPONENTS

A guide for determining the component values will be illustrated with a design example. Refer to *Figure 1*. The following steps will configure the LM5008 for:

- Input voltage range (Vin): 12V to 95V
- Output voltage (V_{OUT1}): 10V
- Load current (for continuous conduction mode): 100 mA to 300 mA
- Maximum ripple at V_{OUT2}: 100 mVp-p at maximum input voltage

R1 and R2: From *Figure 1*, $V_{OUT1} = V_{FB}$ x (R1 + R2) / R2, and since V_{FB} = 2.5V, the ratio of R1 to R2 calculates as 3:1. Standard values of 3.01 kΩ (R1) and 1.00 kΩ (R2) are chosen. Other values could be used as long as the 3:1 ratio is maintained. The selected values, however, provide a small amount of output loading (2.5 mA) in the event the main load is disconnected. This allows the circuit to maintain regulation until the main load is reconnected.

F_s and R_{ON}: The recommended operating frequency range for the LM5008 is 50kHz to 600 kHz. Unless the application requires a specific frequency, the choice of frequency is generally a compromise since it affects the size of L1 and C2, and

the switching losses. The maximum allowed frequency, based on a minimum on-time of 400 ns, is calculated from:

$$F_{MAX} = V_{OUT} / (V_{INMAX} \times 400ns)$$

For this exercise, Fmax = 263kHz. From equation 1, R_{ON} calculates to 304 kΩ. A standard value 357 kΩ resistor will be used to allow for tolerances in equation 1, resulting in a frequency of 224kHz.

L1: The main parameter affected by the inductor is the output current ripple amplitude. The choice of inductor value therefore depends on both the minimum and maximum load currents, keeping in mind that the maximum ripple current occurs at maximum Vin.

a) **Minimum load current:** To maintain continuous conduction at minimum Io (100 mA), the ripple amplitude (I_{OR}) must be less than 200 mA p-p so the lower peak of the waveform does not reach zero. L1 is calculated using the following equation:

$$L1 = \frac{V_{OUT1} \times (V_{IN} - V_{OUT1})}{I_{OR} \times F_s \times V_{IN}}$$

At Vin = 95V, L1(min) calculates to 200 µH. The next larger standard value (220 µH) is chosen and with this value I_{OR} calculates to 181 mA p-p at Vin = 95V, and 34 mA p-p at Vin = 12V.

b) **Maximum load current:** At a load current of 300 mA, the peak of the ripple waveform must not reach the minimum guaranteed value of the LM5008's current limit threshold (410 mA). Therefore the ripple amplitude must be less than 220 mA p-p, which is already satisfied in the above calculation. With L1 = 220 µH, at maximum Vin and Io, the peak of the ripple will be 391 mA. While L1 must carry this peak current without saturating or exceeding its temperature rating, it also must be capable of carrying the maximum guaranteed value of the LM5008's current limit threshold (610 mA) without saturating, since the current limit is reached during startup.

The DC resistance of the inductor should be as low as possible. For example, if the inductor's DCR is one ohm, the power dissipated at maximum load current is 0.09W. While small, it is not insignificant compared to the load power of 3W.

C3: The capacitor on the V_{CC} output provides not only noise filtering and stability, but its primary purpose is to prevent false triggering of the V_{CC} UVLO at the buck switch on/off transitions. For this reason, C3 should be no smaller than 0.1 µF.

C2, and R3: When selecting the output filter capacitor C2, the items to consider are ripple voltage due to its ESR, ripple voltage due to its capacitance, and the nature of the load.

a) ESR and R3: A low ESR for C2 is generally desirable so as to minimize power losses and heating within the capacitor. However, a hysteretic regulator requires a minimum amount of ripple voltage at the feedback input for proper loop operation. For the LM5008 the minimum ripple required at pin 5 is 25 mV p-p, requiring a minimum ripple at V_{OUT1} of 100 mV. Since the minimum ripple current (at minimum Vin) is 34 mA p-p, the minimum ESR required at V_{OUT1} is 100mV/34mA = 2.94Ω. Since quality capacitors for SMPS applications have an ESR considerably less than this, R3 is inserted as shown in Figure 1. R3's value, along with C2's ESR, must result in at least 25 mV p-p ripple at pin 5. Generally, R3 will be 0.5 to 3.0Ω.

b) Nature of the Load: The load can be connected to V_{OUT1} or V_{OUT2}. V_{OUT1} provides good regulation, but with a ripple voltage which ranges from 100 mV (@ Vin = 12V) to 500mV (@Vin = 95V). Alternatively, V_{OUT2} provides low ripple, but lower regulation due to R3.

For a maximum allowed ripple voltage of 100 mVp-p at V_{OUT2} (@ Vin = 95V), assume an ESR of 0.4Ω for C2. At maximum Vin, the ripple current is 181 mAp-p, creating a ripple voltage of 72 mVp-p. This leaves 28 mVp-p of ripple due to the capacitance. The average current into C2 due to the ripple current is calculated using the waveform in *Figure 12*.

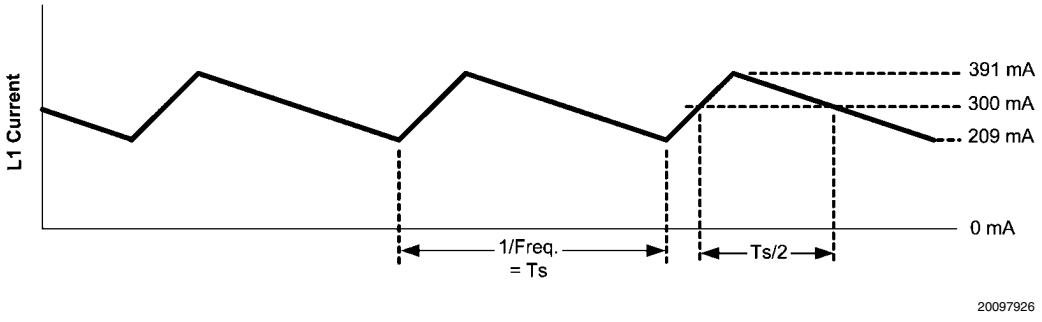


FIGURE 12. Inductor Current Waveform

Starting when the current reaches Io (300 mA in *Figure 12*) half way through the on-time, the current continues to increase to the peak (391 mA), and then decreases to 300 mA half way through the off-time. The average value of this portion of the waveform is 45.5mA, and will cause half of the voltage ripple, or 14 mV. The interval is one half of the frequency cycle time, or 2.23 µs. Using the capacitor's basic equation:

$$C = I \times \Delta t / \Delta V$$

the minimum value for C2 is 7.2 µF. The ripple due to C2's capacitance is 90° out of phase from the ESR ripple, and the two numbers do not add directly. However, this calculation provides a practical minimum value for C2 based on its ESR, and the target spec. To allow for the capacitor's tolerance, temperature effects, and voltage effects, a 15 µF, X7R capacitor will be used.

c) In summary: The above calculations provide a minimum value for C2, and a calculation for R3. The ESR is just as important as the capacitance. The calculated values are guidelines, and should be treated as starting points. For each application, experimentation is needed to determine the optimum values for R3 and C2.

R_{CL}: When a current limit condition is detected, the minimum off-time set by this resistor must be greater than the maximum normal off-time which occurs at maximum Vin. Using equation 2, the minimum on-time is 0.470 µs, yielding a maximum off-time of 3.99 µs. This is increased by 117 ns (to 4.11 µs) due to a ±25% tolerance of the on-time. This value is then increased to allow for:

The response time of the current limit detection loop (400ns),

The off-time determined by equation 3 has a ±25% tolerance,

$$t_{OFFCL(MIN)} = (4.11\ \mu s + 0.40\mu s) \times 1.25 = 5.64\ \mu s$$

Using equation 3, R_{CL} calculates to 264kΩ (at V_{FB} = 2.5V). The closest standard value is 267 kΩ.

D1: The important parameters are reverse recovery time and forward voltage. The reverse recovery time determines how long the reverse current surge lasts each time the buck switch is turned on. The forward voltage drop is significant in the event the output is short-circuited as it is only this diode's voltage which forces the inductor current to reduce during the forced off-time. For this reason, a higher voltage is better, although that affects efficiency. A good choice is an ultrafast power diode, such as the MURA110T3 from ON Semiconductor. Its reverse recovery time is 30ns, and its forward voltage drop is approximately 0.72V at 300 mA at 25°C. Other types of diodes may have a lower forward voltage drop, but may have longer recovery times, or greater reverse leakage. D1's reverse voltage rating must be at least as great as the maximum Vin, and its current rating be greater than the maximum current limit threshold (610 mA).

C1: This capacitor's purpose is to supply most of the switch current during the on-time, and limit the voltage ripple at Vin, on the assumption that the voltage source feeding Vin has an output impedance greater than zero. At maximum load current, when the buck switch turns on, the current into pin 8 will suddenly increase to the lower peak of the output current waveform, ramp up to the peak value, then drop to zero at turn-off. The average input current during this on-time is the load current (300 mA). For a worst case calculation, C1 must supply this average load current during the maximum on-time. To keep the input voltage ripple to less than 2V (for this exercise), C1 calculates to:

$$C1 = \frac{I \times t_{ON}}{\Delta V} = \frac{0.3A \times 3.72\ \mu s}{2.0V} = 0.56\ \mu F$$

Quality ceramic capacitors in this value have a low ESR which adds only a few millivolts to the ripple. It is the capacitance which is dominant in this case. To allow for the capacitor's tolerance, temperature effects, and voltage effects, a 1.0 µF, 100V, X7R capacitor will be used.

C4: The recommended value is 0.01µF for C4, as this is appropriate in the majority of applications. A high quality ceramic capacitor, with low ESR is recommended as C4 supplies the surge current to charge the buck switch gate at turn-on. A low ESR also ensures a quick recharge during each off-time. At minimum Vin, when the on-time is at maximum, it is possible during start-up that C4 will not fully recharge during each 300 ns off-time. The circuit will not be able to complete the start-up, and achieve output regulation. This can occur when the frequency is intended to be low (e.g., R_{ON} = 500K). In this case C4 should be increased so it can maintain sufficient voltage across the buck switch driver during each on-time.

C5: This capacitor helps avoid supply voltage transients and ringing due to long lead inductance at V_{IN}. A low ESR, 0.1µF ceramic chip capacitor is recommended, located close to the LM5008.

FINAL CIRCUIT

The final circuit is shown in *Figure 13*. The circuit was tested, and the resulting performance is shown in *Figure 6* through *Figure 8*.

MINIMUM LOAD CURRENT

A minimum load current of 1 mA is required to maintain proper operation. If the load current falls below that level, the bootstrap capacitor 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 1 mA in the application, the feedback resistors should be chosen low enough in value so they provide the minimum required current at nominal Vout.

PC BOARD LAYOUT

The LM5008 regulation and over-voltage comparators are very fast, and as such will respond to short duration noise pulses. Layout considerations are therefore critical for optimum performance. The components at pins 1, 2, 3, 5, and 6 should be as physically close as possible to the IC, thereby minimizing noise pickup in the PC tracks. The current loop formed by D1, L1, and C2 should be as small as possible. The ground connection from C2 to C1 should be as short and direct as possible.

If the internal dissipation of the LM5008 produces excessive 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 bottom of the LLP-8 package can be soldered to a ground plane on the PC board, and that plane should extend out from beneath the IC to help dissipate the heat. Additionally, the use of wide PC board traces, where possible, can also help conduct heat away from the IC. Judicious positioning of the PC board within the end product, along with use of any available air flow (forced or natural convection) can help reduce the junction temperatures.

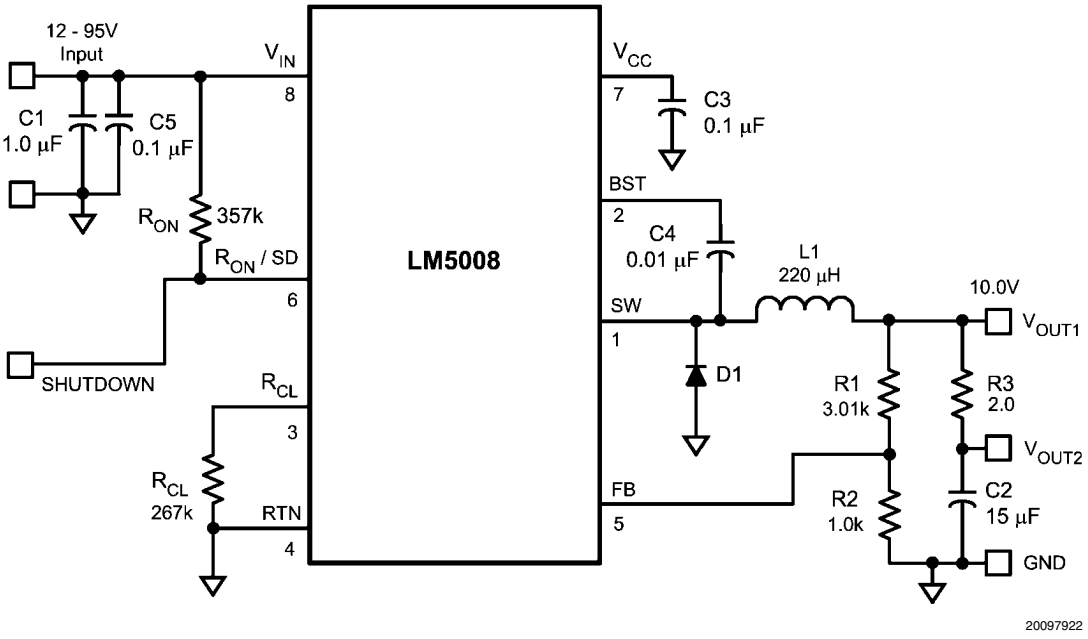
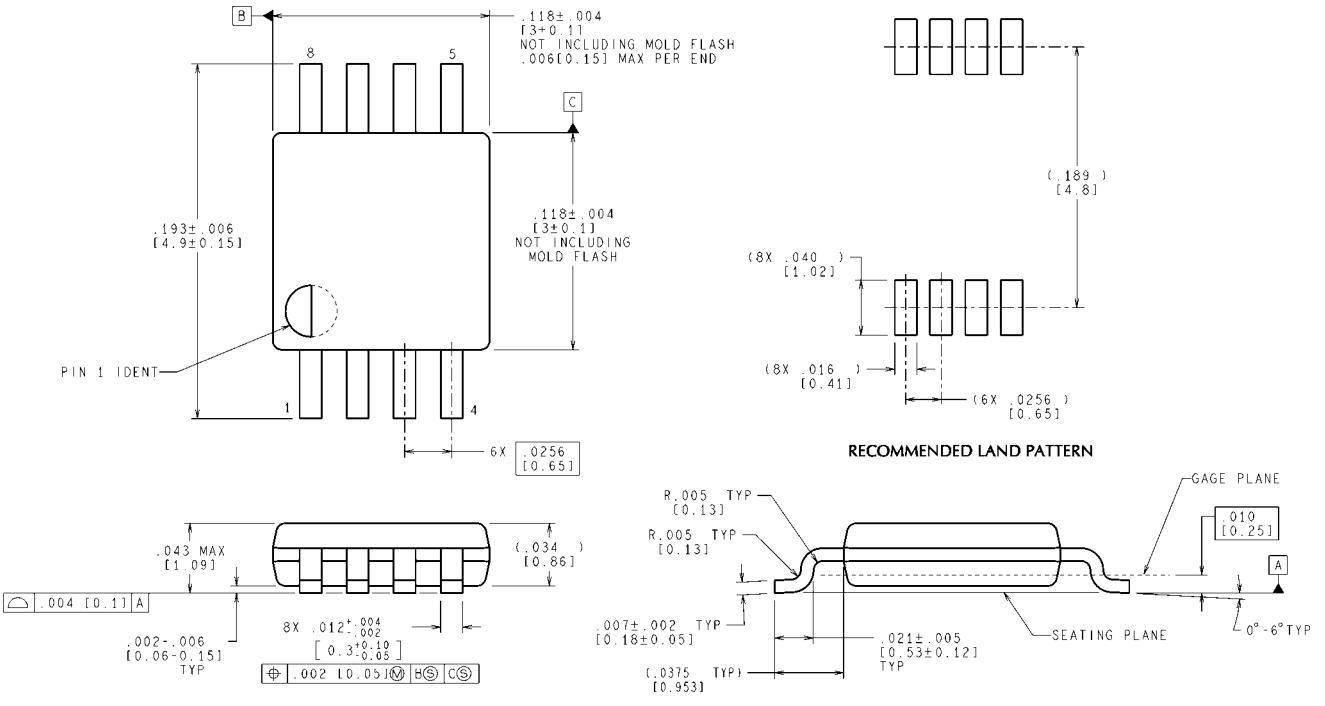


FIGURE 13. LM5008 Example Circuit

Bill of Materials (Circuit of *Figure 13*)

Item	Description	Part Number	Value
C1	Ceramic Capacitor	TDK C4532X7R2A105M	1µF, 100V
C2	Ceramic Capacitor	TDK C4532X7R1E156M	15µF, 25V
C3	Ceramic Capacitor	Kemet C1206C104K5RAC	0.1µF, 50V
C4	Ceramic Capacitor	Kemet C1206C103K5RAC	0.01µF, 50V
C5	Ceramic Capacitor	TDK C3216X7R2A104M	0.1µF, 100V
D1	UltraFast Power Diode	ON Semi MURA110T3	100V, 1A
L1	Power Inductor	Coilcraft DO3316-224 or	220 µH
		TDK SLF10145T-221MR65	
R1	Resistor	Vishay CRCW12063011F	3.01 kΩ
R2	Resistor	Vishay CRCW12061001F	1.0 kΩ
R3	Resistor	Vishay CRCW12062R00F	2.0 Ω
R_{ON}	Resistor	Vishay CRCW12063573F	357 kΩ
R_{CL}	Resistor	Vishay CRCW12062673F	267 kΩ
U1	Switching Regulator	National Semiconductor LM5008	

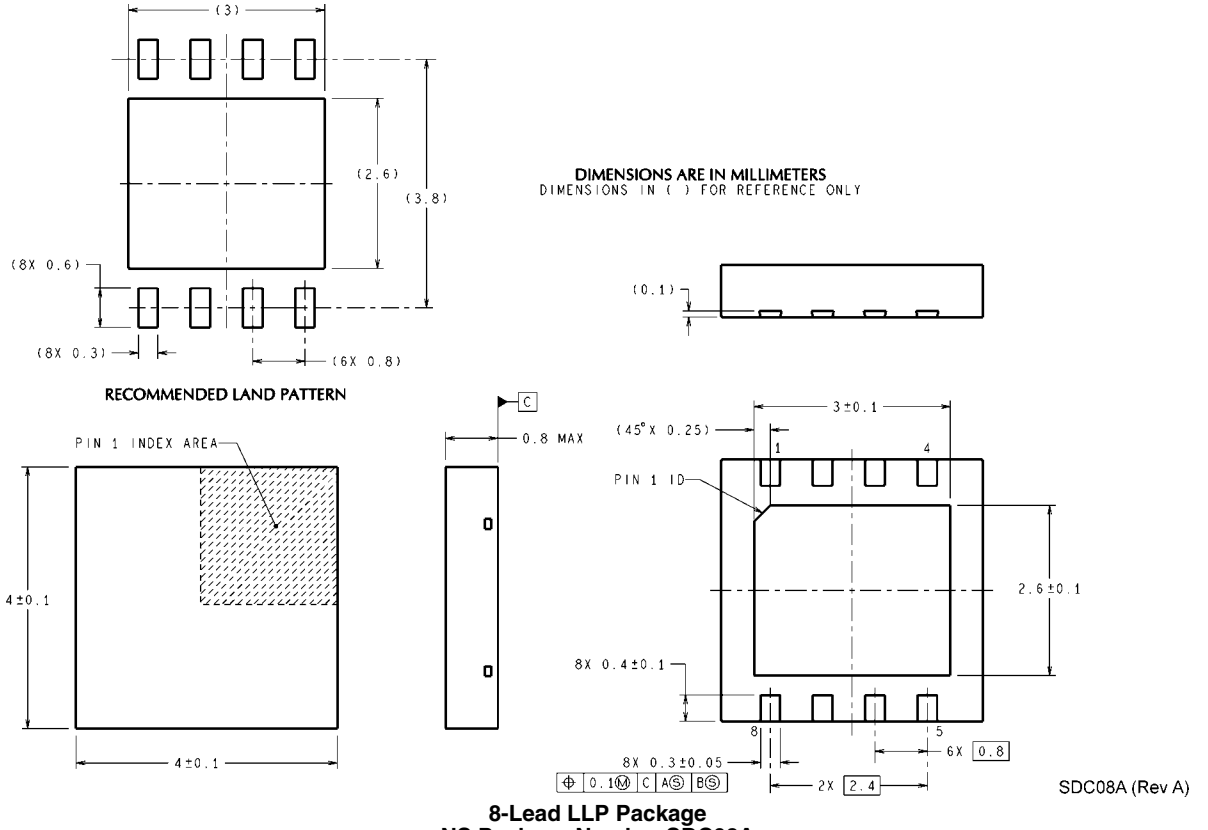
Physical Dimensions inches (millimeters) unless otherwise noted



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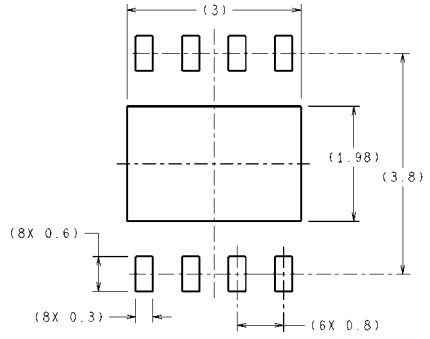
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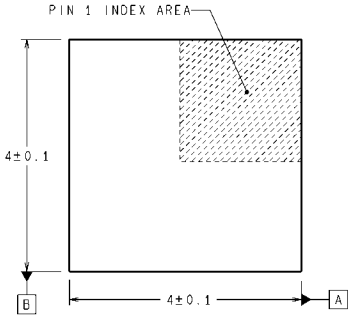
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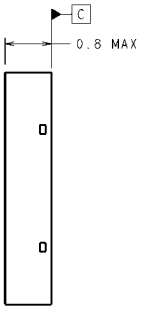


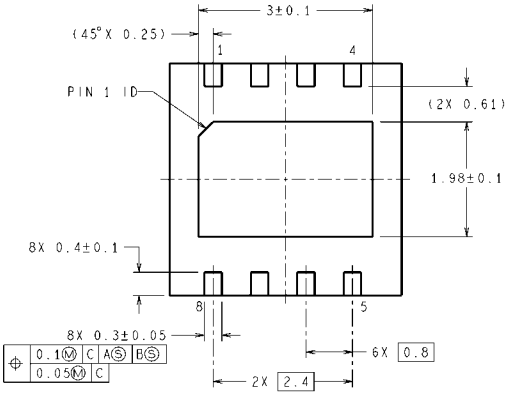
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RECOMMENDED LAND PATTERN







SDC08B (Rev A)

8-Lead LLP Package
NS Package Number SDC08B

Notes

Notes

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