Data Sheet

LT8638-2

42V, 10A/12A Peak Synchronous Step-Down Silent Switcher

FEATURES

- **Silent Switcher® Architecture**
  - **Ultralow EMI Emissions**
  - **Optional Spread Spectrum Modulation**
- **High Efficiency at High Frequency**
  - **Up to 96% Efficiency at 1MHz, $12V_{IN}$ to $5V_{OUT}$**
  - **Up to 94% Efficiency at 2MHz, $12V_{IN}$ to $5V_{OUT}$**
- **Wide Input Voltage Range: 2.8V to 42V**
- **10A Maximum Continuous, 12A Peak Transient Output**
- Fast Transient Response with External Compensation
- Low Quiescent Current Burst Mode® Operation
  - 90µA I_Q Regulating $12V_{IN}$ to $5V_{OUT}$
  - Output Ripple < $10mV_{P-P}$
- Reference Accuracy: ±1% Over Temperature
- Fast Minimum Switch On-Time: 25ns
- PolyPhase® Operation: Up to 12 Phases
- Low Dropout Under All Conditions: 45mV at 1A
- Adjustable and Synchronizable: 200kHz to 3MHz
- Output Soft-Start and Power Good
- Safely Tolerates High Reverse Current
- 28-Lead 5mm × 4mm LQFN Package
- AEC-Q100 Qualified for Automotive Applications

APPLICATIONS

- Automotive and Industrial Supplies
- General Purpose Step-Down

GENERAL DESCRIPTION

The **LT®8638-2** synchronous step-down regulator features the Silent Switcher® architecture designed to minimize EMI emissions while delivering high efficiency at high switching frequencies. This performance makes the LT8638-2 ideal for noise sensitive applications and environments.

The fast, clean, low overshoot switching edges enable high efficiency operation even at high switching frequencies, leading to a small overall solution size. Peak current mode control with a 25ns minimum on-time allows high step down ratios even at high switching frequencies. External compensation through the V_C pin allows for fast transient response. PolyPhase operation allows multiple LT8638-2 regulators to run with interleaving phase shift to provide more output current.

Burst Mode operation enables low standby current consumption, forced continuous mode can control frequency harmonics across the entire output load range, or spread spectrum operation can further reduce EMI emissions. Soft-start and tracking functionality is accessed through the SS pin, and an accurate input voltage UVLO threshold can be set using the EN/UV pin.

	INTERNAL V_{IN} CAPS
LT8638S*	YES
LT8638-2	NO

* See *LT8638S data sheet*.

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SIMPLIFIED APPLICATION DIAGRAM

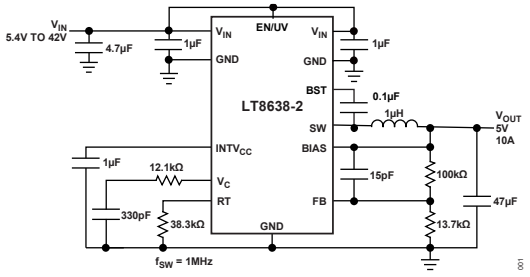

Figure 1. 5V 10A Step-Down Converter

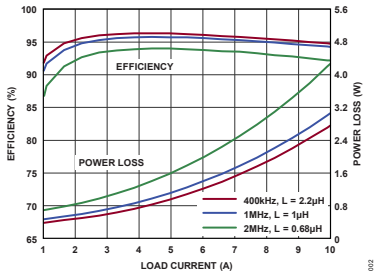

Figure 2. $12V_{IN}$ to $5V_{OUT}$ Efficiency

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SPECIFICATIONS

Table 1. Electrical Characteristics

(Specifications are at T_J = -40°C to +150°C, unless otherwise noted. Typical values are at T_A = +25°C. All voltages are referenced to GND, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS/COMMENTS	MIN	TYP	MAX	UNITS
Minimum Input Voltage	V_{IN}	f_{SW} = 2MHz		2.6	2.8	V
V_{IN} Quiescent Current in Shutdown	$I_{Q(SHDN)}$	$V_{EN/UV}$ = 0V, V_{IN} = 12V, T_A = +25°C		6	9	µA
V_{IN} Quiescent Current in Sleep	I_Q	$V_{EN/UV}$ = 2V, V_{FB} > 0.6V, V_{SYNC} = 0V, V_{BIAS} = 0V, T_A = +25°C		125	195	µA
		$V_{EN/UV}$ = 2V, V_{FB} > 0.6V, V_{SYNC} = 0V, V_{BIAS} = 0V		125	245	
		$V_{EN/UV}$ = 2V, V_{FB} > 0.6V, V_{SYNC} = 0V, V_{BIAS} = 5V, T_A = +25°C		20	29	
BIAS Quiescent Current in Sleep	$I_{Q(BIAS)}$	$V_{EN/UV}$ = 2V, V_{FB} > 0.6V, V_{SYNC} = 0V, V_{BIAS} = 5V, T_A = +25°C		100	145	µA
Feedback Reference Voltage	V_{FB}	V_{IN} = 12V, T_A = +25°C	0.598	0.6	0.602	V
		V_{IN} = 12V	0.594	0.6	0.604	
Feedback Voltage Line Regulation	$\Delta V_{FB(LINE)}$	V_{IN} = 4.0V to 40V, V_C = 1.25V		0.004	0.03	%/V
Feedback Pin Input Current	I_{FB}	V_{FB} = 0.6V, T_A = +25°C	-20		20	nA
Error Amp Transconductance	$g_{m(EA)}$	V_C = 1.25V, T_A = +25°C	1.05	1.4	1.75	mS
Error Amp Gain	A_V			700		
V_C Source Current	I_{VC}	V_{FB} = 0.4V, V_C = 1.25V		320		µA
V_C Sink Current	I_{VC}	V_{FB} = 0.8V, V_C = 1.25V		320		µA
V_C Pin to Switch Current Gain	G_M			12		A/V
V_C Clamp Voltage	V_{C_MAX}			2.3		V
BIAS Pin Current Consumption	I_{BIAS}	V_{BIAS} = 3.3V, f_{SW} = 2MHz, V_{IN} = 12V		45		mA
Minimum On-Time	$t_{ON(MIN)}$	I_{LOAD} = 3A, FCM		25	40	ns
Minimum Off-Time	$t_{OFF(MIN)}$	T_A = +25°C		80	100	ns
Oscillator Frequency	f_{sw}	R_T = 226k	170	200	230	kHz
		R_T = 38.3k	0.96	1	1.04	MHz
		R_T = 16.9k	1.85	2	2.15	
Top Power NMOS On-Resistance	R_{TOP}	I_{SW} = 1A		20		mΩ

(Specifications are at T_J = -40°C to +150°C, unless otherwise noted. Typical values are at T_A = +25°C. All voltages are referenced to GND, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS/COMMENTS	MIN	TYP	MAX	UNITS
Top Power NMOS Current Limit	$I_{PEAK-LIMIT}$		17	20	23	A
Bottom Power NMOS On-Resistance	R_{BOT}	V_{INTVCC} = 3.4V, I_{SW} = 1A		8		mΩ
Bottom Power NMOS Current Limit	$I_{VALLEY-LIMIT}$	V_{INTVCC} = 3.4V, T_A = +25°C	11.5	15.5	19	A
SW Leakage Current	I_{SW-LKG}	V_{IN} = 40V, V_{SW} = 0V, 40V, T_A = +25°C	−3		3	µA
EN/UV Pin Threshold	V_{EN}	EN/UV Rising	0.93	0.98	1.03	V
		EN/UV Hysteresis		40		mV
EN/UV Pin Current	I_{EN}	$V_{EN/UV}$ = 2V, T_A = +25°C	−20		20	nA
PG Upper Threshold Offset from V_{FB}	PGH	V_{FB} Rising	6	7.75	9.5	%
PG Lower Threshold Offset from V_{FB}	PGL	V_{FB} Falling	-9.5	-7.75	-6	%
PG Hysteresis	PG_{HYS}			0.4		%
PG Leakage	I_{PG-LKG}	V_{PG} = 3.3V, T_A = +25°C	-80		80	nA
PG Pull-Down Resistance	R_{PG}	V_{PG} = 0.1V		600	2000	Ω
SYNC/MODE Threshold	$V_{SYNC/MODE}$	SYNC/MODE DC and Clock Low Level Voltage	0.7			V
		SYNC/MODE Clock High Level Voltage			1.5	
		SYNC/MODE DC High Level Voltage	2.2		2.9	
Spread Spectrum Modulation Frequency Range	Δf_{SSFM}	R_T = 38.3k		24		%
Spread Spectrum Modulation Frequency	f_{SSFM}			3		KHz
SS Source Current	I_{SS}		1.3	2.0	2.7	µA
SS Pull-Down Resistance	R_{SS}	Fault Condition, SS = 0.1V		200		Ω
V_{IN} to Disable Forced Continuous Mode	$V_{IN-OV-FCM}$	V_{IN} Rising, T_A = +25°C	35	37	39	V
PHMODE Thresholds	V_{PHMODE}	Between 180° and 120°, T_A = +25°C	0.7		1.5	V
		Between 120° and 90°, T_A = +25°C	2.2		2.9	

ABSOLUTE MAXIMUM RATINGS

T_A = 25°C unless otherwise specified.

Table 2. Absolute Maximum Ratings[1]

PARAMETER	RATING
V_{IN}, EN/UV, PG	42V
BIAS	25V
FB, SS, PHMODE	4V
SYNC/MODE Voltage	6V
Operating Junction Temperature Range[2][3] LT8638RV-2	−40°C to 150°C
Storage Temperature Range	−65°C to 150°C
Maximum Reflow (Package Body) Temperature	260°C

1 Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

2 The LT8638RV-2 is specified over the –40°C to 150°C operating junction temperature range. High junction temperatures degrade operating lifetimes; operating lifetime is derated for junction temperatures greater than 125°C. Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with the board layout, rated package thermal impedance, and other environmental factors.

The junction temperature (T_J, in °C) is calculated from the ambient temperature (T_A in °C) and power dissipation (PD, in Watts) according to the formula:

$T_J = T_A + (PD \times \theta_{JA})$

where, θ_{JA} (in °C/W) is the package thermal impedance.

3 This IC includes overtemperature protection intended to protect the device during overload conditions. Junction temperature exceeds 150°C when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature reduces lifetime.

4 θ values determined per JEDEC 51-7, 51-12. See the *Applications Information* section for information on improving the thermal resistance and for actual temperature measurements of a demo board in typical operating conditions.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

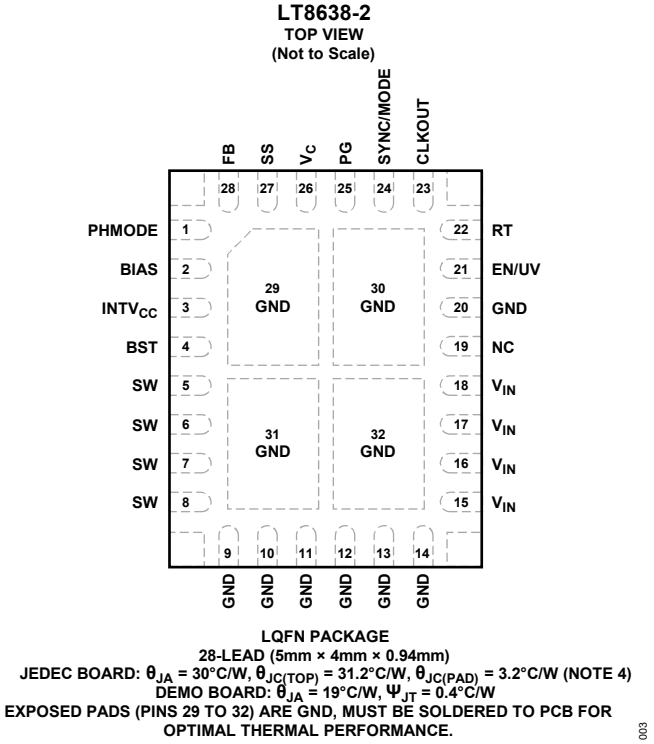


Figure 3. Pin Configuration

Table 3. Pin Descriptions

PIN	NAME	DESCRIPTION
Pin 1	PHMODE	Pin determines the phase relationship between the LT8638-2's internal clock and CLKOUT. Tie it to GND for 2-phase operation, float the pin for 3-phase operation, or tie it to $INTV_{CC}$ for 4-phase operation. See *Block Diagram* for internal pull-up and pull-down resistance.
Pin 2	BIAS	The internal regulator draws current from BIAS instead of V_{IN} when BIAS is tied to a voltage higher than 3.1V. For output voltages of 3.3V to 25V, this pin should be tied to V_{OUT}. If this pin is tied to a supply other than V_{OUT}, use a 1µF local bypass capacitor on this pin. If no supply is available, tie to GND. However, especially for high input or high frequency applications, BIAS should be tied to output or an external supply of 3.3V or above.
Pin 3	$INTV_{CC}$	Internal 3.4V Regulator Bypass Pin. The internal power drivers and control circuits are powered from this voltage. Do not load the $INTV_{CC}$ pin with external circuitry. $INTV_{CC}$ current is supplied from BIAS if BIAS > 3.1V, otherwise current is drawn from V_{IN}. Voltage on $INTV_{CC}$ varies between 2.8V and 3.4V when BIAS is between 3.0V and 3.6V. Place a low ESR ceramic capacitor of at least 1µF from this pin to ground close to the IC.

Pin 4	BST	This pin is used to provide a drive voltage, higher than the input voltage, to the topside power switch. Place a 0.1µF boost capacitor as close as possible to the IC.
Pins 5 to 8	SW	The SW pins are the outputs of the internal power switches. Tie these pins together and connect them to the inductor. This node should be kept small on the PCB for good performance and low EMI.
Pins 9 to 14, 20, Exposed Pad Pins 29 to 32	GND	Ground. Place the negative terminal of the input capacitor as close to the GND pins as possible. The exposed pads should be soldered to the PCB for good thermal performance. If necessary due to manufacturing limitations, pins 29 to 32 may be left disconnected. However thermal performance is degraded.
Pins 15 to 18	V_{IN}	The V_{IN} pins supply current to the LT8638-2 internal circuitry and internal topside power switch. The LT8638-2 requires the use of multiple V_{IN} bypass capacitors. Two small 1µF capacitors should be placed as close as possible to the LT8638-2, one capacitor on each side of the device (C_{IN1}, C_{IN2}). A third capacitor with a larger value, 4.7µF or higher, should be placed near C_{IN1} or C_{IN2}. See the *Applications Information* section for sample layout.
Pins 19	NC	No Connect. This pin is not connected to internal circuitry and can be tied anywhere on the PCB, typically ground.
Pin 21	EN/UV	The LT8638-2 is shut down when this pin is low and active when this pin is high. The hysteretic threshold voltage is 0.98V going up and 0.94V going down. Tie to V_{IN} if the shutdown feature is not used. An external resistor divider from V_{IN} can be used to program a V_{IN} threshold, below which the LT8638-2 shuts down.
Pin 22	RT	A resistor is tied between RT and ground to set the switching frequency.
Pin 23	CLKOUT	Output Clock Signal for PolyPhase Operation. In forced continuous mode, spread spectrum, and synchronization modes, the CLKOUT pin provides a 50% duty cycle square wave of the switching frequency. The phase of CLKOUT with respect to the LT8638-2's internal clock is determined by the state of the PHMODE pin. CLKOUT's peak-to-peak amplitude is $INTV_{CC}$ to GND. In Burst Mode operation, the CLKOUT pin is low. Float this pin if the CLKOUT function is not used.
Pin 24	SYNC/MODE	For the LT8638-2, this pin programs four different operating modes: 1) Burst Mode operation. Tie this pin to ground for Burst Mode operation at low output loads (this results in low quiescent current). 2) Forced Continuous mode (FCM). This mode offers fast transient response and full frequency operation over a wide load range. Float this pin for FCM. When floating, pin leakage currents should be <1µA. 3) Spread spectrum mode. Tie this pin high to $INTV_{CC}$ (or >3V) for forced continuous mode with spread spectrum modulation. 4) Synchronization mode. Drive this pin with a clock source to synchronize to an external frequency. During synchronization, the part operates in forced continuous mode.
Pin 25	PG	The PG pin is the open-drain output of an internal comparator. PG remains low until the FB pin is within ±7.75% of the final regulation voltage, and there are no fault conditions. PG is also pulled low when EN/ UV is below 1V, $INTV_{CC}$ has fallen too low, V_{IN} is too low, or thermal shutdown. PG is valid when V_{IN} is above 2.8V.

Pin 26	V_C	The V_C pin is the output of the internal error amplifier. The voltage on this pin controls the peak switch current. Tie an RC network from this pin to ground to compensate the control loop.
Pin 27	SS	Output Tracking and Soft-Start Pin. This pin allows user control of output voltage ramp rate during start-up. A SS voltage below 1V forces the LT8638-2 to regulate the FB pin to a function of the SS pin voltage. See the plot in the *Typical Performance Characteristics* section. When SS is above 1V, the tracking function is disabled and the internal reference resumes control of the error amplifier. An internal 2µA pull-up current from $INTV_{CC}$ on this pin allows a capacitor to program output voltage slew rate. This pin is pulled to ground with an internal 200Ω MOSFET during shutdown and fault conditions; use a series resistor if driving from a low impedance output. This pin may be left floating if the soft-start feature is not being used.
Pin 28	FB	The LT8638-2 regulates the FB pin to 0.6V. Connect the feedback resistor divider tap to this pin. Also, connect a phase lead capacitor between FB and V_{OUT}. Typically, this capacitor is 4.7pF to 47pF.
	Corner Pins	These pins are for mechanical support only and can be tied anywhere on the PCB, typically ground.

TYPICAL PERFORMANCE CHARACTERISTICS

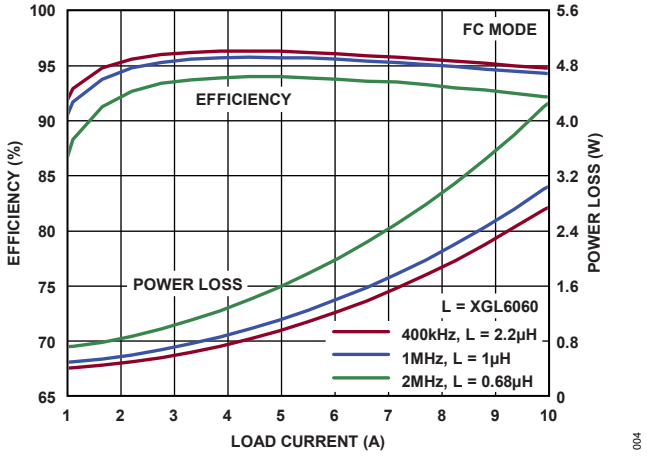


Figure 4. $12V_{IN}$ to $5V_{OUT}$ Efficiency vs. Frequency

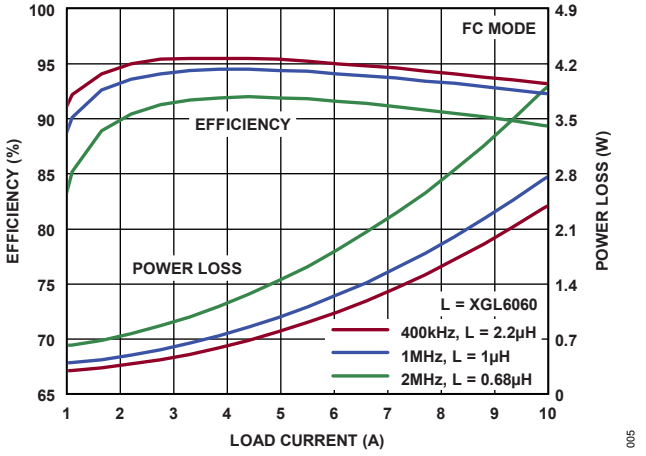


Figure 5. $12V_{IN}$ to $3.3V_{OUT}$ Efficiency vs. Frequency

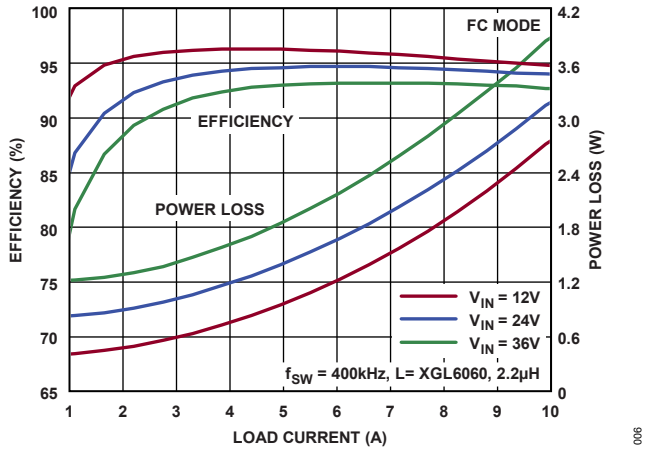


Figure 6. Efficiency at $5V_{OUT}$

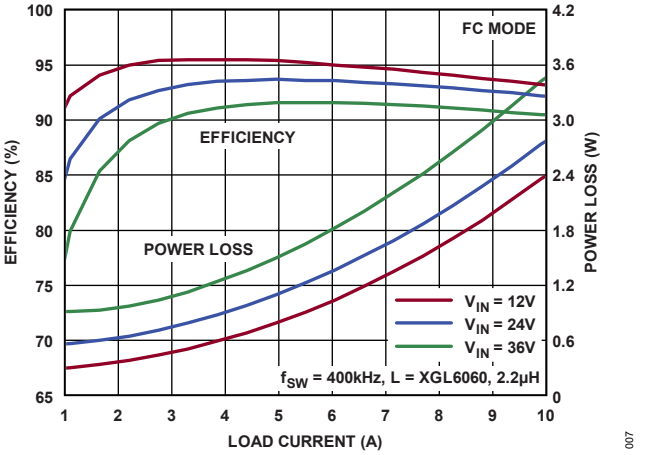


Figure 7. Efficiency at $3.3V_{OUT}$

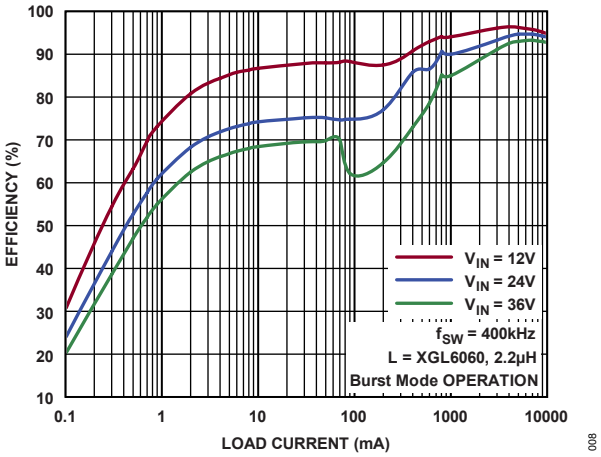


Figure 8. Light Load Efficiency at $5V_{OUT}$

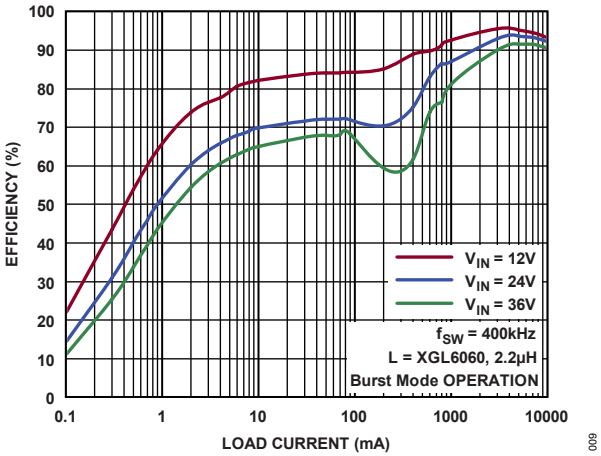


Figure 9. Light Load Efficiency at $3.3V_{OUT}$

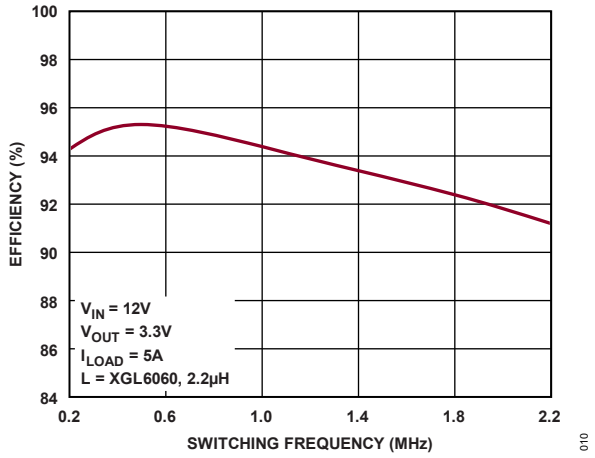


Figure 10. Efficiency vs. Frequency

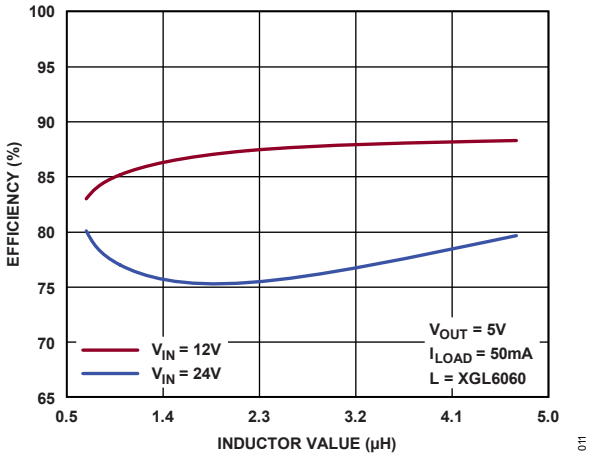


Figure 11. Burst Mode Operation Efficiency vs. Inductor Value

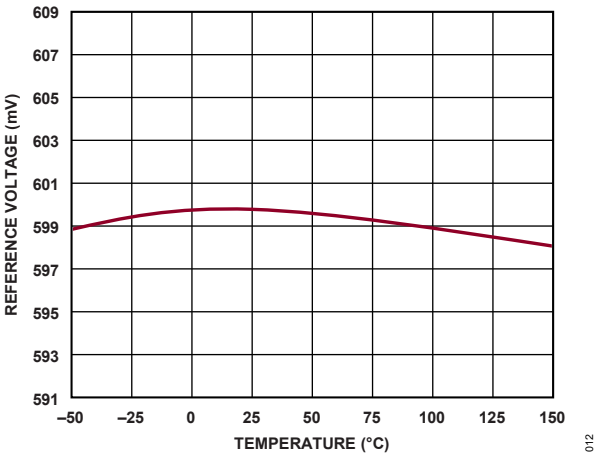


Figure 12. Reference Voltage

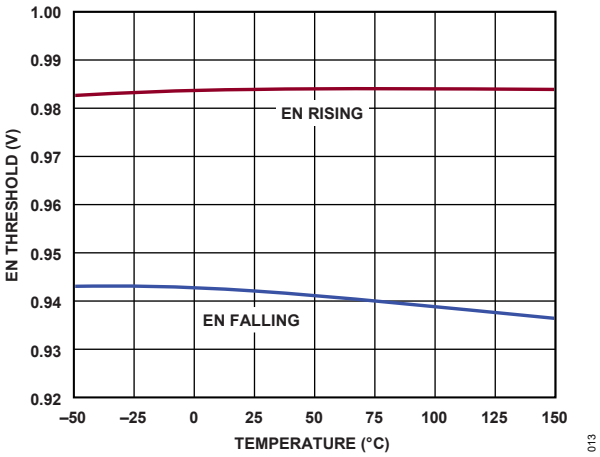


Figure 13. EN Pin Thresholds

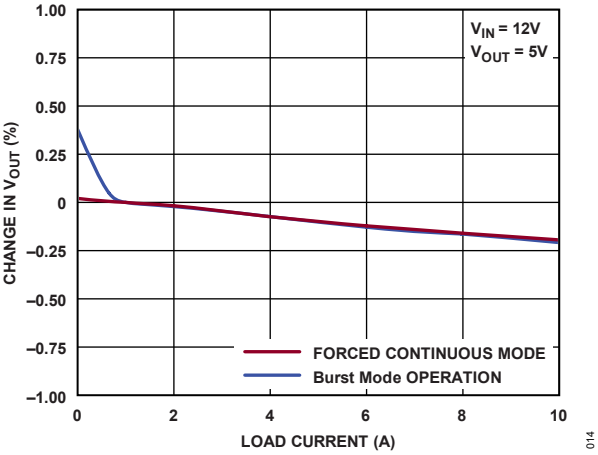


Figure 14. Load Regulation

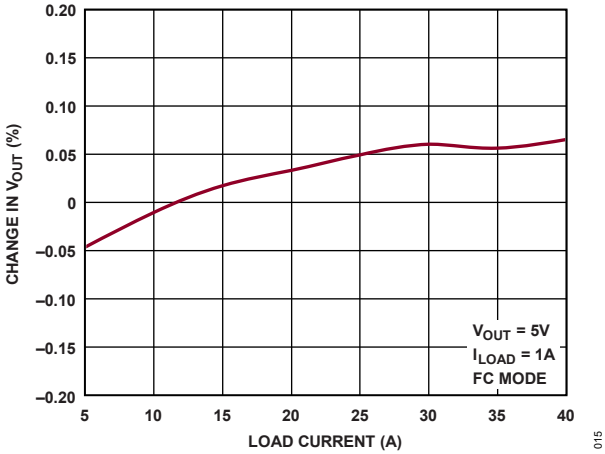


Figure 15. Line Regulation

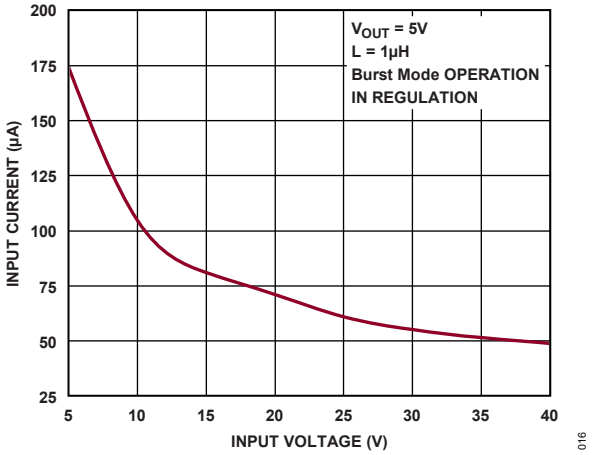


Figure 16. No-Load Supply Current

Figure 17. Top FET Current Limit vs. Duty Cycle

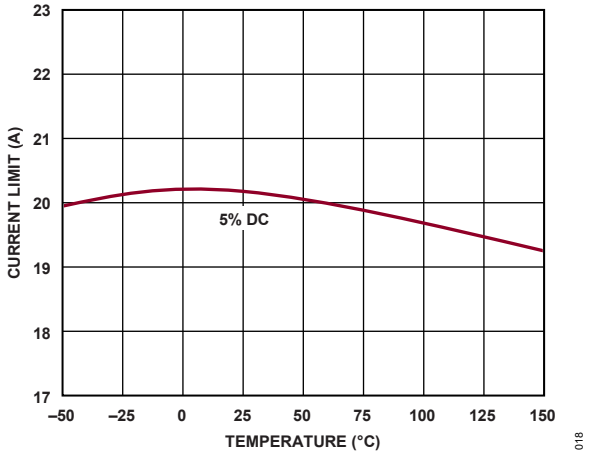


Figure 18. Top FET Current Limit vs. Temperature

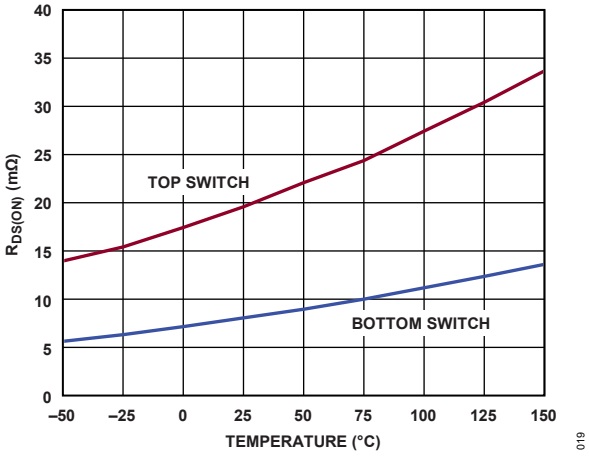


Figure 19. Switch $R_{DS(ON)}$ vs. Temperature

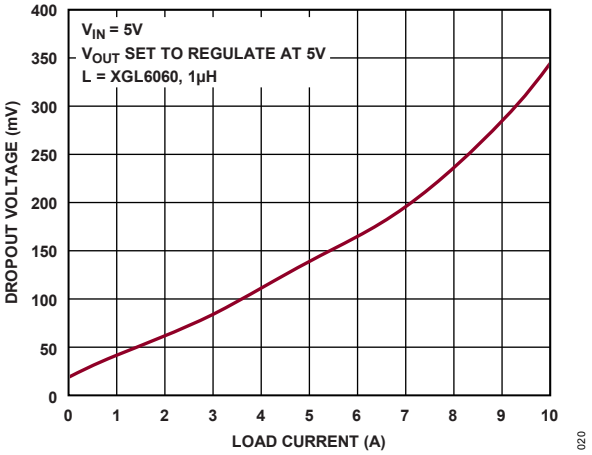


Figure 20. Dropout Voltage

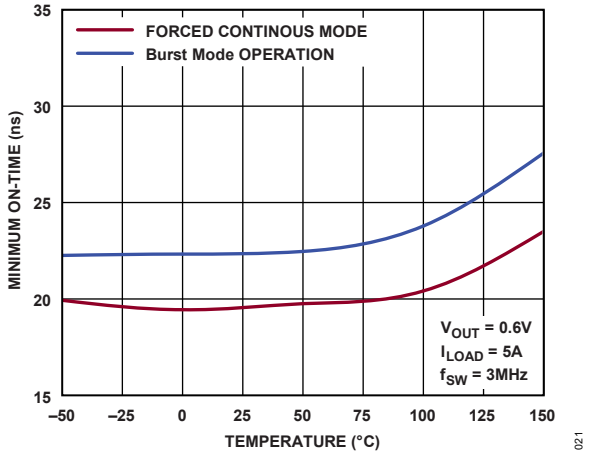


Figure 21. Minimum On-Time

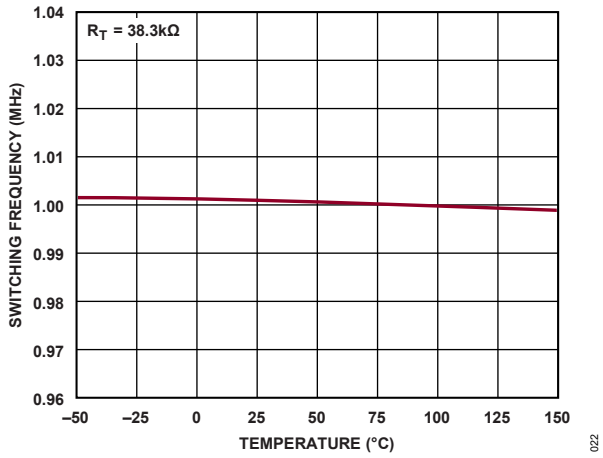


Figure 22. Switching Frequency

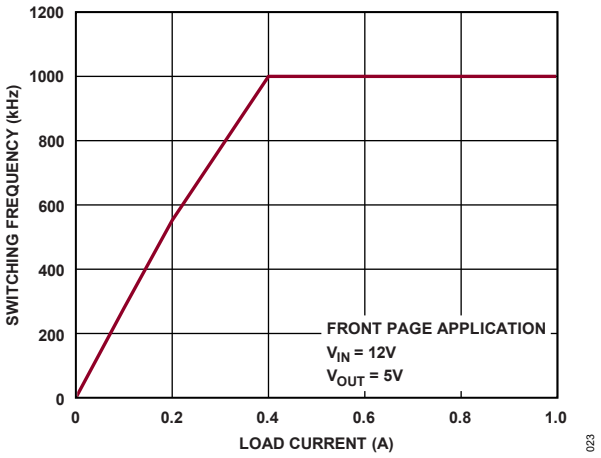


Figure 23. Burst Frequency

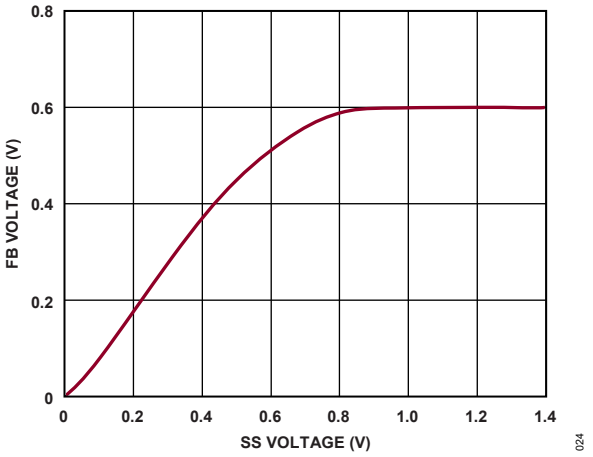


Figure 24. Soft-Start Tracking

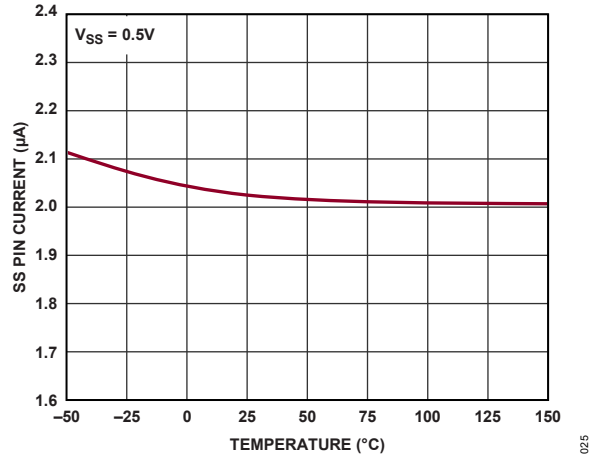


Figure 25. Soft-Start Current

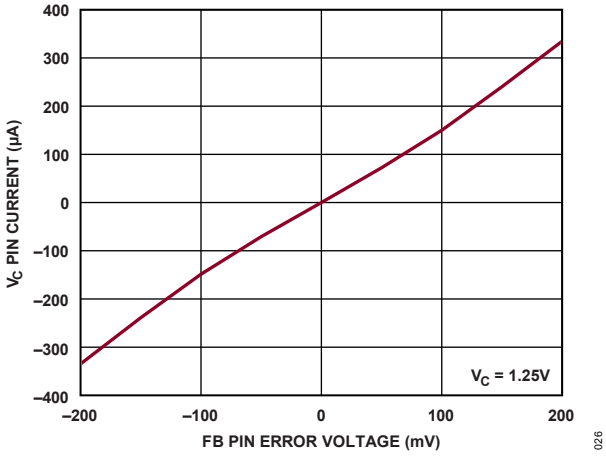


Figure 26. Error Amplifier Output Current

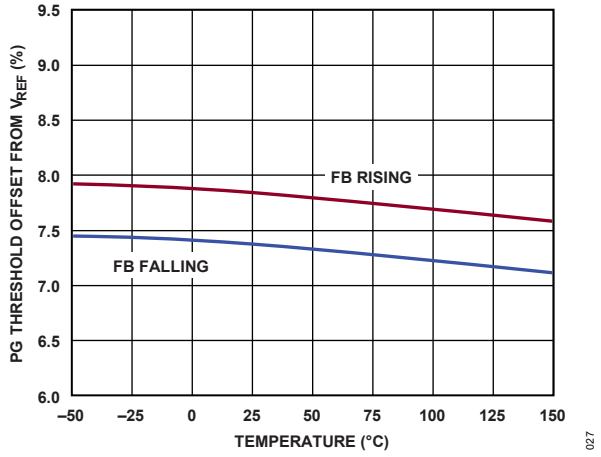


Figure 27.PG Thresholds Above V_{REF}

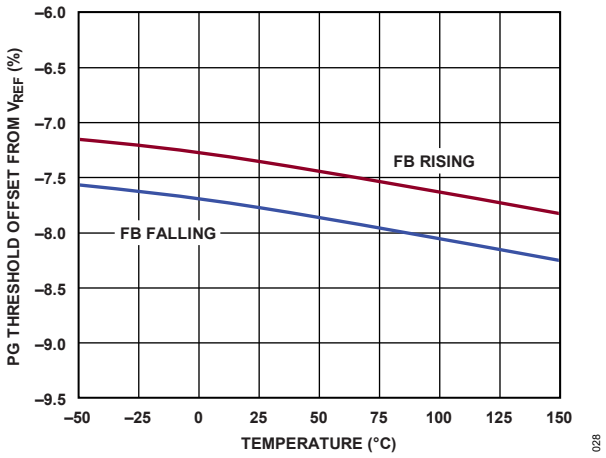


Figure 28. PG Thresholds Below V_{REF}

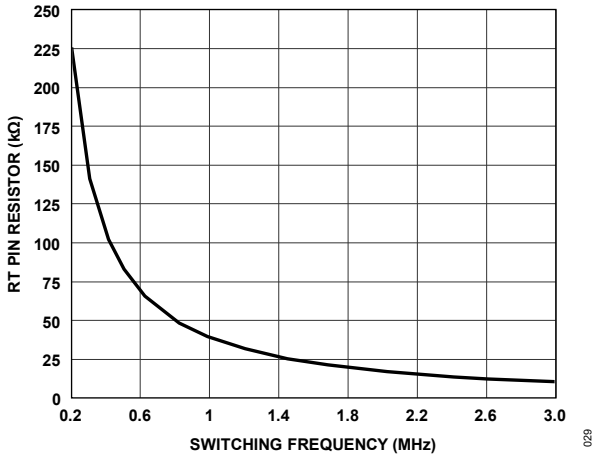


Figure 29. R_T Programmed Switching Frequency

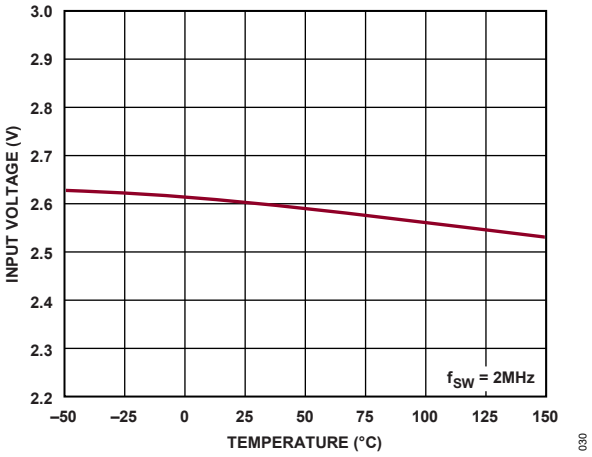


Figure 30. Minimum Input Voltage

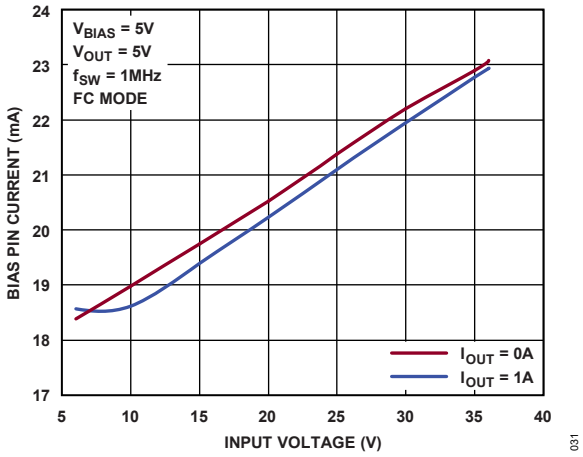


Figure 31. Bias Pin Current vs. Input Voltage

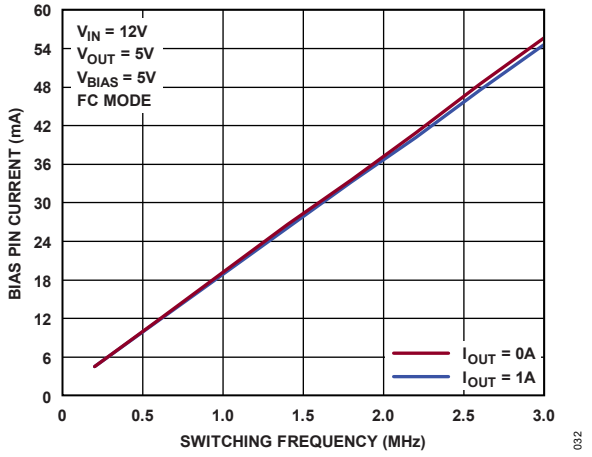


Figure 32. Bias Pin Current vs. Switching Frequency

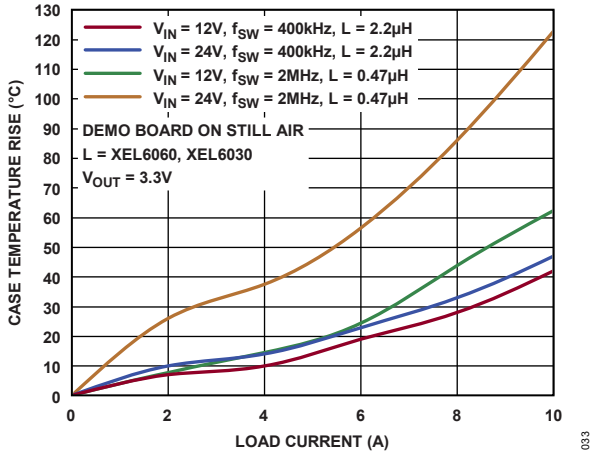


Figure 33. Case Temperature Rise

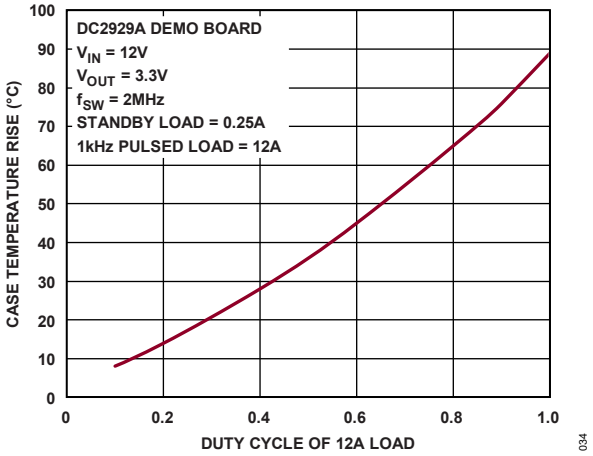


Figure 34. Case Temperature Rise vs. 12A Pulsed Load

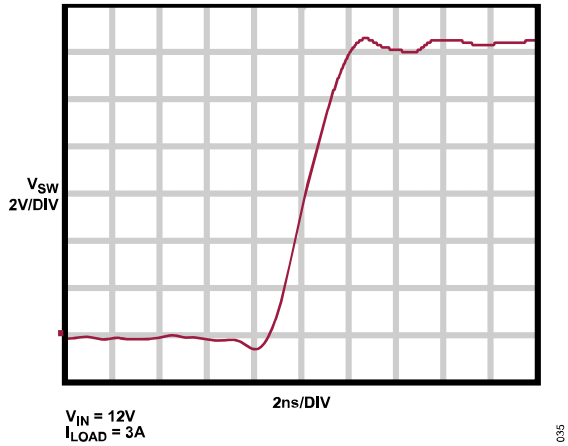


Figure 35. Switch Rising Edge

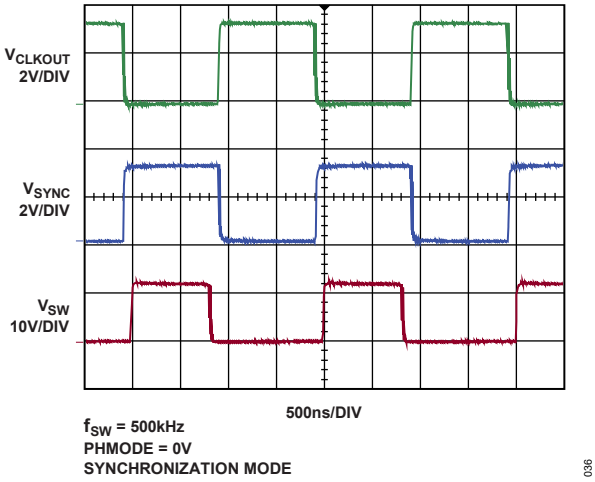


Figure 36. CLKOUT Waveforms

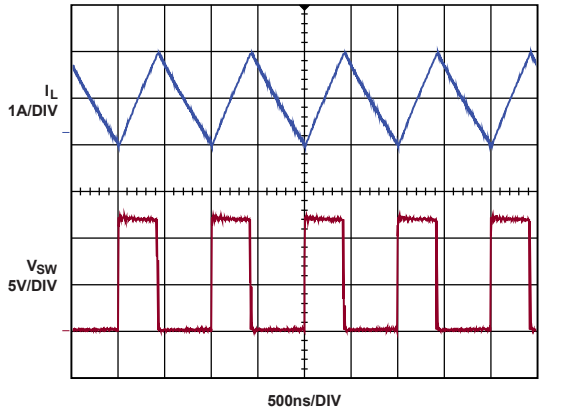


Figure 37. Switching Waveforms, Full Frequency Continuous Operation

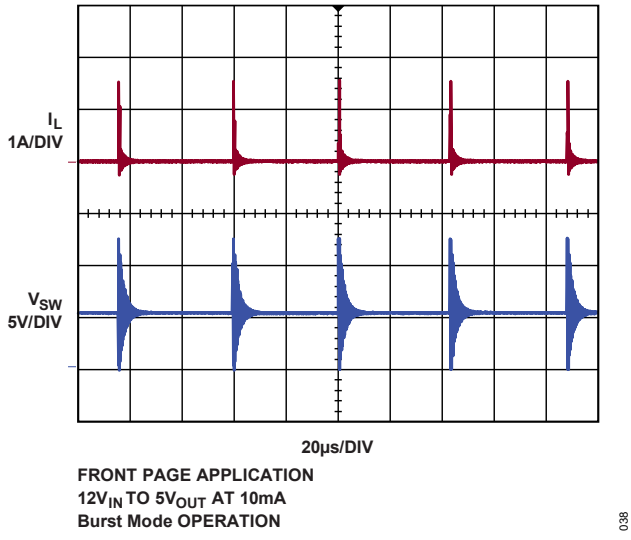


Figure 38. Switch Waveforms, Burst Mode Operation

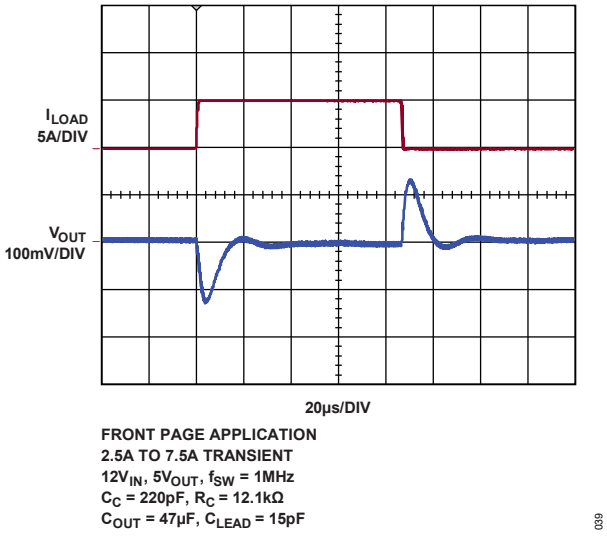


Figure 39. Transient Response; 2.5A to 7.5A Load Step

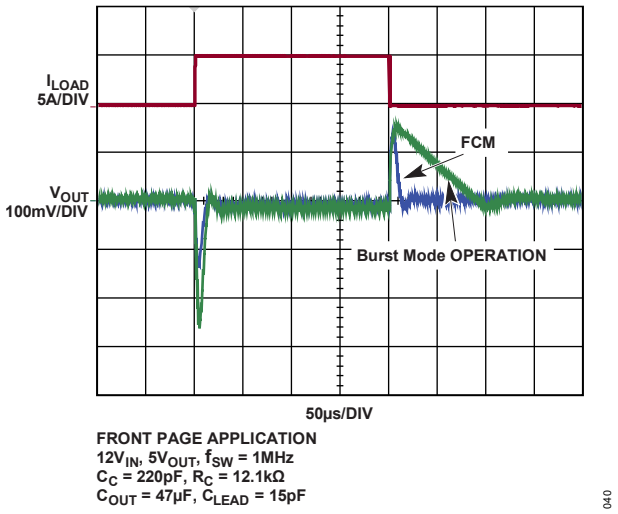


Figure 40. Transient Response; 100mA to 5.1A Load Step

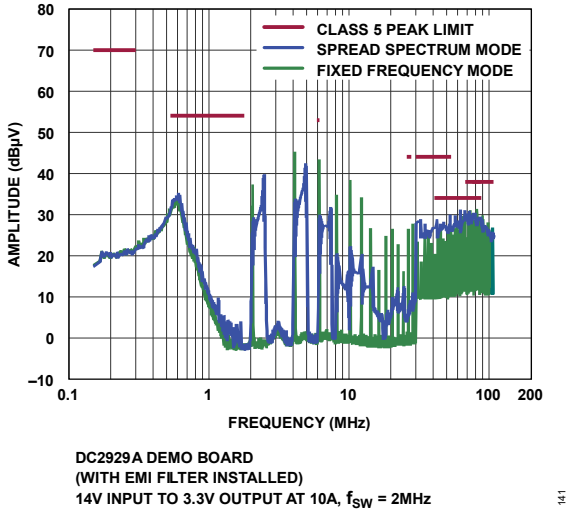


Figure 41. Conducted EMI Performance (CISPR25 Conducted Emission Test with Class 5 Peak Limits)

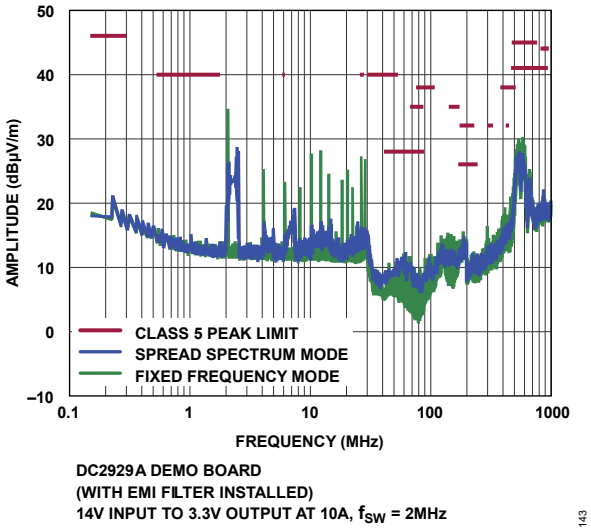


Figure 42. Radiated EMI Performance (CISPR25 Radiated Emission Test with Class 5 Peak Limits)

BLOCK DIAGRAM

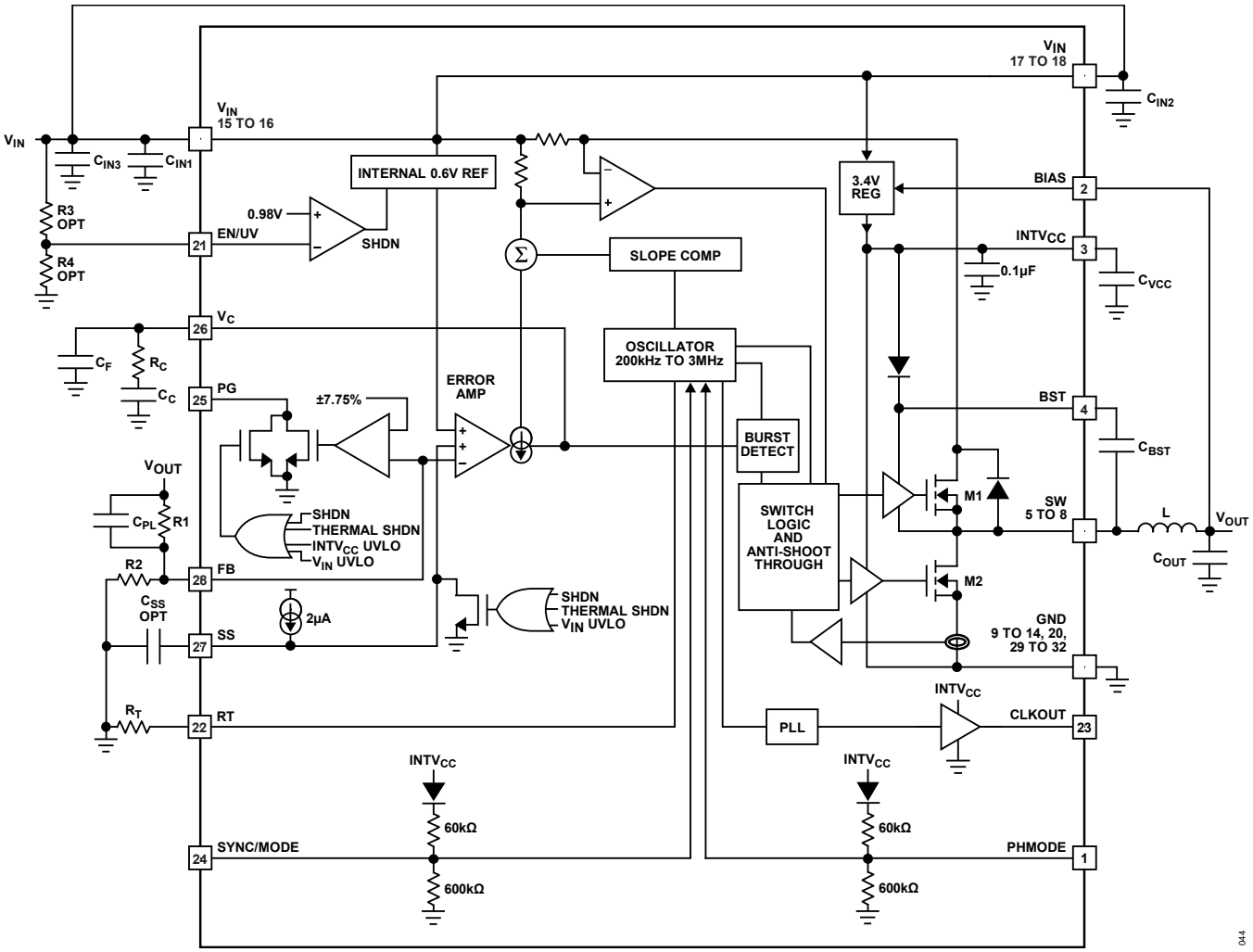


Figure 43. Block Diagram

THEORY OF OPERATION

The LT8638-2 is a monolithic, constant frequency, current mode step-down DC/DC converter. An oscillator, with frequency set using a resistor on the RT pin, turns on the internal top power switch at the beginning of each clock cycle. Current in the inductor then increases until the top switch current comparator trips and turns off the top power switch. The peak inductor current at which the top switch turns off is controlled by the voltage on the internal VC node. The error amplifier servos the VC node by comparing the voltage on the V_{FB} pin with an internal 0.6V reference. When the load current increases, it causes a reduction in the feedback voltage relative to the reference leading the error amplifier to raise the VC voltage until the average inductor current matches the new load current. When the top power switch turns off, the synchronous power switch turns on until the next clock cycle begins or in Burst Mode operation, inductor current falls to zero. If overload conditions result in more than 15.5A flowing through the bottom switch, the next clock cycle is delayed until switch current returns to a safe level.

If the EN/UV pin is low, the LT8638-2 is shut down and draws approximately 6µA from the input. When the EN/UV pin is above 0.98V, the switching regulator becomes active.

To optimize efficiency at light loads, the LT8638-2 operates in Burst Mode operation in light load situations. Between bursts, all circuitry associated with controlling the output switch is shut down, reducing the input supply current to 125µA (BIAS = 0). In a typical application, 90µA (V_{IN} = 12V, BIAS = $5V_{OUT}$) is consumed from the input supply when regulating with no load. The SYNC/ MODE pin is tied low to use Burst Mode operation and can be floated to use forced continuous mode (FCM). If a clock is applied to the SYNC/MODE pin, the part synchronizes to an external clock frequency and operates in FCM.

The LT8638-2 can operate in FCM for fast transient response and full frequency operation over a wide load range. When in FCM, the oscillator operates continuously, and positive SW transitions are aligned to the clock. Negative inductor current is allowed. The LT8638-2 can sink current from the output and return this charge to the input in this mode, improving load step transient response.

To improve EMI, the LT8638-2 can operate in spread spectrum mode. This feature varies the clock with a triangular frequency modulation of +24%. For example, if the LT8638-2's frequency is programmed to switch at 2MHz, spread spectrum mode modulates the oscillator between 2MHz and approximately 2.5MHz. The SYNC/MODE pin should be tied high to $INTV_{CC}$ (or >3V) to enable spread spectrum modulation with forced continuous mode.

To improve efficiency across all loads, supply current to internal circuitry can be sourced from the BIAS pin when biased at 3.3V or above. Else, the internal circuitry draws current from V_{IN}. The BIAS pin should be connected to V_{OUT} if the LT8638-2 output is programmed at 3.3V to 25V.

The V_C pin allows the loop compensation of the switching regulator to be optimized based on the programmed switching frequency, allowing for a fast transient response. The V_C and CLKOUT pins enable multiple LT8638-2 regulators to run with interleaving phase shift, reducing the amount of required input and output capacitors. The PHMODE pin selects the phasing of CLKOUT for different multiphase applications.

Comparators monitoring the FB pin voltage pull the PG pin low if the output voltage varies more than ±7.75% (typical) from the set point, or if a fault condition is present.

The oscillator reduces the LT8638-2 device's operating frequency when the voltage at the FB pin is low. This frequency foldback helps to control the inductor current when the output voltage is lower than the programmed value, which occurs during start-up or overcurrent conditions. When a clock is applied to the SYNC/MODE pin, the SYNC/MODE pin is floated, or held DC high, the frequency foldback is disabled, and the switching frequency slows down only during overcurrent conditions.

APPLICATIONS INFORMATION

Low EMI PCB Layout

The LT8638-2 is specifically designed to minimize EMI emissions and to maximize efficiency when switching at high frequencies. For optimal performance, the LT8638-2 should use multiple V_{IN} bypass capacitors.

Two small 1µF capacitors should be placed as close as possible to the LT8638-2, one capacitor on each side of the device (C_{IN1}, C_{IN2}). A third capacitor with a larger value, 4.7µF or higher, should be placed near C_{IN1} or C_{IN2}.

See *Figure 44* for a recommended PCB layout.

For more detail and PCB design files, refer to the demo board guide for the LT8638-2.

Note that large, switched currents flow in the LT8638-2 V_{IN} and GND pins, and the input capacitors. The loops formed by the input capacitors should be as small as possible by placing the capacitors adjacent to the V_{IN} and GND pins. Capacitors with small case size such as 0603 are optimal due to lowest parasitic inductance.

The input capacitors, along with the inductor and output capacitors, should be placed on the same side of the circuit board, and their connections should be made on that layer. Place a local, unbroken ground plane under the application circuit on the layer closest to the surface layer. The SW and BOOST nodes should be as small as possible.Finally, keep the FB and RT nodes small so that the ground traces shield them from the SW and BOOST nodes. The exposed pads on the bottom of the package should be soldered to the PCB to reduce thermal resistance to ambient. To keep thermal resistance low, extend the ground plane from GND as much as possible, and add thermal vias to additional ground planes within the circuit board and on the bottom side.

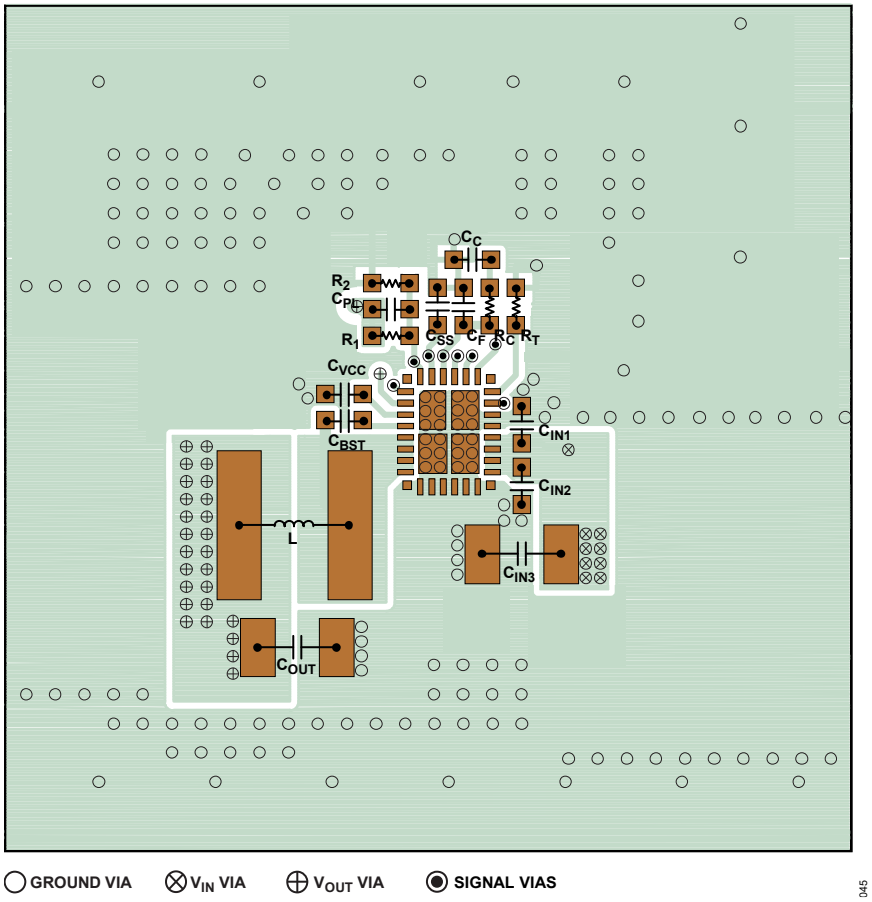


Figure 44. Recommended PCB Layout

Burst Mode Operation

To enhance efficiency at light loads, the LT8638-2 operates in low ripple Burst Mode operation, which keeps the output capacitor charged to the desired output voltage while minimizing the input quiescent current and minimizing output voltage ripple. In Burst Mode operation, the LT8638-2 delivers single small pulses of current to the output capacitor, followed by sleep periods where the output power is supplied by the output capacitor. While in sleep mode, the LT8638-2 consumes 125µA.

As the output load decreases, the frequency of single current pulses decreases (see *Figure 45*) and the percentage of time the LT8638-2 is in sleep mode increases, resulting in much higher light load efficiency than for typical converters. By maximizing the time between pulses, the quiescent current approaches 90µA for a typical application when there is no output load. Therefore, to optimize the quiescent current performance at light loads, the current in the feedback resistor divider must be minimized as it appears to the output as load current.

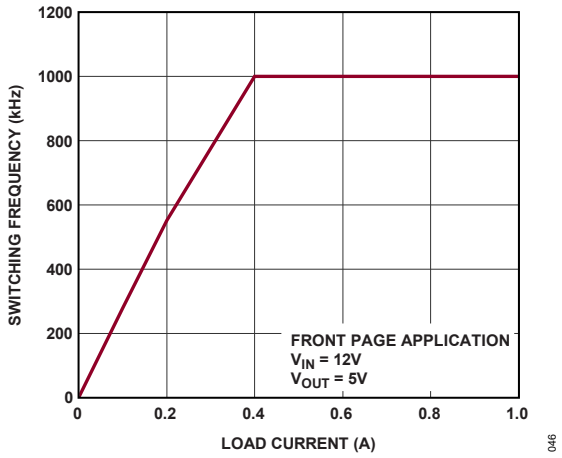


Figure 45. SW Frequency vs. Load Information in Burst Mode Operation

To achieve higher light load efficiency, more energy must be delivered to the output during the single small pulses in Burst Mode operation such that the LT8638-2 can stay in sleep mode longer between each pulse. This can be achieved using a larger value inductor (that is, 4.7µH), and should be considered independent of switching frequency when choosing an inductor. For example, while a lower inductor value is typically used for a high switching frequency application, if high light load efficiency is desired, a higher inductor value should be chosen. See the curve in Typical Performance Characteristics.

While in Burst Mode operation, the current limit of the top switch is approximately 2A (as shown in *Figure 46*), resulting in low output voltage ripple. Increasing the output capacitance decreases output ripple proportionally. As load ramps upward from zero, the switching frequency increases, but only up to the switching frequency programmed by the resistor at the RT pin, as shown in *Figure 45*.

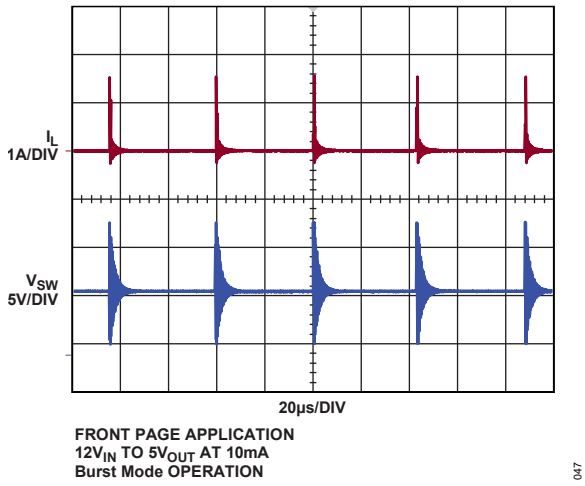


Figure 46. Burst Mode Operation

The output load at which the LT8638-2 reaches the programmed frequency varies based on input voltage, output voltage, and inductor choice. To select low ripple Burst Mode operation, tie the SYNC/MODE pin below 0.7V (this can be ground or a logic low output).

Forced Continuous Mode

The LT8638-2 can operate in forced continuous mode (FCM) for fast transient response and full frequency operation over a wide load range. When in FCM, the oscillator operates continuously and positive SW transitions are aligned to the clock. Negative inductor current is allowed at light loads or under large transient conditions. The LT8638-2 can sink current from the output and return this charge to the input in this mode, improving load step transient response (see *Figure 47*). At light loads, FCM operation is less efficient than Burst Mode operation, but may be desirable in applications where it is necessary to keep switching harmonics out of the signal band. FCM must be used if the output is required to sink current. To enable FCM, float the SYNC/MODE pin. Leakage current on this pin should be <1µA. See *Block Diagram* for internal pull-up and pull-down resistance.

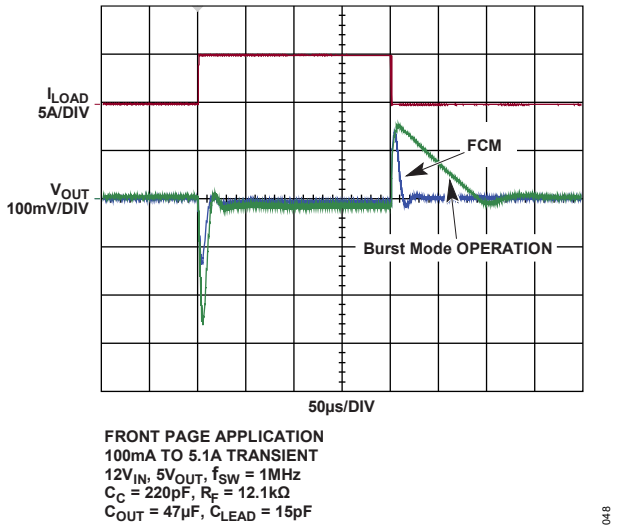


Figure 47. LT8638-2 Load Step Transient Response with and without Forced Continuous Mode

FCM is disabled if the V_{IN} pin is held above 37V or if the FB pin is held greater than 7.75% above the feedback reference voltage. FCM is also disabled during soft-start until the soft-start capacitor is fully charged. When FCM is disabled in these ways, negative inductor current is not allowed, and the LT8638-2 operates in pulse-skipping mode.

Spread Spectrum Mode

The LT8638-2 features spread spectrum operation to further reduce EMI emissions. To enable spread spectrum operation, the SYNC/MODE pin should be tied high to $INTV_{CC}$ (or >3V). In this mode, triangular frequency modulation is used to vary the switching frequency between the value programmed by RT to approximately 24% higher than that value. The modulation frequency is approximately 3kHz. For example, when the LT8638-2 is programmed to 2MHz, the frequency varies from 2MHz to approximately 2.5MHz at a 3kHz rate. When spread spectrum operation is selected, Burst Mode operation is disabled, and the part runs in forced continuous mode.

Synchronization

To synchronize the LT8638-2 oscillator to an external frequency, connect a square wave to the SYNC/MODE pin. The square wave amplitude should have valleys below 0.7V and peaks above 1.5V (up to 6V), with a minimum on-time and off-time of 50ns

The LT8638-2 does not enter Burst Mode operation at low output loads while synchronized to an external clock, but instead runs forced continuous mode to maintain regulation. The LT8638-2 may be synchronized over a 200kHz to 3MHz range. The RT resistor should be chosen to set the LT8638-2 switching frequency equal to or below the lowest synchronization input. For example, if the synchronization signal is 500kHz and higher, the RT should be selected for

500kHz. The slope compensation is set by the RT value, while the minimum slope compensation required to avoid subharmonic oscillations is established by the inductor size, input voltage, and output voltage. Since the synchronization frequency does not change the slopes of the inductor current waveform, if the inductor is large enough to avoid subharmonic oscillations at the frequency set by RT, then the slope compensation is sufficient for all synchronization frequencies.

FB Resistor Network

The output voltage is programmed with a resistor divider between the output and the FB pin. Choose the resistor values according to equation 1.

$$R1 = R2\left(\frac{V_{OUT}}{0.6V} - 1\right) \qquad (1)$$

Reference designators see the *Block Diagram*. 1% resistors are recommended to maintain output voltage accuracy.

When using large FB resistors, a 4.7pF to 47pF phase-lead capacitor should be connected from V_{OUT} to FB.

Setting the Switching Frequency

The LT8638-2 uses a constant frequency PWM architecture that can be programmed to switch from 200kHz to 3MHz by using a resistor tied from the RT pin to ground. *Table 4* shows the necessary RT value for a desired switching frequency.

The R_T resistor required for a desired switching frequency can be calculated using Equation 2.

$$R_T = \frac{44.8}{f_{SW}} - 5.9$$

where, R_T is in kΩ and f_{SW} is the desired switching frequency in MHz.

Table 4. SW Frequency vs. R_T Value

f_{SW} (MHz)	R_T (kΩ)
0.2	226
0.3	143
0.4	105
0.5	82.5
0.6	66.5
0.7	56.2
0.8	48.7
1.0	38.3
1.2	31.6
1.4	26.1
1.6	22.1
1.8	19.1
2.0	16.9
2.2	15.4
3.0	10.5

Operating Frequency Selection and Trade-Offs

Selecting the operating frequency is a trade-off between efficiency, component size, and input voltage range. The advantage of high frequency operation is that smaller inductor and capacitor values may be used. The disadvantages are lower efficiency and a smaller input voltage range.

The highest switching frequency ($f_{SW(MAX)}$) for a given application can be calculated as follows:

$$f_{SW(MAX)} = \frac{V_{OUT} + V_{SW(BOT)}}{t_{ON(MIN)}(V_{IN} - V_{SW(TOP)} + V_{SW(BOT)}} \quad (3)$$

where, V_{IN} is the typical input voltage, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively, at maximum load) and $t_{ON(MIN)}$ is the minimum top switch on-time (see Electrical Characteristics). Equation 3 shows that a slower switching frequency is necessary to accommodate a high V_{IN}/V_{OUT} ratio.

For transient operation, V_{IN} may go as high as the absolute maximum rating of 42V regardless of the R_T value. However, the LT8638-2 reduces switching frequency as necessary to maintain control of the inductor current to assure safe operation.

The LT8638-2 is capable of a maximum duty cycle of approximately 99%, and the V_{IN}-to-V_{OUT} dropout is limited by the $R_{DS(ON)}$ of the top switch. In this mode, the LT8638-2 skips switch cycles, resulting in a lower switching frequency than programmed by RT.

For applications that cannot allow deviation from the programmed switching frequency at low V_{IN}/V_{OUT} ratios, use Equation 4 to set switching frequency.

$$V_{IN(MIN)} = \frac{V_{OUT} + V_{SW(BOT)}}{1 - f_{SW} \times t_{OFF(MIN)}} - V_{SW(BOT)} + V_{SW(TOP)} \quad (4)$$

where, $V_{IN(MIN)}$ is the minimum input voltage without skipped cycles, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively, at maximum load), f_{SW} is the switching frequency (set by R_T), and $t_{OFF(MIN)}$ is the minimum switch off-time. Note that higher switching frequency increases the minimum input voltage, below which cycles are dropped to achieve higher duty cycle.

Inductor Selection and Maximum Output Current

The LT8638-2 is designed to minimize solution size by allowing the inductor to be chosen based on the output load requirements of the application. During overload or short-circuit conditions, the LT8638-2 safely tolerates operation with a saturated inductor through the use of a high speed peak-current mode architecture.

A good first choice for the inductor value is given by Equation 5.

$$L = \left(\frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}}\right) \times 0.2 \quad (5)$$

where, f_{SW} is the switching frequency in MHz, V_{OUT} is the output voltage, $V_{SW(BOT)}$ is the bottom switch drop (~0.08V), and L is the inductor value in µH.

To avoid overheating and poor efficiency, an inductor must be chosen with an RMS current rating greater than the maximum expected output load of the application. In addition, the saturation current (typically labeled I_{SAT}) rating of the inductor must be higher than the load current plus 1/2 of in inductor ripple current (Equation 6)

$$I_{L(PEAK)} = I_{LOAD(MAX)} + \frac{1}{2}\Delta I_L \qquad (6)$$

where, ΔI_L is the inductor ripple current as calculated in Equation 8 and $I_{LOAD(MAX)}$ is the maximum output load for a given application.

As a quick example, an application requiring 3A output should use an inductor with an RMS rating of greater than 3A and an I_{SAT} of greater than 4A. During long duration overload or short-circuit conditions, the inductor RMS rating requirement is greater to avoid overheating of the inductor. To keep the efficiency high, the series resistance (DCR) should be less than 8mΩ, and the core material should be intended for high frequency applications.

The LT8638-2 limits the peak switch current to protect the switches and the system from overload faults. The top switch current limit (I_{LIM}) is 20A at low duty cycles and decreases linearly to 15A at DC = 0.8. The inductor value must then be sufficient to supply the desired maximum output current ($I_{OUT(MAX)}$), which is a function of the switch current limit (I_{LIM}) and the ripple current (Equation 7).

$$I_{OUT(MAX)} = I_{LIM} - \frac{\Delta I_L}{2} \qquad (7)$$

The peak-to-peak ripple current in the inductor can be calculated using Equation 8.

$$\Delta I_L = \frac{V_{OUT}}{L \times f_{SW}} \times \left(1 - \frac{V_{OUT}}{V_{IN(MAX)}}\right) \qquad (8)$$

where, f_{SW} is the switching frequency of the LT8638-S, and L is the value of the inductor.

Therefore, the maximum output current the LT8638-2 delivers depends on the switch current limit, inductor value, and input and output voltages. The inductor value may have to be increased if the inductor ripple current does not allow sufficient maximum output current ($I_{OUT(MAX)}$) given the switching frequency, and maximum input voltage used in the desired application.

To achieve higher light load efficiency, more energy must be delivered to the output during the single small pulses in Burst Mode operation such that the LT8638-2 can stay in sleep mode longer between each pulse. This can be achieved using a larger value inductor (that is, 4.7µH), and should be considered independent of switching frequency when choosing an inductor. For example, while a lower inductor value is typically used for a high switching frequency application, if high light load efficiency is desired, a higher inductor value should be chosen. See the curve in Typical Performance Characteristics.

The optimum inductor for a given application may differ from the one indicated by this design guide. A larger value inductor provides a higher maximum load current and reduces the output voltage ripple. For applications requiring smaller load currents, the value of the inductor may be lower and the LT8638-2 may operate with higher ripple current. This allows the use of a physically smaller inductor, or one with a lower DCR resulting in higher efficiency. Be aware that low inductance may result in discontinuous mode operation, which further reduces maximum load current.

For more information about maximum output current and discontinuous operation, refer to *application note 44*.

For duty cycles greater than 50% ($V_{OUT}/V_{IN} > 0.5$), a minimum inductance is required to avoid subharmonic oscillation (Equation 9). Refer to *application note 19* for more details.

$$L_{MIN} = \frac{V_{IN}(2 \times DC - 1)}{5 \times f_{SW}} \qquad (9)$$

where, DC is the duty cycle ratio (V_{OUT}/V_{IN}) and f_{SW} is the switching frequency.

Input Capacitors

The V_{IN} of the LT8638-2 should be bypassed with at least three ceramic capacitors for best performance. Two small ceramic capacitors of 1µF should be placed close to the part (C_{IN1}, C_{IN2}). These capacitors should be 0402 or 0603 in size. For automotive applications requiring 2 series input capacitors, two small 0402 or 0603 may be placed at each side of the LT8638-2 near the V_{IN} and GND pins.

A third, larger ceramic capacitor of 4.7µF or larger should be placed close to C_{IN1} or C_{IN2}. See Low EMI PCB Layout section for more detail. X7R or X5R capacitors are recommended for best performance across temperature and input voltage variations.

Note that larger input capacitance is required when a lower switching frequency is used. If the input power source has high impedance, or there is significant inductance due to long wires or cables, additional bulk capacitance may be necessary. This can be provided with a low performance electrolytic capacitor.

A ceramic input capacitor combined with trace or cable inductance forms a high quality (under damped) tank circuit. If the LT8638-2 circuit is plugged into a live supply, the input voltage can ring to twice its nominal value, possibly exceeding the LT8638-2 device's voltage rating. This situation is easily avoided (see *application note 88*).

Output Capacitor and Output Ripple

The output capacitor has two essential functions. Along with the inductor, it filters the square wave generated by the LT8638-2 to produce the DC output. In this role, it determines the output ripple. Thus, low impedance at the switching frequency is important. The second function is to store energy to satisfy transient loads and stabilize the LT8638-2 device's control loop. Ceramic capacitors have very low equivalent series resistance (ESR) and provide the best ripple performance. For good starting values, see the *Typical Applications* section.

Use X5R or X7R types for low output ripple and good transient response. Transient performance can be improved with a higher value output capacitor and the addition of a feedforward capacitor placed between V_{OUT} and FB. Increasing the output capacitance also decreases the output voltage ripple. A lower value of output capacitor can be used to save space and cost, but transient performance suffers and may cause loop instability. See the *Typical Applications* in this data sheet for suggested capacitor values.

When choosing a capacitor, special attention should be given to the data sheet to calculate the effective capacitance under the relevant operating conditions of voltage bias and temperature. A physically larger capacitor or one with a higher voltage rating may be required.

Ceramic Capacitors

Ceramic capacitors are small, robust, and have very low ESR. However, ceramic capacitors can cause problems when used with the LT8638-2 due to their piezoelectric nature. When in Burst Mode operation, the LT8638-2's switching frequency depends on the load current, and at very light loads, the LT8638-2 can excite the ceramic capacitor at audio frequencies, generating audible noise. Since the LT8638-2 operates at a lower current limit during Burst Mode operation, the noise is typically very quiet to a casual ear. If this is unacceptable, use a high performance tantalum or electrolytic capacitor at the output. Low noise ceramic capacitors are also available.

A final precaution regarding ceramic capacitors concerns the maximum input voltage rating of the LT8638-2. As previously mentioned, a ceramic input capacitor combined with trace or cable inductance forms a high quality (underdamped) tank circuit. If the LT8638-2 circuit is plugged into a live supply, the input voltage can ring to twice its nominal value, possibly exceeding the LT8638-2 device's rating. This situation is easily avoided (refer to *application note 88*).

Enable Pin

The LT8638-2 is in shut down when the EN pin is low and active when the pin is high. The rising threshold of the EN comparator is 0.98V, with 40mV of hysteresis. The EN pin can be tied to V_{IN} if the shutdown feature is not used, or tied to a logic level if shutdown control is required.

Adding a resistor divider from V_{IN} to EN programs the LT8638-2 to regulate the output only when V_{IN} is above a desired voltage (see the *Block Diagram*). Typically, this threshold, $V_{IN(EN)}$, is used in situations where the input supply is current limited, or has a relatively high source resistance. A switching regulator draws constant power from the source. So, source current increases as source voltage drops. This looks like a negative resistance load to the source and can cause the source to current limit or latch low under low source voltage conditions. The $V_{IN(EN)}$ threshold prevents the regulator from operating at source voltages where the problems might occur. This threshold can be adjusted by setting the values R3 and R4 such that they satisfy Equation 10

$$V_{IN(EN)} = \left(\frac{R3}{R4} + 1\right) \times 0.98V \qquad (10)$$

where, the LT8638-2 remains off until V_{IN} is above $V_{IN(EN)}$. Due to the comparator's hysteresis, switching does not stop until the input falls slightly below $V_{IN(EN)}$.

When operating in Burst Mode operation for light load currents, the current through the $V_{IN(EN)}$ resistor network can easily be greater than the supply current consumed by the LT8638-2. Therefore, the $V_{IN(EN)}$ resistors should be large to minimize their effect on efficiency at low loads.

$INTV_{CC}$ Regulator

An internal low dropout (LDO) regulator produces the 3.4V supply from V_{IN} that powers the drivers and the internal bias circuitry and must be bypassed to ground with a minimum of 1µF ceramic capacitor. The $INTV_{CC}$ can supply enough current for the LT8638-2 device's circuitry. To improve efficiency, the internal LDO can also draw current from the BIAS pin when the BIAS pin is 3.1V or higher. Typically, the BIAS pin can be tied to the output of the LT8638-2, or can be tied to an external supply of 3.3V or above. If BIAS is connected to a supply other than V_{OUT}, be sure to bypass with a local ceramic capacitor. If the BIAS pin is below 3.0V, the internal LDO consumes current from V_{IN}. Applications with high input voltage and high switching frequency where the internal LDO pulls current from V_{IN} increases die temperature because of the higher power dissipation across the LDO. Do not connect an external load to the $INTV_{CC}$ pin.

Frequency Compensation

Loop compensation determines the stability and transient performance, and is provided by the components tied to the V_C pin. Generally, a capacitor (C_C) and a resistor (R_C) in series to ground are used. Designing the compensation network is a bit complicated and the best values depend on the application. A practical approach is to start with one of the circuits in this data sheet similar to the user application and tune the compensation network to optimize the performance. LTspice® or LTpowerCAD® simulations can help in this process. Stability should then be checked across all operating conditions, including load current, input voltage, and temperature. The *LT1375 data sheet* contains a more thorough discussion of loop compensation and describes how to test the stability using a transient load.

Figure 48 shows an equivalent circuit for the LT8638-2 control loop. The error amplifier is a transconductance amplifier with finite output impedance. The power section, consisting of the modulator, power switches, and inductor, is modeled as a transconductance amplifier generating an output current proportional to the voltage at the V_C pin. Note that the output capacitor integrates this current, and that the capacitor on the V_C pin (C_C) integrates the error amplifier output current, resulting in two poles in the loop. A zero is required and comes from a resistor R_C

in series with C_C. This simple model works well as long as the value of the inductor is not too high and the loop crossover frequency is much lower than the switching frequency. A phase lead capacitor (C_{PL}) across the feedback divider can be used to improve the transient response and is required to cancel the parasitic pole caused by the feedback node to ground capacitance.

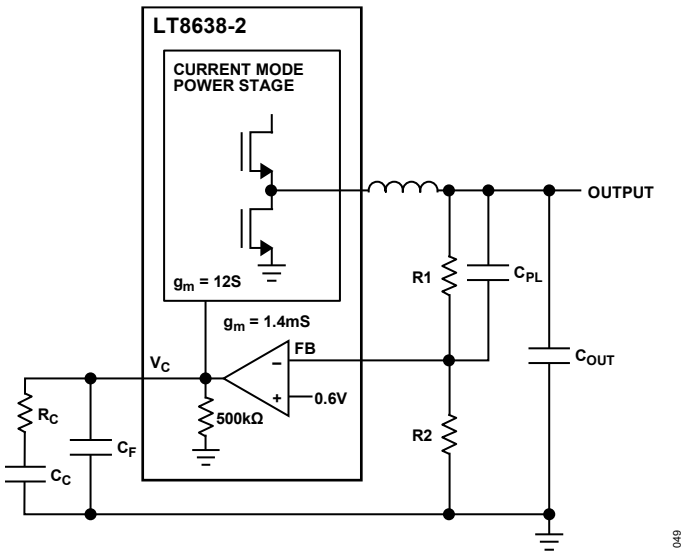


Figure 48. Model for Loop Response

Table 5 provides a guidance for the compensation values of several typical applications. Slight tweaks to these values may be required depending on the specific application. All applications were using R1 = 100k

Table 5. Compensation Values

V_{OUT}	f_{SW}	C_C	R_C	C_{OUT}	C_{PL}
3.3V	400k	820pF	8.87k	47µF ×3	33pF
3.3V	2M	220pF	12.1k	47µF ×2	15pF
5V	400k	820pF	9.31k	47µF ×3	33pF
5V	2M	220pF	13.7k	47µF	10pF

Output Voltage Tracking and Soft-Start

The LT8638-2 allows the user to program its output voltage ramp rate with the SS pin. An internal 2µA pulls up the SS pin to $INTV_{CC}$. Putting an external capacitor on SS enables soft starting the output to prevent current surge on the input supply. During the soft-start ramp, the output voltage proportionally tracks the SS pin voltage. For output tracking applications, SS can be externally driven by another voltage source. From 0V to 1V, the SS voltage overrides the internal 0.6V reference input to the error amplifier, thus regulating the FB pin voltage to a function of the SS pin. See the plot in *Typical Performance Characteristics*. When SS is above 1V, tracking is disabled, and the feedback voltage regulates to the internal reference voltage. The SS pin may be left floating if the function is not needed.

An active pull-down circuit is connected to the SS pin, which discharges the external soft-start capacitor in the case of fault conditions and restarts the ramp when the faults are cleared. Fault conditions that clear the soft-start capacitor are the EN/UV pin transitioning low, V_{IN} voltage falling too low, or thermal shutdown.

Multiphase Operation

For output loads that demand more current, multiple LT8638-2 devices can be connected in parallel to the same output. To do this, the V_C and FB pins are connected together, and each LT8638-2's SW node is connected to the common output through its own inductor. The CLKOUT signal can be connected to the SYNC/MODE pin of the following LT8638-2 to line up both the frequency and the phase of the entire system. Tying the PHMODE pin to GND, $INTV_{CC}$, or floating the pin generates a phase difference between the LT8638-2 device's internal clock and CLKOUT of 180°, 90°, or 120°, respectively, which corresponds to 2-phase, 4-phase, or 3-phase operation. A total of 12 phases can be paralleled to run simultaneously with interleaving phase shift with respect to each other by programming the PHMODE pin of each LT8638-2 to different voltage levels. During FCM, spread spectrum, and synchronization modes, all devices operate at the same frequency. *Figure 49* shows a 2-phase application, where two LT8638-2s are paralleled to get one output capable of up to 20A.

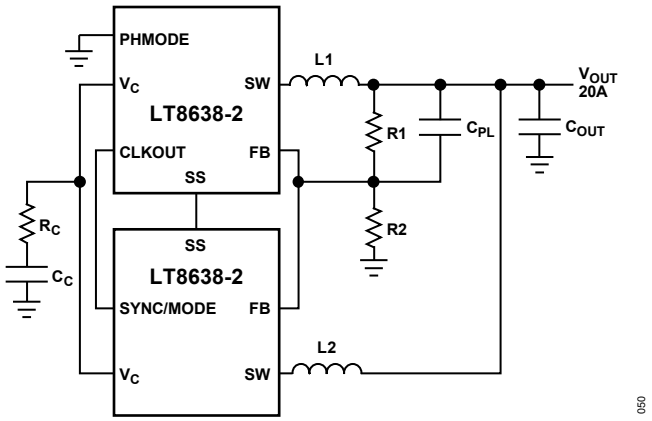


Figure 49. Paralleling Two LT8638-2 Devices

Output Power Good

When the LT8638-2 device's output voltage is within the ±7.75% window of the regulation point, the output voltage is considered good, the open-drain PG pin goes high impedance, and is typically pulled high with an external resistor. Otherwise, the internal pull-down device pulls the PG pin low. To prevent glitching both the upper and lower thresholds, include 0.4% of hysteresis. PG is valid when V_{IN} is above 2.8V.

The PG pin is also actively pulled low during several fault conditions: EN/UV pin is below 0.98V, $INTV_{CC}$ has fallen too low, V_{IN} is too low, or thermal shutdown.

Shorted and Reversed Input Protection

The LT8638-2 tolerates a shorted output. Several features are used for protection during output short-circuit and brownout conditions. The first is the switching frequency is folded back while the output is lower than the set point to maintain inductor current control. Second, the bottom switch current is monitored such that if inductor current is beyond safe levels, switching of the top switch is delayed until such time as the inductor current falls to safe levels.

Frequency foldback behavior depends on the state of the SYNC pin; if the SYNC pin is low, the switching frequency slows while the output voltage is lower than the programmed level. If the SYNC pin is connected to a clock source, floated or tied high, the LT8638-2 stays at the programmed frequency without foldback and only slow switching if the inductor current exceeds safe levels.

There is another situation to consider in systems where the output is held high when the input to the LT8638-2 is absent. This may occur in battery charging applications or in battery-backup systems where a battery or some other supply is diode O Red with the LT8638-2 device's output. If the V_{IN} pin is allowed to float and the EN pin is held high

(either by a logic signal or because it is tied to V_{IN}), then the LT8638-2 device's internal circuitry pulls its quiescent current through its SW pin. This is acceptable if the system can tolerate several µA in this state. If the EN pin is grounded, the SW pin current drops to near 6µA. However, if the V_{IN} pin is grounded while the output is held high, regardless of EN, parasitic body diodes inside the LT8638-2 can pull current from the output through the SW pin and the V_{IN} pin. *Figure 50* shows a connection of the V_{IN} and EN/UV pins that allows the LT8638-2 to run only when the input voltage is present, and that protects against a shorted or reversed input.

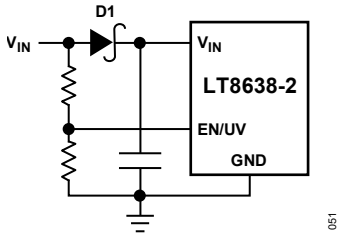


Figure 50. Reverse V_{IN} Protection

Thermal Considerations and Peak Output Current

For higher ambient temperatures, care should be taken in the layout of the PCB to ensure good heat sinking of the LT8638-2. The ground pins on the bottom of the package should be soldered to a ground plane. This ground should be tied to large copper layers below with thermal vias; these layers spread heat dissipated by the LT8638-2. Placing additional vias can reduce thermal resistance further. The maximum load current should be derated as the ambient temperature approaches the maximum junction rating. Power dissipation within the LT8638-2 can be estimated by calculating the total power loss from an efficiency measurement and subtracting the inductor loss. The die temperature is calculated by multiplying the LT8638-2 power dissipation by the thermal resistance from junction to ambient.

The internal overtemperature protection monitors the junction temperature of the LT8638-2. If the junction temperature reaches approximately 175°C, the LT8638-2 stops switching and indicates a fault condition until the temperature drops about 10°C cooler.

Temperature rise of the LT8638-2 is worst when operating at high load, high V_{IN}, and high switching frequency. If the case temperature is too high for a given application, then either V_{IN}, switching frequency, or load current can be decreased to reduce the temperature to an acceptable level. *Figure 51* shows examples of how case temperature rise can be managed by reducing V_{IN}, switching frequency, or load.

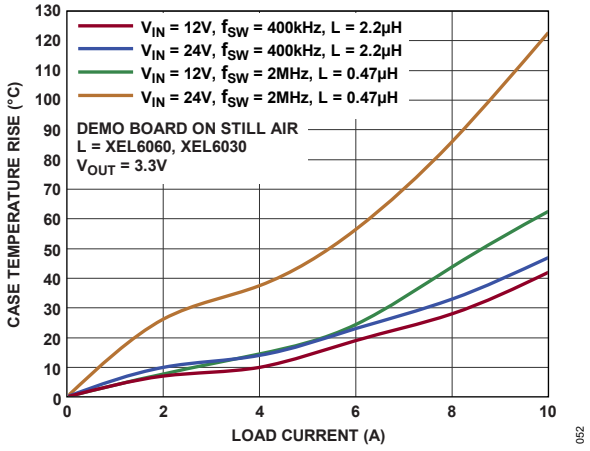


Figure 51. Case Temperature Rise

The LT8638-2's internal power switches are capable of safely delivering up to 12A of peak output current. However, due to thermal limits, the package can only handle 12A loads for short periods of time. This time is determined by how quickly the case temperature approaches the maximum junction rating. *Figure 52* shows an example of how case temperature rise changes with the duty cycle of a 1kHz pulsed 12A load.

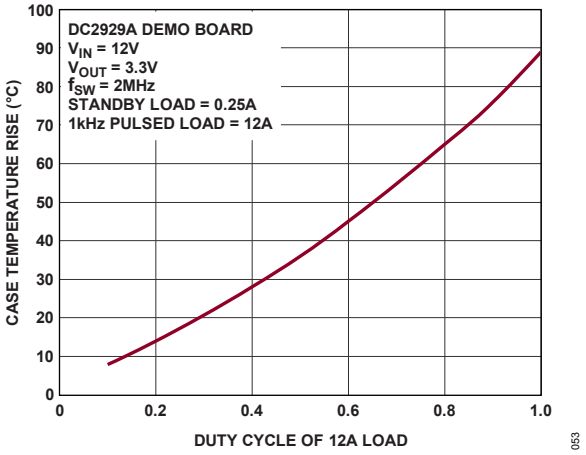


Figure 52. Case Temperature Rise vs. 12A Pulsed Load

The LT8638-2 device's top switch current limit decreases with higher duty cycle operation for slope compensation. This also limits the peak output current the LT8638-2 can deliver for a given application. See the curve in *Typical Performance Characteristics*.

TYPICAL APPLICATIONS

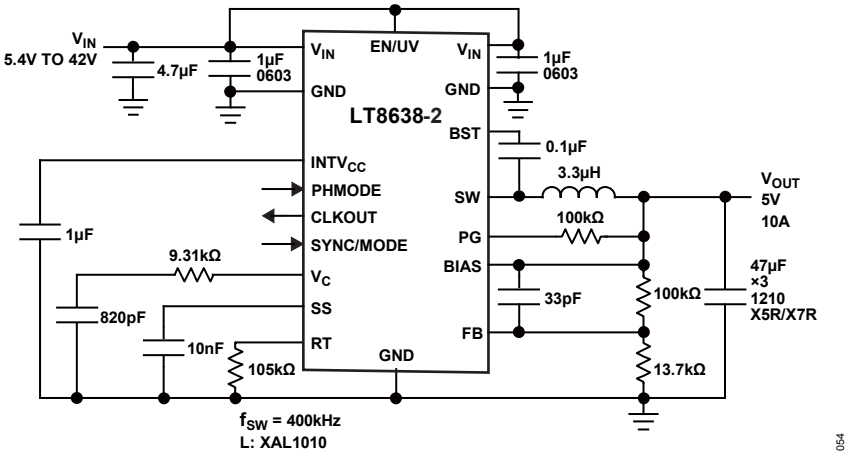


Figure 53. 400kHz 5V 10A Step-Down Converter with Soft-Start and Power Good

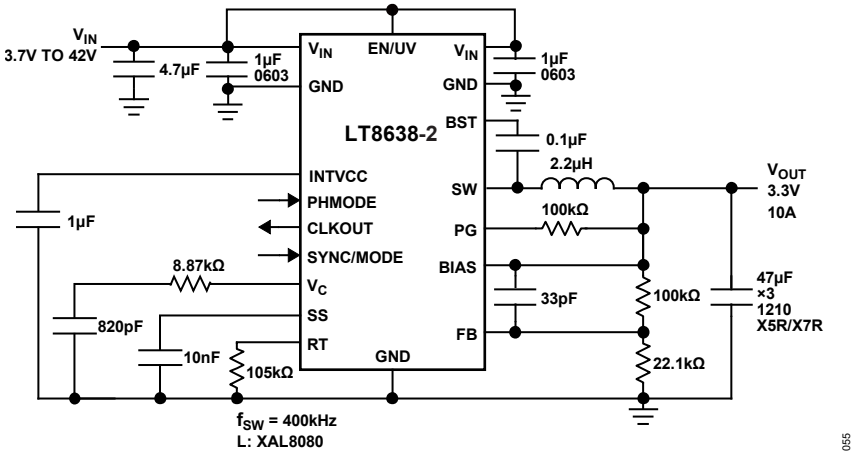


Figure 54. 400kHz 3.3V, 10A Step-Down Converter with Soft-Start and Power Good

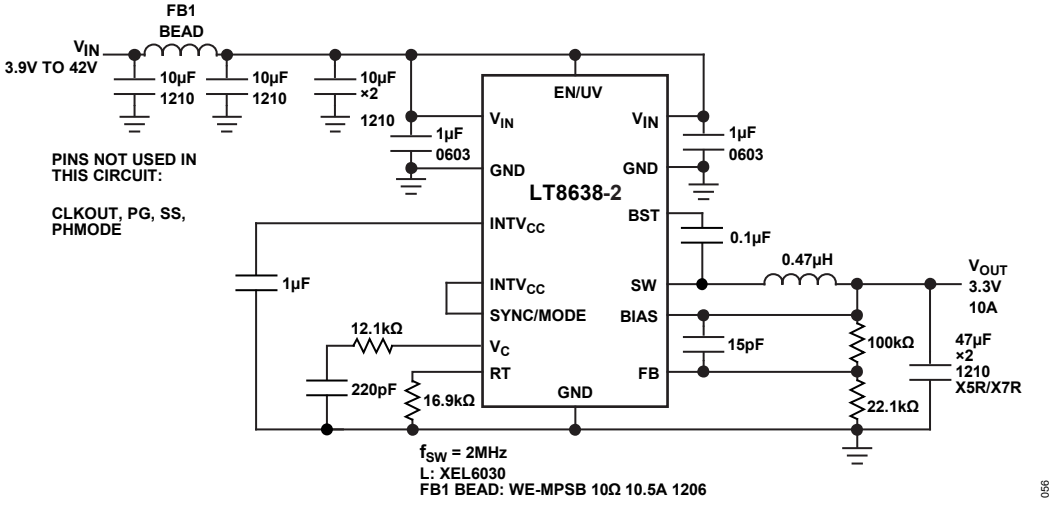


Figure 55. Ultralow EMI 3.3V, 10A Step-Down Converter with Spread Spectrum

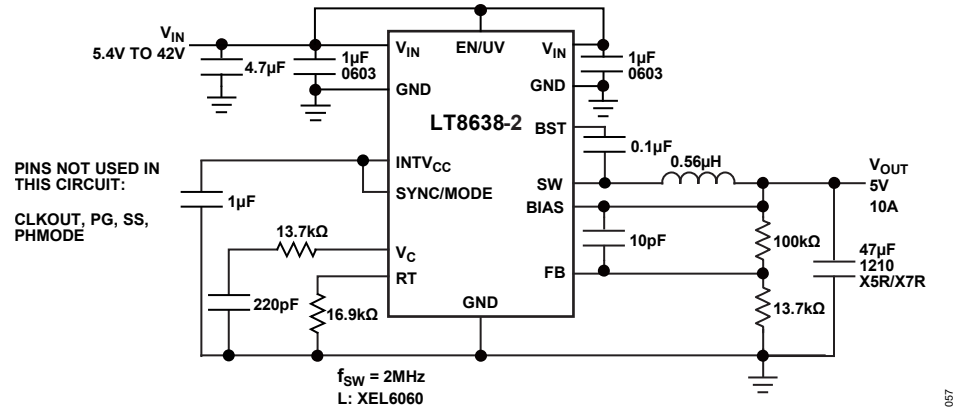


Figure 56. 2MHz 5V, 10A Step-Down Converter with Spread Spectrum

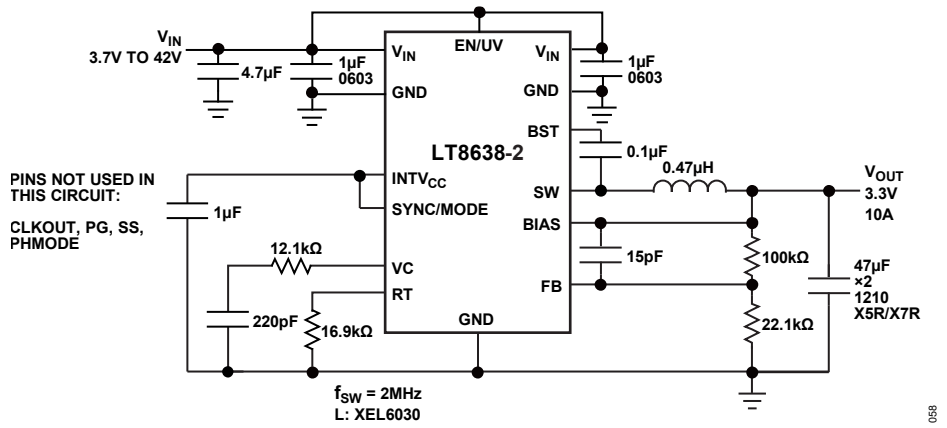


Figure 57. 2MHz 3.3V, 10A Step-Down Converter with Spread Spectrum

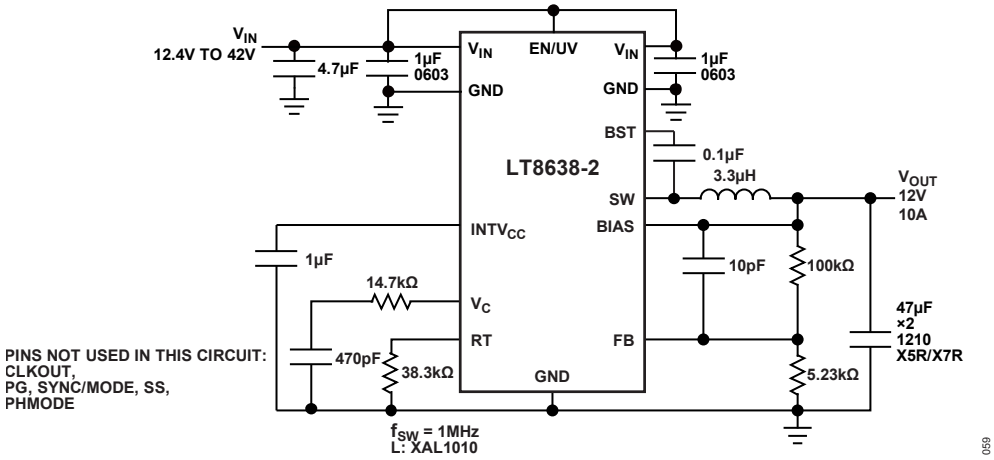


Figure 58. 1MHz 12V, 10A Step-Down Converter

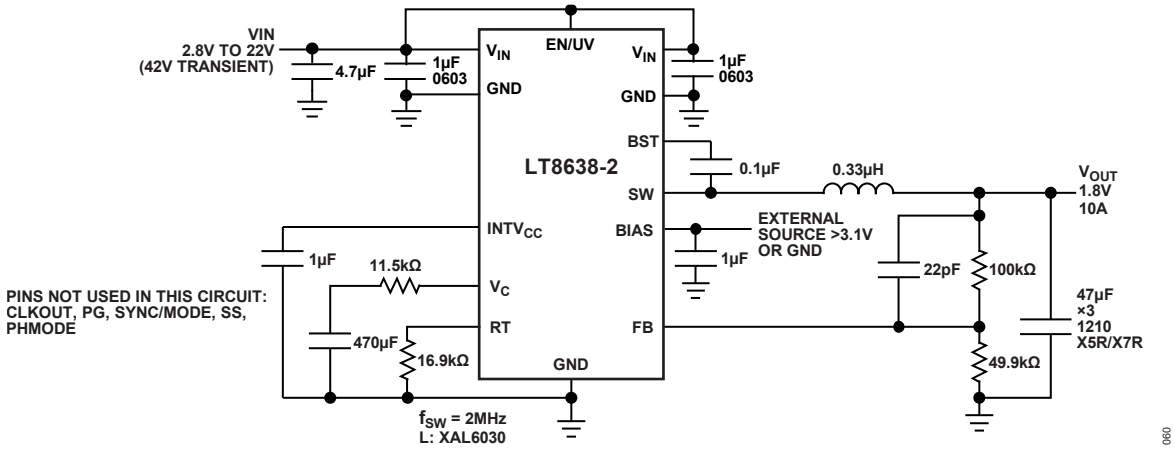
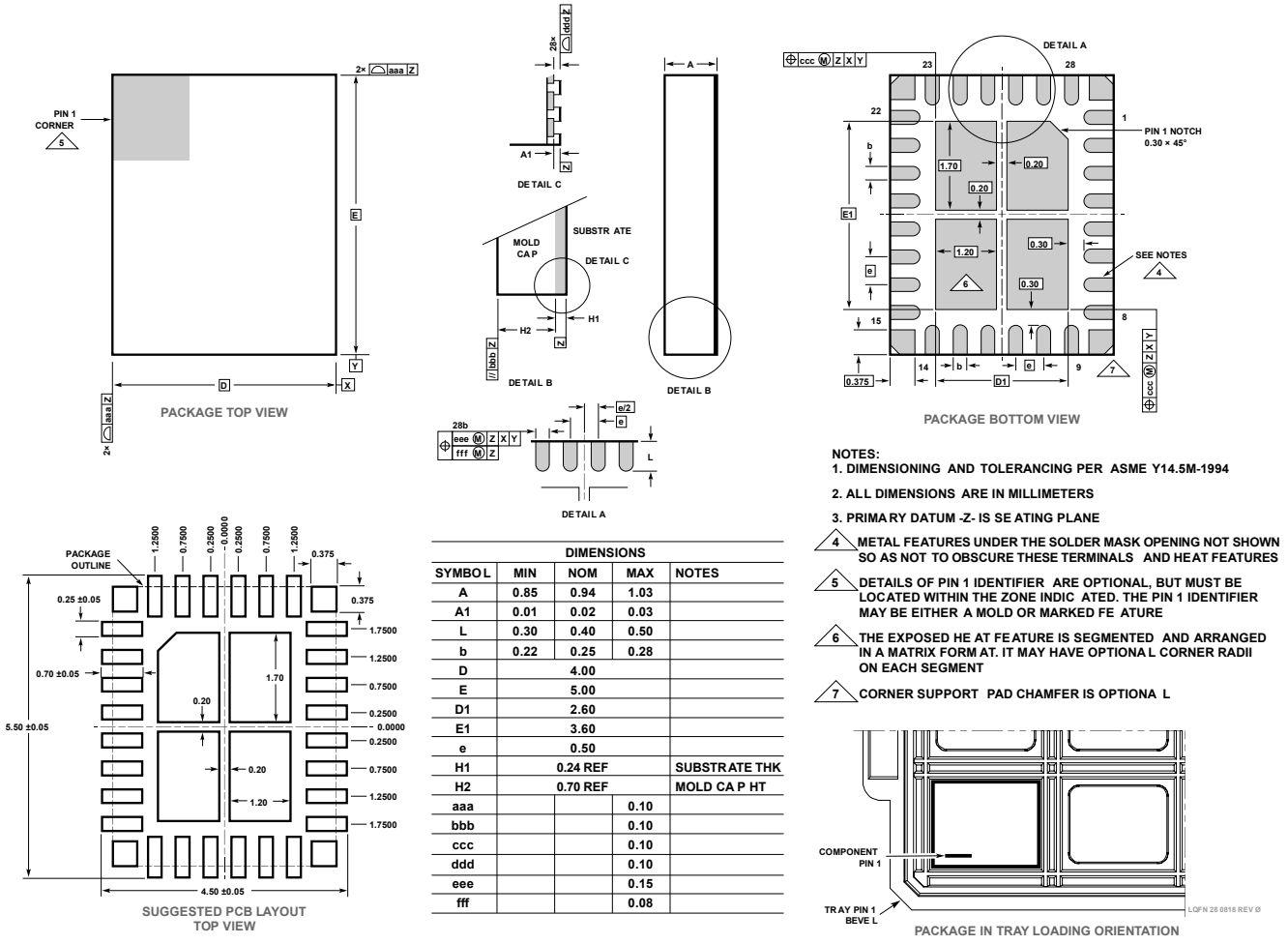


Figure 59. 2MHz 1.8V, 10A Step-Down Converter

PACKAGE DESCRIPTION



DIMENSIONS				
SYMBOL	MIN	NOM	MAX	NOTES
A	0.85	0.94	1.03	
A1	0.01	0.02	0.03	
L	0.30	0.40	0.50	
b	0.22	0.25	0.28	
D		4.00		
E		5.00		
D1		2.60		
E1		3.60		
e		0.50		
H1		0.24 REF		SUBSTRATE THK
H2		0.70 REF		MOLD CA P HT
aaa			0.10	
bbb			0.10	
ccc			0.10	
ddd			0.10	
eee			0.15	
fff			0.08	

NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
2. ALL DIMENSIONS ARE IN MILLIMETERS
3. PRIMA RY DATUM -Z- IS SE ATING PLANE
4. METAL FEATURES UNDER THE SOLDER MASK OPENING NOT SHOWN SO AS NOT TO OBSCURE THESE TERMINALS AND HEAT FEATURES
5. DETAILS OF PIN 1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDIC ATED. THE PIN 1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FE ATURE
6. THE EXPOSED HE AT FE ATURE IS SEGMENTED AND ARRANGED IN A MATRIX FORM AT. IT MAY HAVE OPTIONA L CORNER RADII ON EACH SEGMENT
7. CORNER SUPPORT PAD CHAMFER IS OPTIONA L

Figure 60. Outline Dimensions

RELATED PARTS

PART	DESCRIPTION	COMMENTS
LT8638S	42V, 10A/12A Synchronous Step-Down Silent Switcher 2	V_{IN} = 2.8V to 42V, $V_{OUT(MIN)}$ = 0.6V, I_Q = 100µA, I_{SD} = 6µA, 5mm × 4mm LQFN-28
LT8648S	42V, 15A Synchronous Step-Down Silent Switcher 2	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.6V, I_Q = 100µA, I_{SD} = 6µA, 7mm × 4mm LQFN-36
LT8636	42V, 5A Synchronous Step-Down Silent Switcher with I_Q = 2.5µA	V_{IN} = 3.4V to 42V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, I_{SD} < 1µA, 4mm × 3mm LQFN-20
LT8640S/ LT8643S	42V, 6A Synchronous Step-Down Silent Switcher 2 with I_Q = 2.5µA	V_{IN} = 3.4V to 42V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, I_{SD} < 1µA, 4mm × 4mm LQFN-24
LT8640/ LT8640-1	42V, 5A, 96% Efficiency, 3MHz Synchronous MicroPower Step-Down DC/ DC Converter with I_Q = 2.5µA	V_{IN} = 3.4V to 42V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, ISD < 1µA, 3mm × 4mm QFN-18
LT8650S	42V, Dual 4A Synchronous Step-Down Silent Switcher 2 with I_Q = 6.2µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.8V, I_Q = 6.2µA, I_{SD} = 1.7µA, 4mm × 6mm LQFN-32
LT8653S	42V, Dual 2A Synchronous Step-Down Silent Switcher 2 with I_Q = 6.2µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.8V, I_Q = 6.2µA, I_{SD} = 1.7µA, 4mm × 3mm LQFN-20
LT8652S	18V, Dual 8.5A Synchronous Step-Down Silent Switcher 2 with I_Q = 16µA	V_{IN} = 3V to 18V, $V_{OUT(MIN)}$ = 0.6V, I_Q = 16µA, I_{SD} = 6µA, 4mm × 7mm LQFN-36
LT8645S/ LT8646S	65V, 8A, Synchronous Step-Down Silent Switcher 2 with I_Q = 2.5µA	V_{IN} = 3.4V to 65V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, I_{SD} < 1µA, 4mm × 6mm LQFN-32
LT8641	65V, 3.5A, 95% Efficiency, 3MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	$V_{IN(MIN)}$ = 3V, $V_{IN(MAX)}$ = 65V, $V_{OUT(MIN)}$ = 0.81V, I_Q = 2.5µA,I_{SD} < 1µA, 3mm × 4mm QFN-18
LT8609S	42V, 2A Synchronous Step-Down Silent Switcher 2 with I_Q = 2.5µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.774V, I_Q = 2.5µA, ISD < 1µA,3mm × 3mm LQFN-16
LT8609/ LT8609A	42V, 2A, 94% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.782V, I_Q = 2.5µA,I_{SD} < 1µA, MSOP-10E, 3mm × 3mm DFN-18

ORDERING GUIDE

Table 6. Ordering Guide

PART NUMBER	PAD OR BALL FINISH	PART MARKING*		PACKAGE TYPE**	MSL RATING	TEMPERATURE RANGE (SEE NOTE 2)
		DEVICE	FINISH CODE			
AUTOMOTIVE PRODUCTS* **						
LT8638RV-2#WPBF	Au (RoHS)	86382	e4	LQFN (Laminate Package with QFN Footprint)	3	–40°C to 150°C
LT8638RV-2#WTRPBF	Au (RoHS)	86382	e4	LQFN (Laminate Package with QFN Footprint)	3	–40°C to 150°C

- Contact the factory for parts specified with wider operating temperature ranges. *Pad or ball finish code is per IPC/JEDEC J-STD-609.
- Device temperature grade is identified by a label on the shipping container.
- Recommended LGA and BGA PCB assembly and manufacturing procedures.
- LGA and BGA package and tray drawings.

Parts ending with PBF are RoHS and WEEE compliant. **The LT8638-2 package has the same dimensions as a standard 5mm × 4mm QFN package.

***Versions of this part are available with controlled manufacturing to support the quality and reliability requirements of automotive applications. These models are designated with a #W suffix. Only the automotive grade products shown are available for use in automotive applications. Contact the local Analog Devices account representative for specific product ordering information and to obtain the specific automotive reliability reports for these models.

REVISION HISTORY

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/23	Initial Release	—
A	09/24	Updated Figure 1	1
		Updated Table 1	4
		Updated Package Thermal Parameters	6
		Replaced Plot for Figure 29	13
		Updated Figures 53, 54, 56, 57, 58, 59	29, 30, 31

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