High Efficiency 42V/120mA Synchronous Buck

FEATURES

- **High Efficiency 2MHz Synchronous Operation**
  - **> 90% Efficiency at 50mA, 12V_{IN} to 5V_{OUT}**
- **Ultralow Quiescent Current Burst Mode® Operation**
  - **< 2.5µA I_Q Regulating 24V_{IN} to 3.3V_{OUT}**
  - **Output Ripple < 10mV_{P-P}**
- **Wide Input Voltage Range: 3.2V to 42V**
- **Fast Minimum Switch-On Time: 35ns**
- **Adjustable Switching Frequency: 200kHz to 2.2MHz**
- Allows Tiny Inductors
- Accurate 1V Enable Pin Threshold
- Internal Compensation
- Output Soft-Start and Tracking
- Small 10-Lead 3mm × 2mm Side-Wettable DFN Package
- AEC-Q100 Qualified for Automotive Applications

APPLICATIONS

- Industrial Sensors
- Industrial Internet of Things
- 4mA to 20mA Current Loops
- Flow Meters
- Automotive Housekeeping Supplies

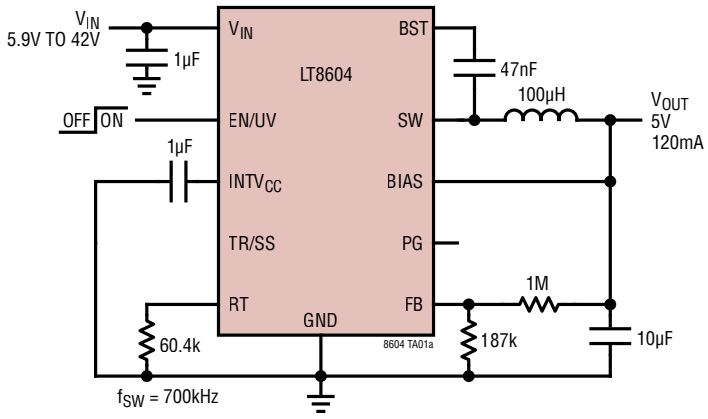
DESCRIPTION

The LT®8604 is a compact, high speed synchronous monolithic step-down switching regulator that delivers up to 120mA with high efficiency at constant switching frequency, even up to 2.2MHz. It accepts a wide input voltage range up to 42V, and consumes only 2.5µA of quiescent current. Top and bottom power switches are included with all necessary circuitry to minimize the need for external components. Low ripple Burst Mode operation enables high efficiency down to very low output currents while keeping the output ripple below 10mV_{P-P}.

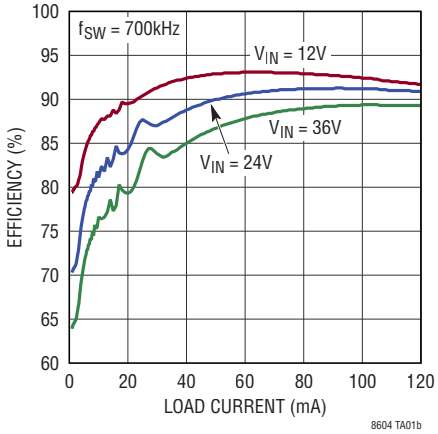
Additional features provide for flexible and robust operation. Internal compensation with peak current mode topology allows the use of small inductors and results in fast transient response and good loop stability. The EN/UV pin has an accurate 1V threshold and can be used to program V_{IN} under voltage lockout or to shut down the LT8604 reducing the input supply current to 1µA. A PG flag signals when V_{OUT} is within ±7.5% of the programmed output voltage as well as fault conditions. Thermal shutdown provides additional protection. The LT8604 is available in a small 10-Lead 3mm × 2mm DFN package with exposed pad for low thermal resistance.

TYPICAL APPLICATION

5V, Step-Down Converter



Efficiency at V_{OUT} = 5V

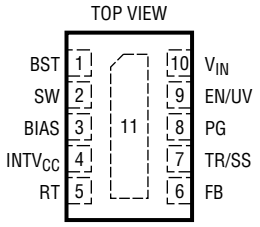


ABSOLUTE MAXIMUM RATINGS

(Note 1)

V_{IN}, EN/UV Voltage ..... –0.3V to 42V
PG Voltage ..... –0.3V to 42V
BIAS Voltage ..... –0.3V to 25V
FB, TR/SS Voltages ..... –0.3V to 4V
Operating Junction Temperature Range (Note 2)
LT8604E, LT8604I ..... –40°C to 125°C
LT8604J ..... –40°C to 150°C
Storage Temperature Range ..... –65°C to 150°C

PIN CONFIGURATION



DDBM PACKAGE
10-LEAD (3mm × 2mm) PLASTIC DFN
θ_{JA} = 76°C/W, θ_{JC} = 13.5°C/W
EXPOSED PAD (PIN 11) IS GND, MUST BE SOLDERED TO PCB

ORDER INFORMATION

Lead Free Finish

TAPE AND REEL (MINI)	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LT8604EDDBM#TRMPBF	LT8604EDDBM#TRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 125°C
LT8604IDDBM#TRMPBF	LT8604IDDBM#TRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 125°C
LT8604JDDBM#TRMPBF	LT8604JDDBM#TRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 150°C
AUTOMOTIVE PRODUCTS**				
LT8604EDDBM#WTRMPBF	LT8604EDDBM#WTRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 125°C
LT8604IDDBM#WTRMPBF	LT8604IDDBM#WTRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 125°C
LT8604JDDBM#WTRMPBF	LT8604JDDBM#WTRPBF	LHNB	10-Lead (3mm × 2mm) Plastic Side-Wettable DFN Package	–40°C to 150°C

TRM = 500 pieces. *Temperature grades are identified by a label on the shipping container.

Contact the factory for parts specified with wider operating temperature ranges.

Contact the factory for information on lead based finish parts.

Tape and reel specifications. Some packages are available in 500 unit reels through designated sales channels with #TRMPBF suffix.

**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 your local Analog Devices account representative for specific product ordering information and to obtain the specific Automotive Reliability reports for these models.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Minimum Input Voltage		●		2.9	3.2	V
V_{IN} Quiescent Current	$V_{EN/UV}$ = 0V $V_{EN/UV}$ = 2V, Not Switching	 ●		1 1.7	4 12	µA µA
V_{IN} Current in Regulation	V_{IN} = 12V, V_{OUT} = 3.3V, I_{LOAD} = 100µA V_{IN} = 12V, V_{OUT} = 3.3V, I_{LOAD} = 1mA			56 400		µA µA
Feedback Reference Voltage		●	0.762	0.778	0.798	V
FB Voltage Line Regulation	V_{IN} = 4V to 42V	●		±0.002	±0.04	%/V
FB Pin Input Current	V_{FB} = 0.8V	●			±20	nA
BIAS Pin Current Consumption	V_{BIAS} = 3.3V, I_{LOAD} = 30mA, 700kHz			0.9		mA
Minimum On-Time		●		35	65	ns
Minimum Off-Time				90	120	ns
Oscillator Frequency	R_T = 221k R_T = 18.2k	● ●	140 1.85	200 2.00	260 2.15	kHz MHz
Top Power NMOS On-Resistance				3.2		Ω
Top Power NMOS Current Limit		●	185	230	275	mA
Bottom Power NMOS On-Resistance				1.2		Ω
SW Leakage Current	V_{IN} = 24V	●			15	µA
EN/UV Pin Threshold	Pin Voltage Rising	●	0.98	1.04	1.11	V V
EN/UV Pin Hysteresis				40		mV
EN/UV Pin Current	$V_{EN/UV}$ = 2V				±20	nA
PG Upper Threshold Offset from $V_{FB/OUT}$	$V_{FB/OUT}$ Rising	●	5.0	7.5	10.0	%
PG Lower Threshold Offset from $V_{FB/OUT}$	$V_{FB/OUT}$ Falling	●	–5.0	–7.5	–10.0	%
PG Hysteresis				0.5		%
PG Leakage	V_{PG} = 42V	●			±200	nA
PG Pull-Down Resistance	V_{PG} = 0.1V			550	1200	Ω
TR/SS Source Current	$V_{TR/SS}$ = 0.1V	●	1	2	3.5	µA
TR/SS Pull-Down Resistance	Fault Condition, $V_{TR/SS}$ = 0.1V			300	900	Ω

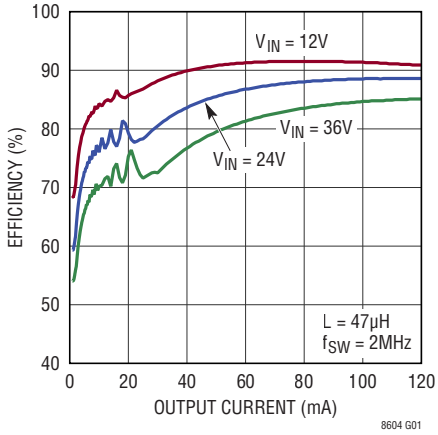
Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: The LT8604E is guaranteed to meet performance specifications from 0°C to 125°C junction temperature. Specifications over the –40°C to 125°C operating junction temperature range are assured by design, characterization and correlation with statistical process controls. The LT8604I is guaranteed over the full –40°C to 125°C operating junction temperature range. The LT8604J is guaranteed over the full –40°C to 150°C operating junction temperature range. High junction temperatures degrade operating lifetimes. Operating lifetime is derated at junction temperatures greater than 125°C.

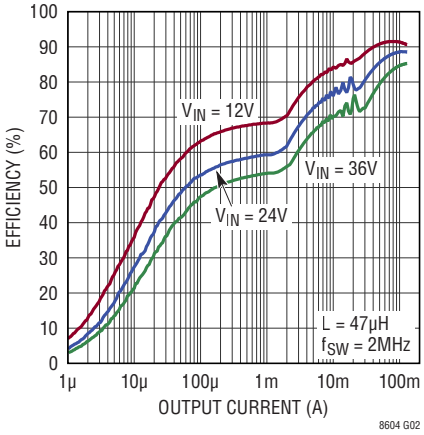
Note 3: This IC includes overtemperature protection that is intended to protect the device during overload conditions. Junction temperature will exceed 150°C when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature will reduce lifetime

TYPICAL PERFORMANCE CHARACTERISTICS

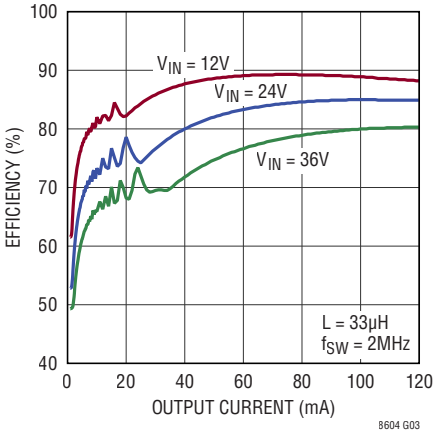
Efficiency (5V Output)



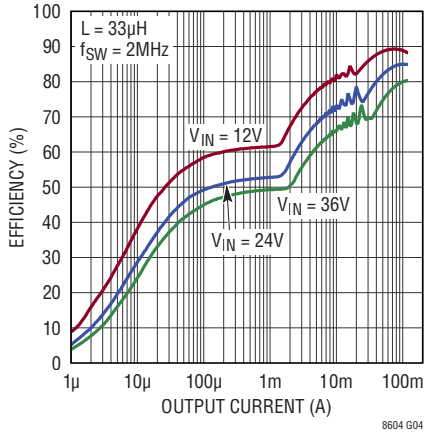
Efficiency (5V Output)



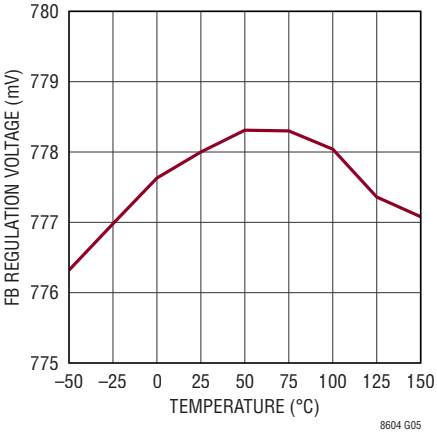
Efficiency (3.3V Output)



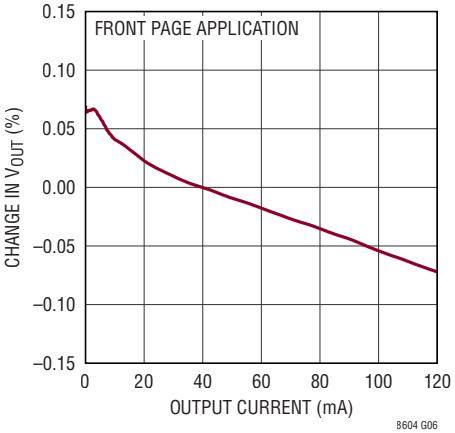
Efficiency (3.3V Output)



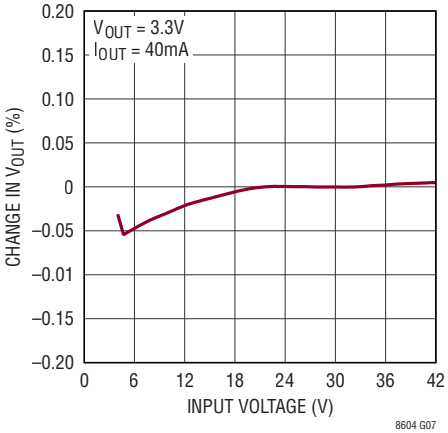
FB Voltage



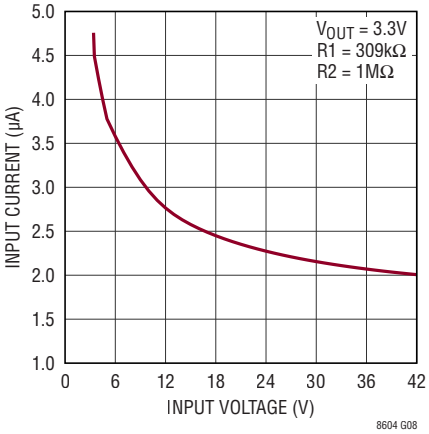
Load Regulation



Line Regulation

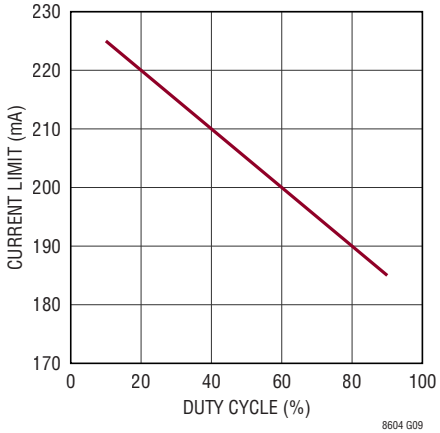


No-Load Supply Current

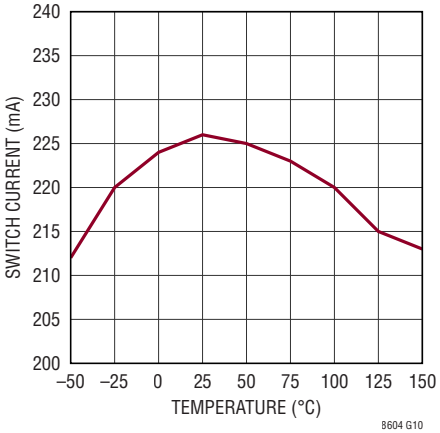


TYPICAL PERFORMANCE CHARACTERISTICS

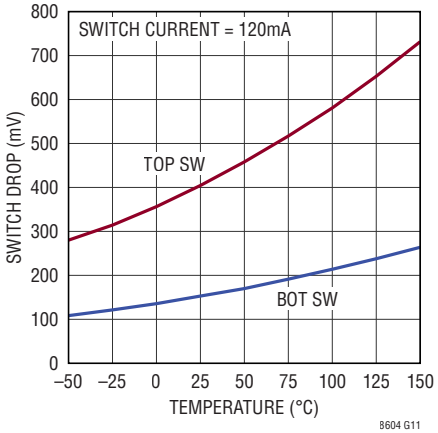
Top FET Current Limit vs Duty Cycle



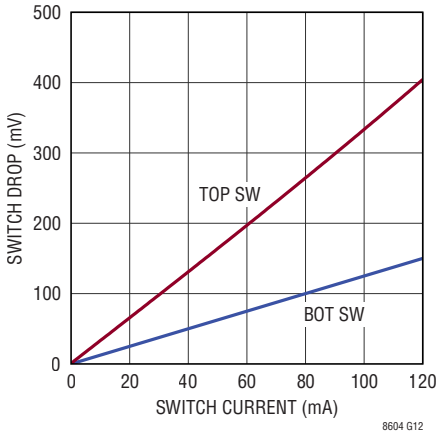
Top FET Current Limit vs Temperature



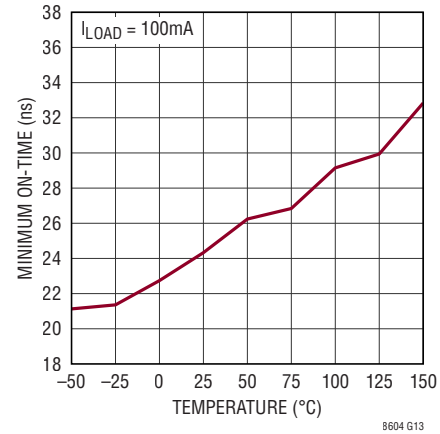
Switch Drop vs Temperature



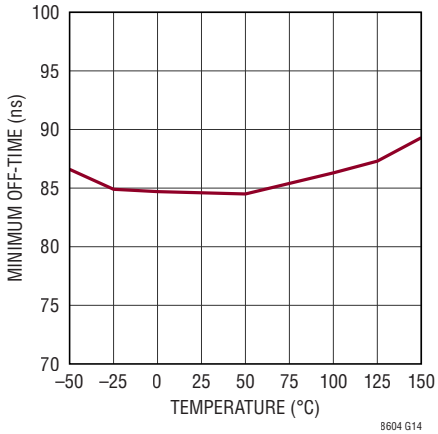
Switch Drop vs Switch Current



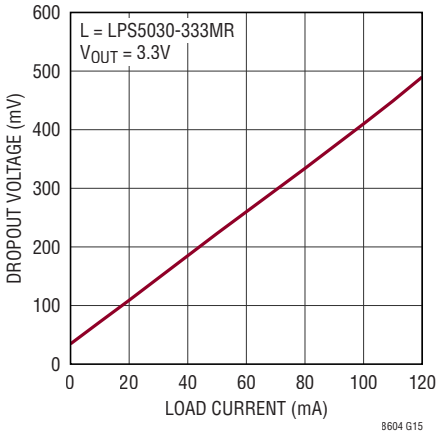
Minimum On-Time vs Temperature



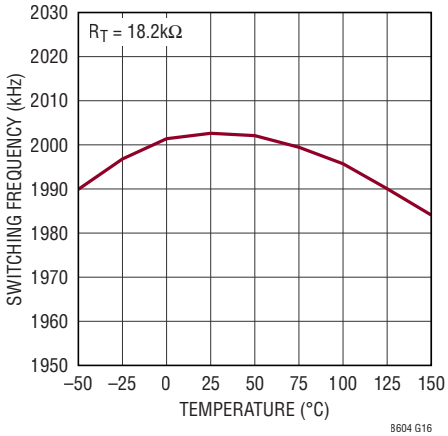
Minimum Off-Time vs Temperature



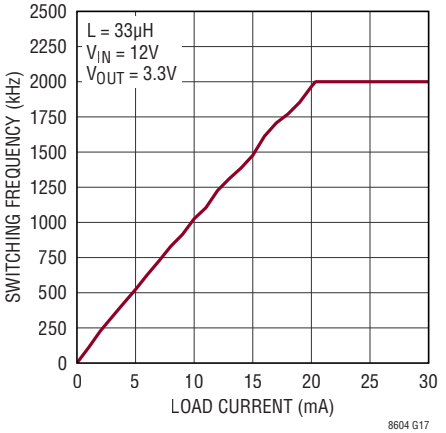
Dropout Voltage vs Load Current



Switching Frequency vs Temperature

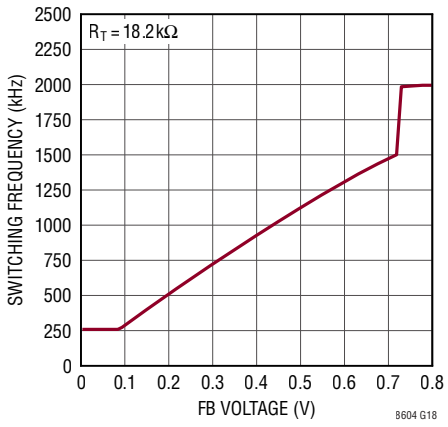


Burst Frequency vs Load Current

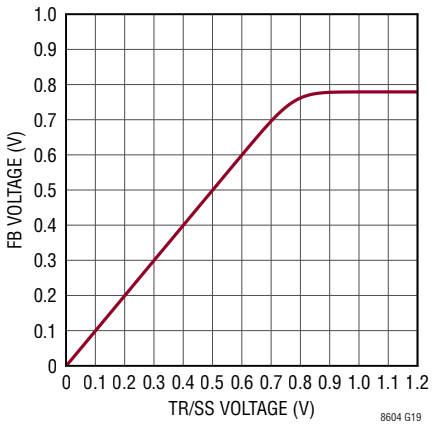


TYPICAL PERFORMANCE CHARACTERISTICS

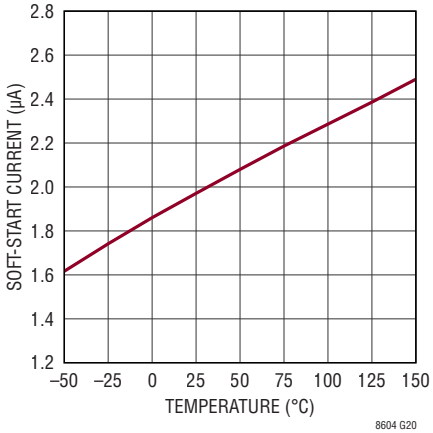
Frequency Foldback



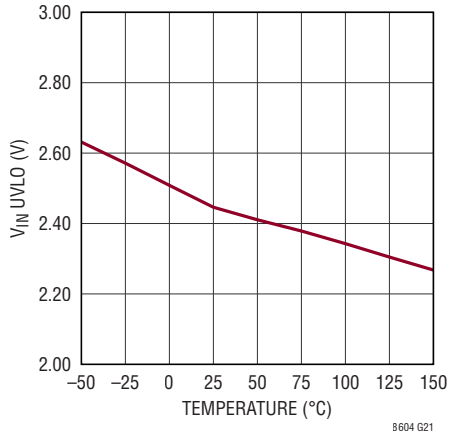
Soft-Start Tracking



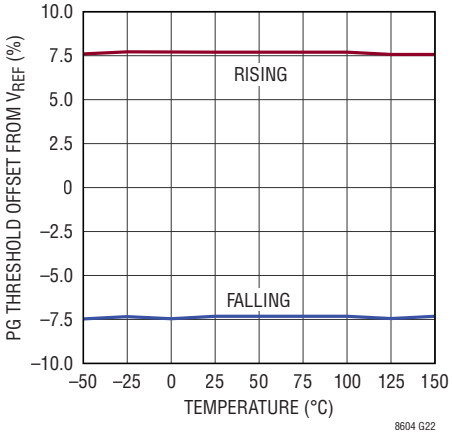
Soft-Start Current vs Temperature



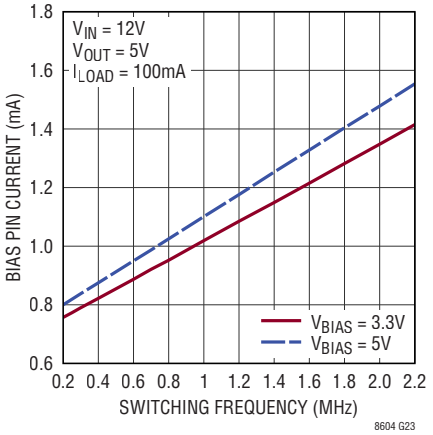
V_{IN} UVLO



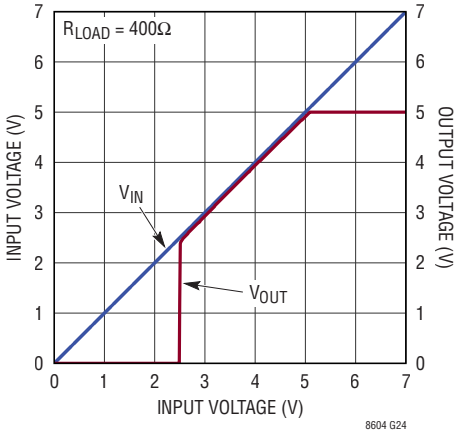
PG Thresholds



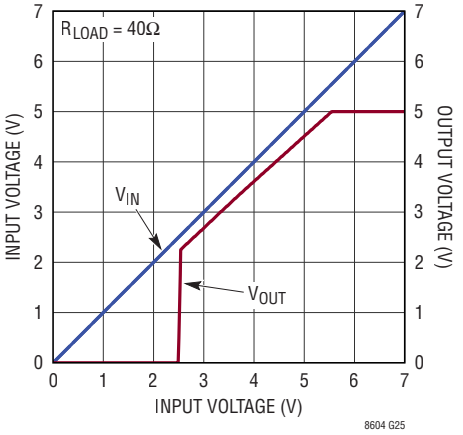
Bias Pin Current



Start-Up Dropout

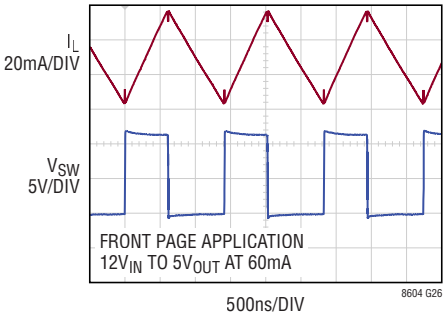


Start-Up Dropout

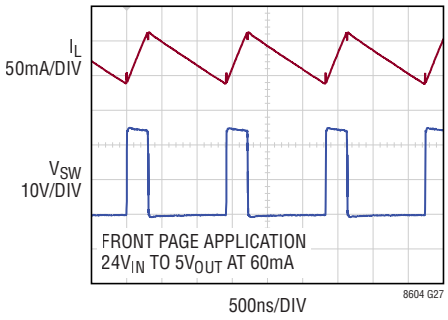


TYPICAL PERFORMANCE CHARACTERISTICS

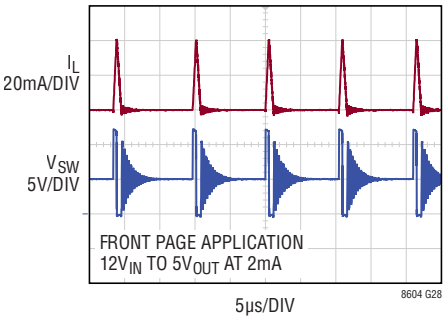
Switching Waveforms



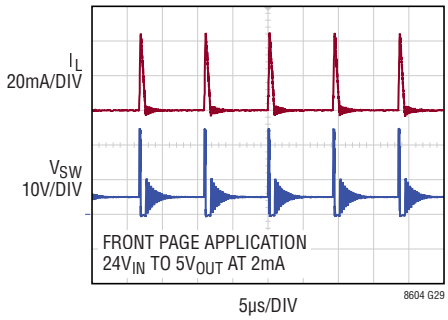
Switching Waveforms



Switching Waveforms



Switching Waveforms



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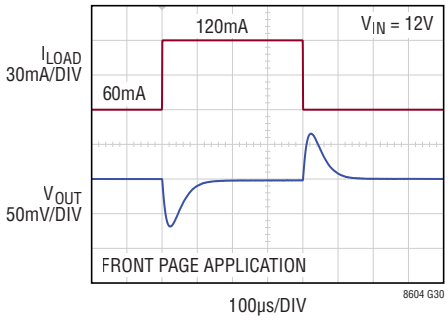
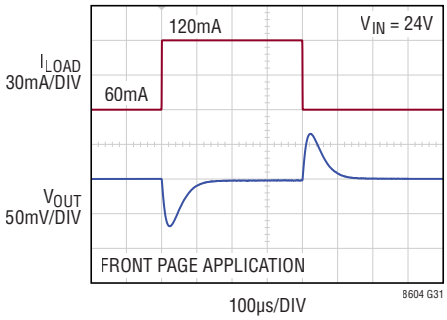


Switching Waveforms



PIN FUNCTIONS

BST (Pin 1): This pin is used to provide a drive voltage higher than the input voltage, to the topside power switch. Place a 47nF boost capacitor as close as possible to the IC. Do not put resistance in series with this pin.

SW (Pin 2): The SW pin is the output of the internal power switches. Connect this pin to the inductor. This node should be kept small on the PCB for good performance.

BIAS (Pin 3): The internal regulator will draw current from BIAS instead of V_{IN} when BIAS is tied to a voltage higher than 3.2V. 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 this pin to GND.

$INTV_{CC}$ (Pin 4): Internal 3.4V Regulator Bypass Pin. The internal power drivers and control circuits are powered from this voltage. $INTV_{CC}$ maximum output current is 2mA. Do not load the $INTV_{CC}$ pin with external circuitry. $INTV_{CC}$ current will be supplied from BIAS if BIAS > 3.2V, otherwise current will be drawn from V_{IN}. Voltage on $INTV_{CC}$ will vary between 2.8V and 3.4V when V_{BIAS} is between 3.0V and 3.6V. Decouple this pin to power ground with a low ESR ceramic capacitor of at least 1µF placed close to the IC.

RT (Pin 5): Tie a resistor between RT and ground to set the switching frequency.

FB (Pin 6): The LT8604 regulates the FB pin to 0.778V. Connect the feedback resistor divider tap to this pin.

TR/SS (Pin 7): Output Tracking and Soft-Start Pin. This pin allows user control of output voltage ramp rate during start-up. A TR/SS voltage below 0.778V forces the LT8604 to regulate the FB pin to equal the TR/SS pin voltage. When TR/SS is above 0.778V, the tracking function is disabled and the internal reference resumes control of the error amplifier. An internal 2µA pull-up current on this pin allows a capacitor to program output voltage slew rate. This pin is pulled to ground with a 300Ω MOSFET during shutdown and fault conditions; use a series resistor if driving from a low impedance output.

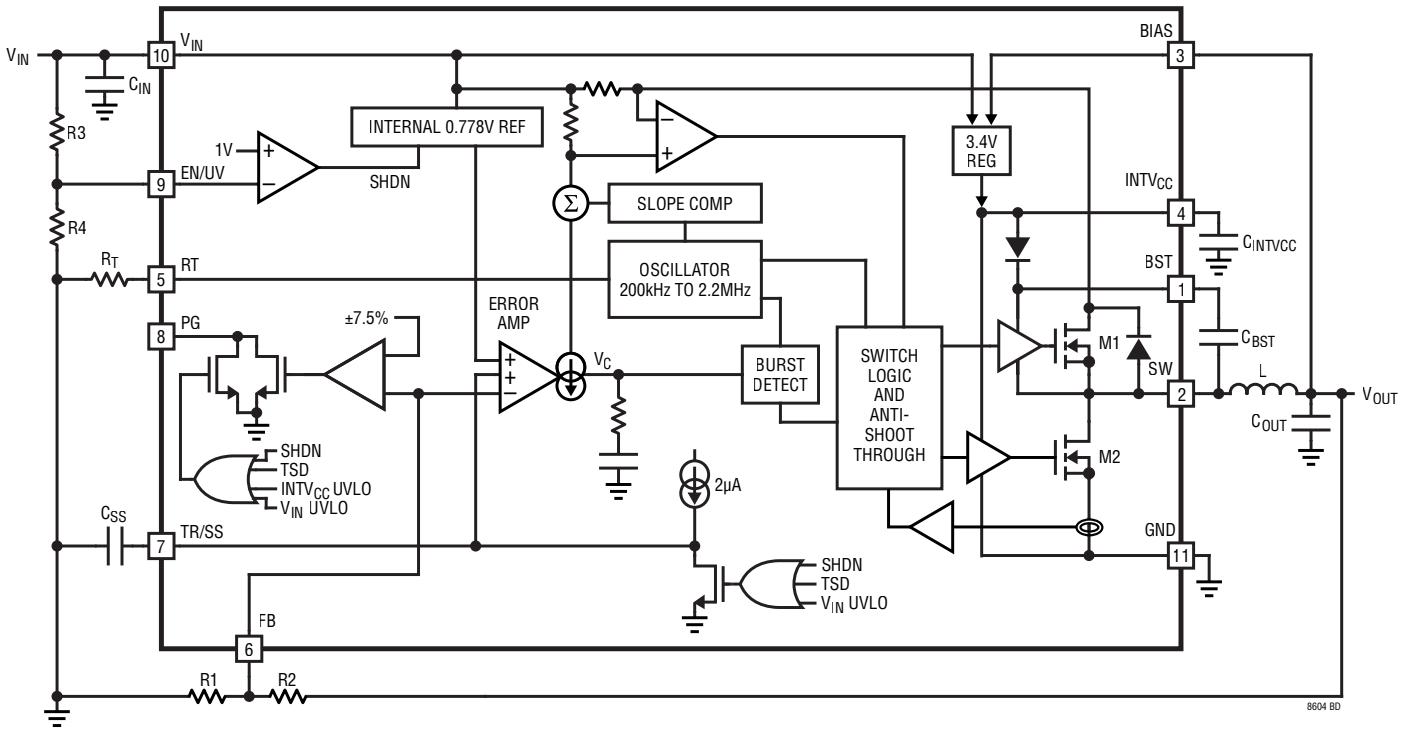
PG (Pin 8): The PG pin is the open-drain output of an internal comparator. PG remains low until the FB pin is within ±7.5% of the final regulation voltage, and there are no fault conditions. PG is valid when V_{IN} is above 3.2V, regardless of EN/UV pin state.

EN/UV (Pin 9): The LT8604 is shut down when this pin is low and active when high. The hysteretic threshold voltage is 1.05V rising and 1.00V falling. 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 LT8604 will shut down.

V_{IN} (Pin 10): The V_{IN} pin supplies current to the LT8604 internal circuitry and to the internal top side power switch. This pin must be locally bypassed. Be sure to place the positive terminal of the input capacitor as close as possible to the V_{IN} pin, and the negative capacitor terminal as close as possible to the GND pin.

GND (Exposed Pad Pin 11): Ground. The exposed pad must be connected to the negative terminal of the input capacitor and soldered to the PCB in order to lower the thermal resistance.

BLOCK DIAGRAM



OPERATION

The LT8604 is a monolithic constant-frequency current mode step-down DC/DC converter. Operation is best understood by referring to the Block Diagram. An internal oscillator turns on the integrated 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 V_C node. The error amplifier servos the V_C node by comparing the voltage on the FB pin with an internal 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 V_C 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 inductor current falls to zero. If overload conditions result in excess current flowing through the bottom switch, the next clock cycle will be delayed until switch current returns to a safe level.

To optimize efficiency, the LT8604 enters Burst Mode operation at light loads. Between bursts, all circuitry associated with controlling the output switch is shut down reducing the input supply current to 1.7µA. In a typical application with a 24V input, 2.5µA will be consumed from the input supply when regulating with no load.

To improve efficiency across all loads, supply current to internal circuitry can be sourced from the BIAS pin when biased at 3.2V or above. Else, the internal circuitry will draw current from V_{IN}. The BIAS pin should be connected to V_{OUT} if the LT8604 output is programmed to a voltage between 3.3V and 25V.

Comparators monitoring the FB pin voltage will pull the PG pin low if the output voltage varies more than ±7.5% (typical) from the set point, or if a fault condition is present.

In the LT8604, the oscillator reduces its 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.

If the EN/UV pin is low, the LT8604 is shut down and draws 1µA from the input. When the EN/UV pin is above 1.05V, the switching regulator becomes active.

APPLICATIONS INFORMATION

Achieving Ultralow Quiescent Current

To enhance efficiency at light loads, the LT8604 enters into 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 LT8604 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 LT8604 consumes 1.7µA.

As the output load decreases, the frequency of single current pulses decreases (see Figure 1) and the percentage of time the LT8604 is in sleep mode increases, resulting in much higher light load efficiency than for typical converters. By maximizing the time between pulses, the converter quiescent current approaches 2.5µA 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.

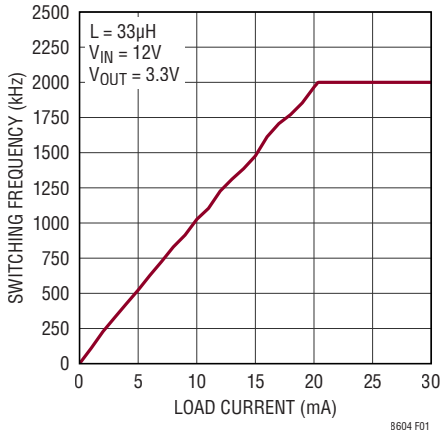


Figure 1. SW Burst Mode Frequency vs Load

While in Burst Mode operation, the current limit of the top switch is approximately 40mA resulting in output voltage ripple shown in Figure 2. As the load ramps upward from zero the switching frequency will increase but only up

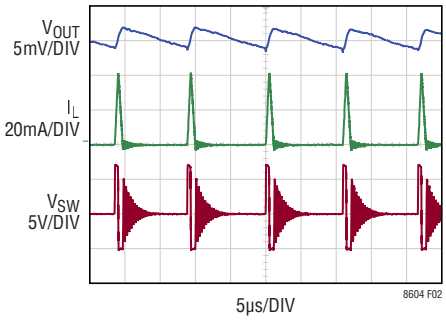


Figure 2. Burst Mode Operation

to the switching frequency programmed by the resistor at the RT pin as shown in Figure 1. The output load at which the LT8604 reaches the programmed frequency varies based on input voltage, output voltage, and inductor choice.

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:

$$R2 = R1\left(\frac{V_{OUT}}{0.778V} - 1\right)$$

1% resistors are recommended to maintain output voltage accuracy.

The total resistance of the FB resistor divider should be selected to be as large as possible when good low load efficiency is desired: The resistor divider generates a small load on the output, which should be minimized to optimize the quiescent current at low loads.

Setting the Switching Frequency

The LT8604 uses a constant frequency PWM architecture that can be programmed to switch from 200kHz to 2.2MHz by using a resistor tied from the RT pin to ground. Table 1 shows the necessary R_T value for a desired switching frequency.

APPLICATIONS INFORMATION

Table 1. SW Frequency vs RT Value

f_{SW} (MHz)	R_T (kΩ)
0.2	221
0.3	143
0.4	110
0.5	86.6
0.6	71.5
0.7	60.4
0.8	52.3
0.9	46.4
1.0	40.2
1.2	33.2
1.4	27.4
1.6	23.7
1.8	20.5
2.0	18.2
2.2	16.2

Operating Frequency Selection and Trade-Offs

Selection of 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:

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

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 (~0.38V, ~0.14V, respectively at max load) and $t_{ON(MIN)}$ is the minimum top switch on-time (see Electrical Characteristics). This equation shows that 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 Abs Max rating regardless of the RT value, however the LT8604 will reduce switching frequency as necessary to maintain control of inductor current to assure safe operation.

The LT8604 is capable of maximum duty cycle approaching 100%, and the V_{IN} to V_{OUT} dropout is limited by the $R_{DS(ON)}$ of the top switch. In this mode the LT8604 skips switch cycles, resulting in a lower switching frequency than programmed by R_T.

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

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

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 (~0.38V, ~0.14V, respectively at max load), f_{SW} is the switching frequency (set by RT), and $t_{OFF(MIN)}$ is the minimum switch off-time. Note that higher switching frequency will increase the minimum input voltage below which cycles will be dropped to achieve higher duty cycle.

Inductor Selection and Maximum Output Current

The LT8604 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 LT8604 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:

$$L = \frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}} \bullet 20$$

where f_{SW} is the switching frequency in MHz, V_{OUT} is the output voltage, $V_{SW(BOT)}$ is the bottom switch drop (~0.14V) and L is the inductor value in µH.

To avoid overheating and poor efficiency, an inductor must be chosen with an RMS current rating that is greater than the maximum expected output load of the application. In addition, the saturation current (typically labeled

APPLICATIONS INFORMATION

I_{SAT}) rating of the inductor must be higher than the load current plus 1/2 of the inductor ripple current:

$$I_{L(PEAK)} = I_{LOAD(MAX)} + \frac{1}{2}\Delta_L$$

where ΔI_L is the inductor ripple current as calculated several paragraphs below and $I_{LOAD(MAX)}$ is the maximum output load for a given application.

As a quick example, an application requiring 120mA output should use an inductor with an RMS rating of greater than 120mA and an I_{SAT} of greater than 180mA. To keep the efficiency high, the series resistance (DCR) should be less than 1Ω, and the core material should be intended for high frequency applications.

The LT8604 limits the peak switch current in order to protect the switches and the system from overload faults. The top switch current limit (I_{LIM}) is at least 185mA at low duty cycles and decreases linearly to 137mA at D = 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:

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

The peak-to-peak ripple current in the inductor can be calculated as follows:

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

where f_{SW} is the switching frequency of the LT8604, and L is the value of the inductor. Therefore, the maximum output current that the LT8604 will deliver depends on the switch current limit, the inductor value, and the 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.

For more information about maximum output current and discontinuous operation, see Analog Devices Application Note 44.

Finally, for duty cycles greater than 50%, a minimum inductance is required to avoid sub-harmonic oscillation:

$$L_{MIN} = \frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}} \bullet 12.5$$

where f_{SW} is the switching frequency, V_{OUT} is the output voltage, $V_{SW(BOT)}$ is the bottom switch drop (~0.14V) and L_{MIN} is the inductor value.

Input Capacitor

Bypass the input of the LT8604 circuit with a ceramic capacitor of X7R or X5R type. Y5V types have poor performance over temperature and applied voltage, and should not be used. A 1µF to 2.2µF ceramic capacitor is adequate to bypass the LT8604 and will easily handle the ripple current. 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.

Step-down regulators draw current from the input supply in pulses with very fast rise and fall times. The input capacitor is required to reduce the resulting voltage ripple at the LT8604 and to force this very high frequency switching current into a tight local loop, minimizing EMI. A 1µF capacitor is capable of this task, but only if it is placed close to the LT8604 (see the PCB Layout section). A second precaution regarding the ceramic input capacitor concerns the maximum input voltage rating of the LT8604. A ceramic input capacitor combined with trace or cable inductance forms a high quality (under damped) tank circuit. If the LT8604 circuit is plugged into a live supply, the input voltage can ring to twice its nominal value, possibly exceeding the LT8604's voltage rating. This situation is easily avoided (see Analog Devices 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 LT8604 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

APPLICATIONS INFORMATION

to store energy in order to satisfy transient loads and stabilize the LT8604's control loop. Ceramic capacitors have very low equivalent series resistance (ESR) and provide the best ripple performance. A good starting value is:

$$C_{OUT} = \frac{50}{V_{OUT} f_{SW}}$$

where f_{SW} is the switching frequency in MHz, V_{OUT} is the output voltage, and C_{OUT} is the recommended output capacitance in µF. Use X5R or X7R types. This choice will provide 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 will also decrease the output voltage ripple. A lower value of output capacitor can be used to save space and cost but transient performance will suffer 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 LT8604 due to their piezoelectric nature. When in Burst Mode operation, the LT8604's switching frequency depends on the load current, and at very light loads the LT8604 can excite the ceramic capacitor at audio frequencies, generating audible noise. Since the LT8604 operates at a lower current limit during Burst Mode operation, the noise is typically very quiet. If this is unacceptable, use a high performance tantalum or electrolytic capacitor at the output.

A final precaution regarding ceramic capacitors concerns the maximum input voltage rating of the LT8604. As previously mentioned, a ceramic input capacitor combined with trace or cable inductance forms a high quality (under damped) tank circuit. If the LT8604 circuit is plugged into a live supply, the input voltage can ring to twice its nominal value, possibly exceeding the LT8604's rating. This situation is easily avoided (see Analog Devices Application Note 88).

EN/UV Pin

The LT8604 is in shutdown when the EN/UV pin is low and active when the pin is high. The rising threshold of the EN/UV comparator is 1.05V, with 50mV of hysteresis. The EN/UV 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/UV programs the LT8604 to regulate the output only when V_{IN} is above a desired voltage (see Block Diagram). Typically, this threshold, $V_{IN(EN/UV)}$, 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 $V_{IN(EN/UV)}$ 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 the following equation:

$$R3 = \left(\frac{V_{IN(EN/UV)}}{1V} - 1 \right) \bullet R4$$

where the LT8604 will remain off until V_{IN} is above $V_{IN(EN/UV)}$. Due to the comparator's hysteresis, switching will not stop until the input falls slightly below $V_{IN(EN/UV)}$.

For light-load currents, the current through the $V_{IN(EN/UV)}$ resistor network can easily be greater than the supply current consumed by the LT8604. Therefore, the $V_{IN(EN/UV)}$ 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. The $INTV_{CC}$ can supply enough current for the LT8604's circuitry and must be bypassed to

APPLICATIONS INFORMATION

ground with a minimum of 1µF ceramic capacitor. Good bypassing is necessary to supply the high transient currents required by the power MOSFET gate drivers. To improve efficiency, the internal LDO can also draw current from the BIAS pin when the BIAS pin is at 3.2V or higher. Typically, the BIAS pin can be tied to the output of the LT8604 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 will consume current from V_{IN}. Applications with high input voltage and high switching frequency where the internal LDO pulls current from V_{IN} will increase die temperature because of the higher power dissipation across the LDO. Do not connect an external load to the $INTV_{CC}$ pin.

Output Voltage Tracking and Soft-Start

The LT8604 allows the user to program its output voltage ramp rate by means of the TR/SS pin. An internal 2µA pulls up the TR/SS pin to $INTV_{CC}$. Putting an external capacitor on TR/SS enables soft-starting the output to prevent current surge on the input supply. During the soft-start ramp the output voltage will proportionally track the TR/SS pin voltage. For output tracking applications, TR/SS can be externally driven by another voltage source. From 0V to 0.778V, the TR/SS voltage will override the internal 0.778V reference input to the error amplifier, thus regulating the FB pin voltage to that of TR/SS pin. When TR/SS is above 0.778V, tracking is disabled and the feedback voltage will regulate to the internal reference voltage.

An active pull-down circuit is connected to the TR/SS pin which will discharge the external soft-start capacitor in the case of fault conditions and restart 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.

Output Power Good

When the LT8604's output voltage is within the ±7.5% window of the regulation point, which is a V_{FB} voltage in the range of 0.720V to 0.836V (typical), the output voltage is considered good and the open-drain PG pin goes high impedance and is typically pulled high with an external resistor. Otherwise, the internal drain pull-down device will pull the PG pin low. To prevent glitching both the upper and lower thresholds include 0.5% of hysteresis.

The PG pin is also actively pulled low during several fault conditions: EN/UV pin is below 1V, $INTV_{CC}$ has fallen too low, V_{IN} is too low, or thermal shutdown.

Shorted and Reversed Input Protection

The LT8604 will tolerate a shorted output. Several features are used for protection during output short-circuit and brownout conditions. The first is the switching frequency will be 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 will be delayed until such time as the inductor current falls to safe levels. This allows for tailoring the LT8604 to individual applications and limiting thermal dissipation during short circuit conditions.

There is another situation to consider in systems where the output will be held high when the input to the LT8604 is absent. This may occur in battery charging applications or in battery backup systems where a battery or some other supply is diode ORed with the LT8604's output. If the V_{IN} pin is allowed to float and the EN/UV pin is held high (either by a logic signal or because it is tied to V_{IN}), then the LT8604's internal circuitry will pull its quiescent current through its SW pin. This is acceptable if the system can tolerate several µA in this state. If the EN/UV pin is grounded the SW pin current will drop to near 0.7µA. However, if the V_{IN} pin is grounded while the output is held high, regardless of EN/UV, parasitic body diodes inside the LT8604 can pull current from the output through the SW pin and the V_{IN} pin. Figure 3 shows a connection of the V_{IN} and EN/UV pins that will allow the LT8604 to run only when the input voltage is present and that protects against a shorted or reversed input.

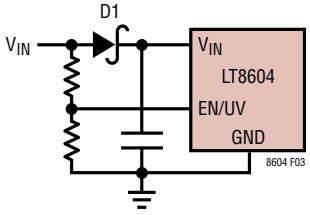


Figure 3. Reverse V_{IN} Protection

APPLICATIONS INFORMATION

PCB Layout

For proper operation and minimum EMI, care must be taken during printed circuit board layout. Figure 4 shows the recommended component placement with trace, ground plane and via locations. Note that large, switched currents flow in the LT8604's V_{IN} pins, GND pins, and the input capacitor (C_{IN}). The loop formed by the input capacitor should be as small as possible by placing the capacitor adjacent to the V_{IN} and GND pins. When using a physically large input capacitor the resulting loop may become too large in which case using a small case/value capacitor placed close to the V_{IN} and GND pins plus a larger capacitor further away is preferred. These components, along with the inductor and output capacitor, 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 will shield them from the SW and BOOST nodes. The exposed pad on the bottom of the package must be soldered to ground so that the pad is connected to ground electrically and also acts as a heat sink thermally. To keep thermal resistance low, extend the ground plane as much as possible, and add thermal vias near the LT8604 to additional ground planes within the circuit board and on the bottom side.

Figure 4 shows the basic guidelines for a layout example.

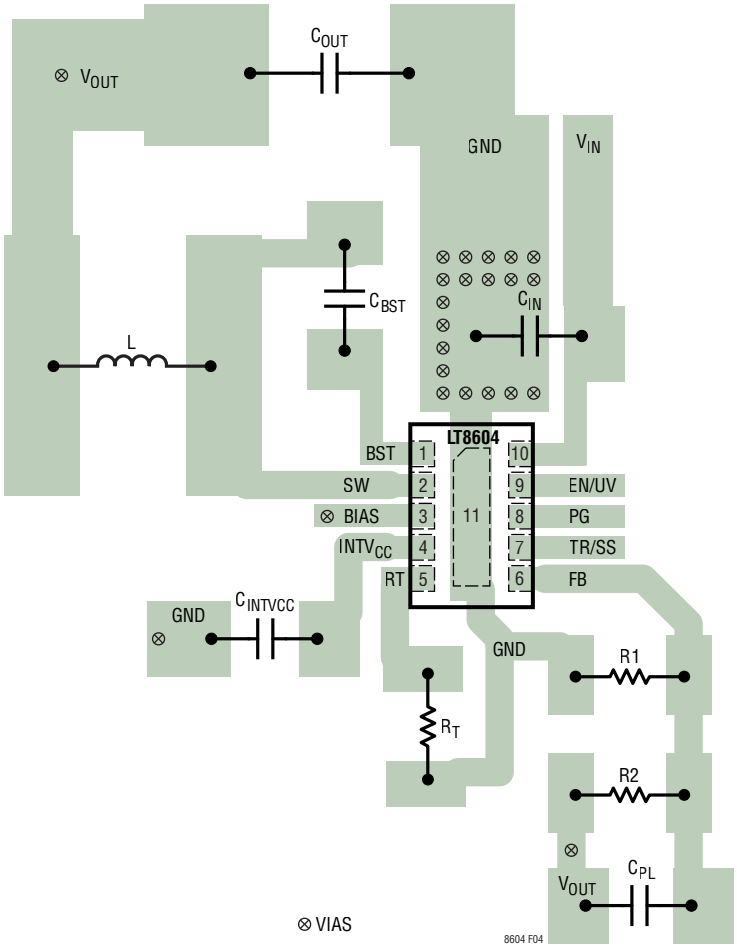
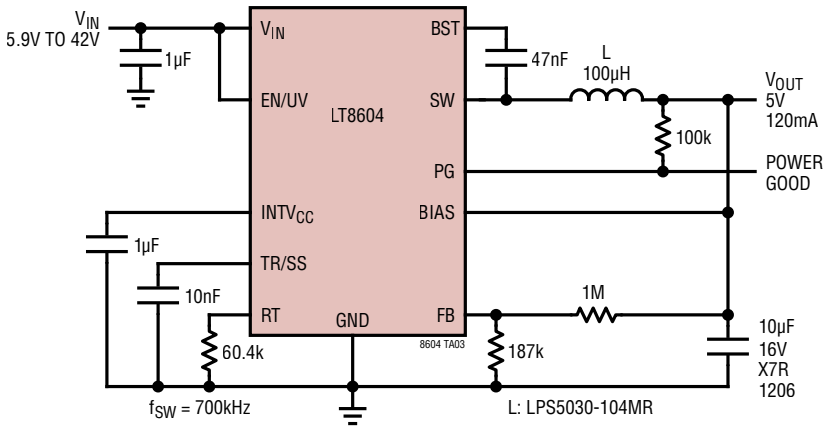


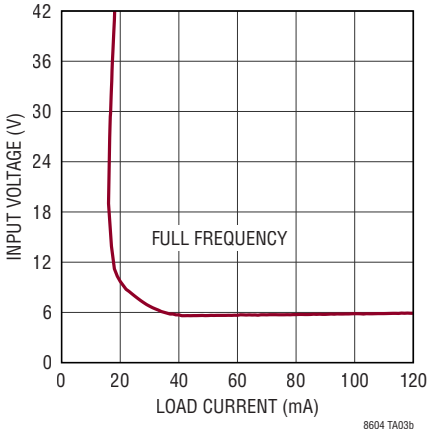
Figure 4. Recommended PCB Layout (Not to Scale)

TYPICAL APPLICATIONS

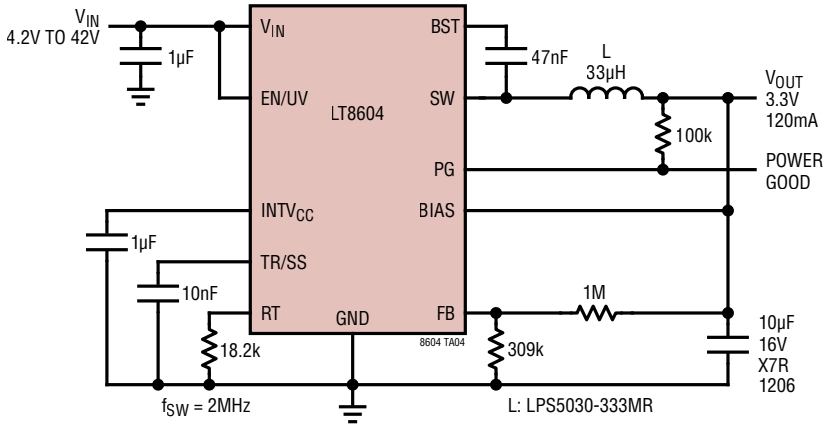
5V Step-Down Converter



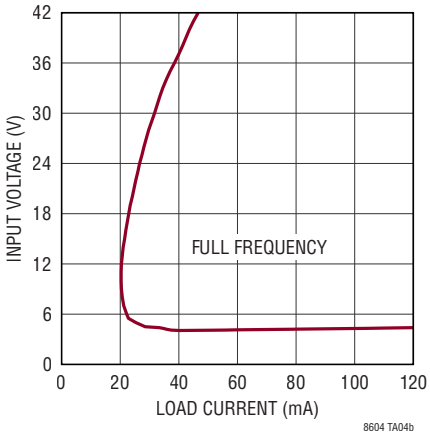
Typical Performance Minimum Load to Full Frequency



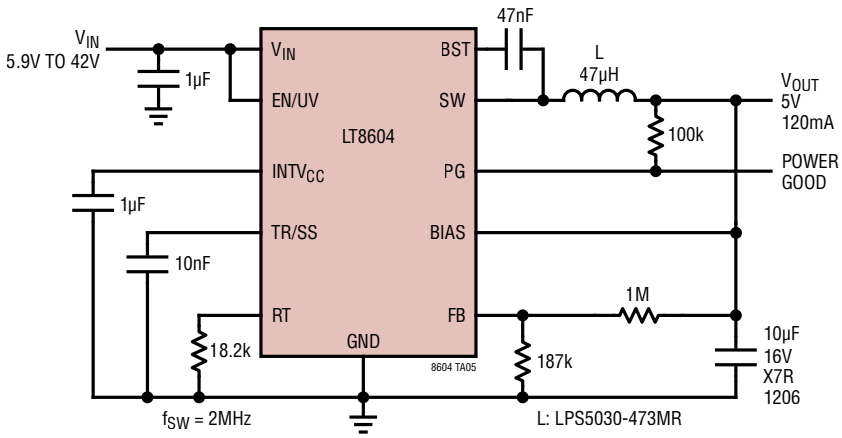
3.3V 2MHz Step-Down Converter



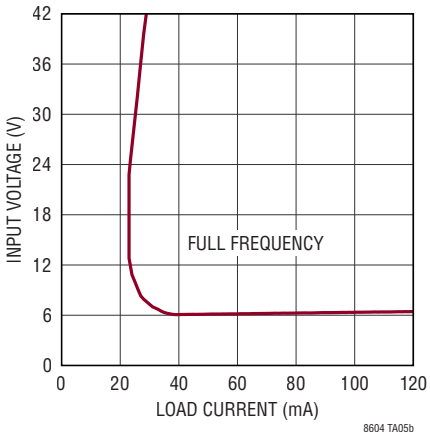
Typical Performance Minimum Load to Full Frequency



5V 2MHz Step-Down Converter

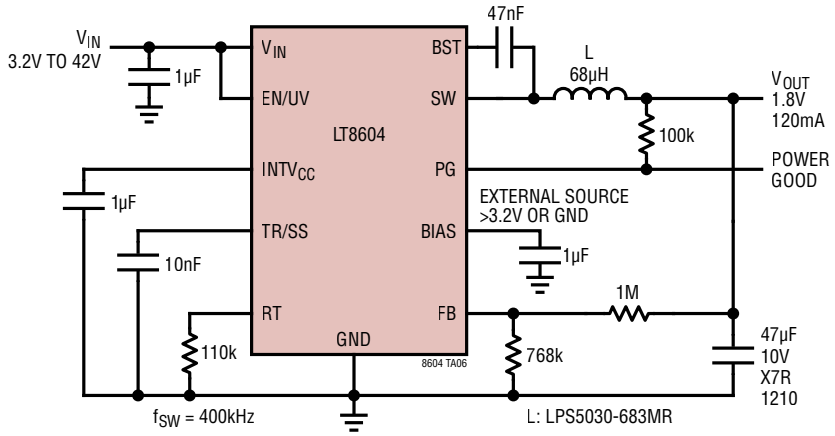


Typical Performance Minimum Load to Full Frequency

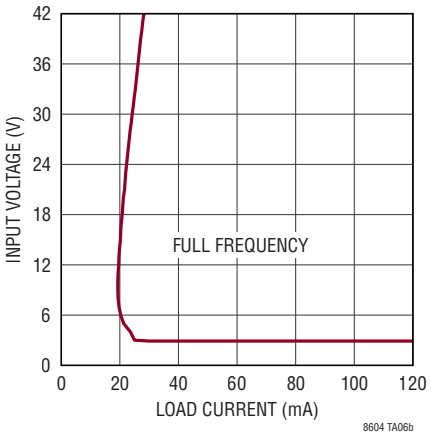


TYPICAL APPLICATIONS

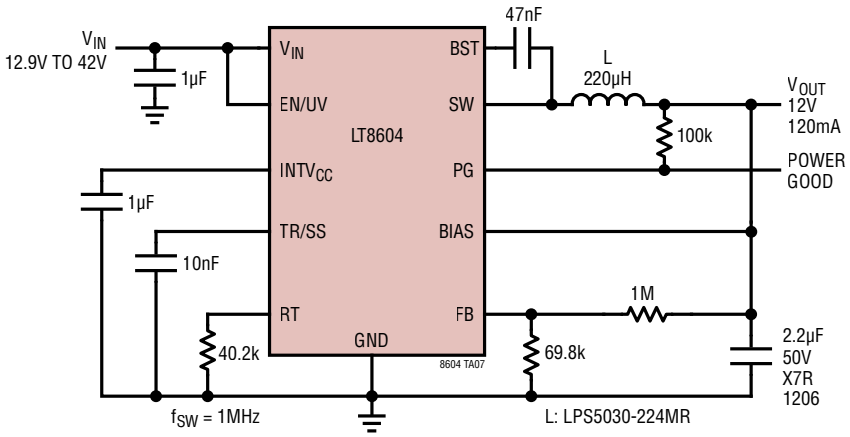
1.8V Step-Down Converter



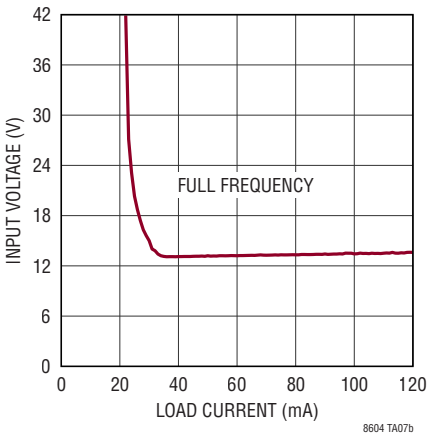
Typical Performance Minimum Load to Full Frequency



12V Step-Down Converter

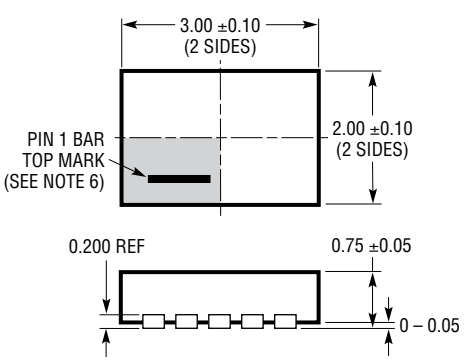


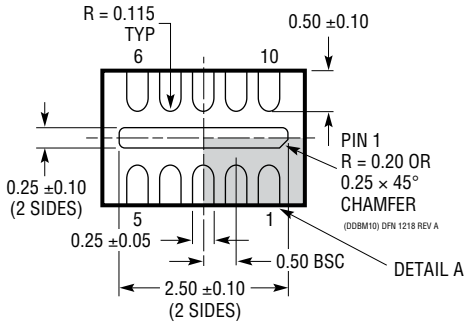
Typical Performance Minimum Load to Full Frequency



PACKAGE DESCRIPTION

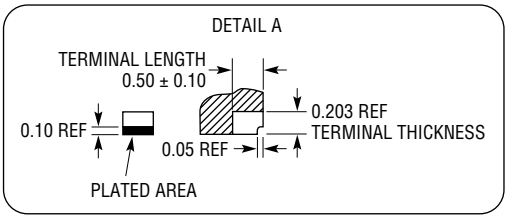
DDBM Package
10-Lead Plastic SIDE WETTABLE DFN (3mm × 2mm)
(Reference LTC DWG # 05-08-1655 Rev A)

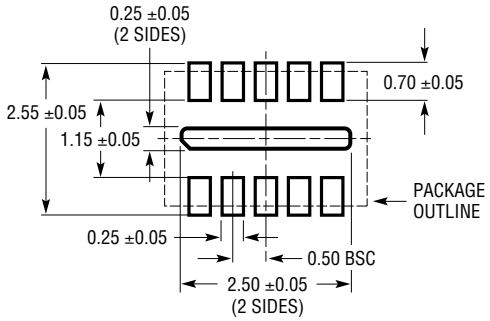




BOTTOM VIEW—EXPOSED PAD

NOTE:
1. DRAWING CONFORMS TO VERSION (WECD-1) IN JEDEC PACKAGE OUTLINE M0-229
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE

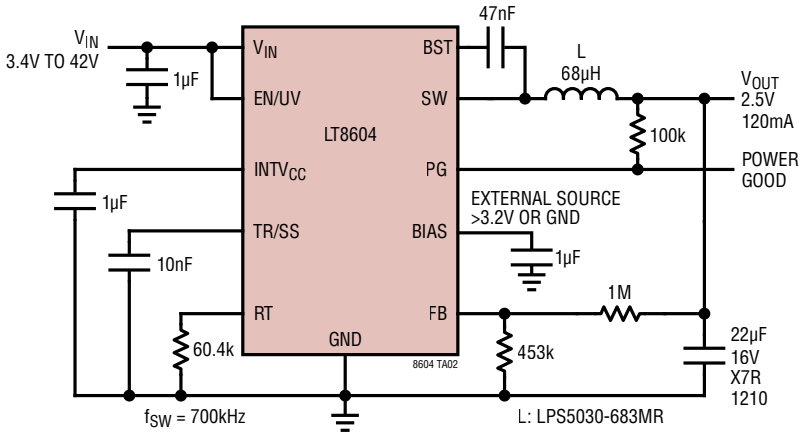




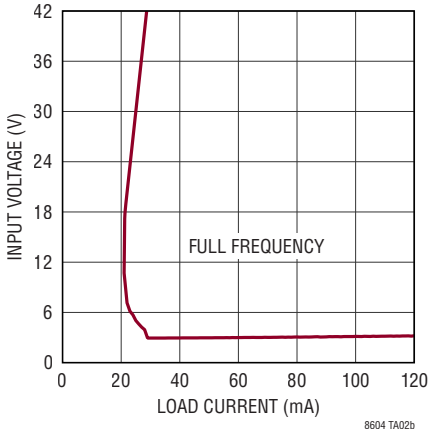
RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

TYPICAL APPLICATION

2.5V Step-Down Converter



Typical Performance Minimum Load to Full Frequency



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT8618	65V 100mA, 90% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	V_{IN} = 3.4V to 60V (65V abs max), $V_{OUT(MIN)}$ = 0.778V, I_Q = 2.5µA, I_{SD} < 1µA, 2mm × 3mm DFN-10 Package
LT8609/ LT8609A	42V, 2A/3A Peak, 93% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	V_{IN} = 3.2V to 42V, $V_{OUT(MIN)}$ = 0.8V, I_Q = 2.5µA, I_{SD} < 1µA, MSOP-10E Package
LT8610A/ LT8610AB	42V, 3.5A, 96% Efficiency, 2.2MHz 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, I_{SD} < 1µA, MSOP-16E Package
LT8610AC	42V, 3.5A, 96% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$ = 0.8V, I_Q = 2.5µA, I_{SD} < 1µA, MSOP-16E Package
LT8610	42V, 2.5A, 96% Efficiency, 2.2MHz 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, I_{SD} < 1µA, MSOP-16E Package
LT8611	42V, 2.5A, 96% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA and Input/Output Current Limit/Monitor	V_{IN} = 3.4V to 42V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, I_{SD} < 1µA, 3mm × 5mm QFN-24 Package
LT8616	42V, Dual 2.5A + 1.5A, 95% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 5µA	V_{IN} = 3.4V to 42V, $V_{OUT(MIN)}$ = 0.8V, I_Q = 5µA, I_{SD} < 1µA, TSSOP-28E, 3mm × 6mm QFN-28 Packages
LT8620	65V, 2.5A, 96% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 2.5µA	V_{IN} = 3.4V to 65V, $V_{OUT(MIN)}$ = 0.97V, I_Q = 2.5µA, I_{SD} < 1µA, MSOP-16E, 3mm × 5mm QFN-24 Packages
LT8614	42V, 4A, 96% Efficiency, 2.2MHz 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, I_{SD} < 1µA, 3mm × 4mm QFN-18 Package
LT8612	42V, 6A, 96% Efficiency, 2.2MHz 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 = 3.0µA, I_{SD} < 1µA, 3mm × 6mm QFN-28 Package
LT8640	42V, 5A/7A Peak, 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, I_{SD} < 1µA, 3mm × 4mm QFN-18 Package
LT8602	42V, Quad Output (2.5A+1.5A+1.5A+1.5A) 95% Efficiency, 2.2MHz Synchronous MicroPower Step-Down DC/DC Converter with I_Q = 25µA	V_{IN} = 3V to 42V, $V_{OUT(MIN)}$= 0.8V, I_Q = 25µA, I_{SD} < 1µA, 6mm × 6mm QFN-40 Package

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