The LTC3423 and LTC3424 are high efficiency, fixed frequency, step-up DC/DC converters that can regulate output voltages as low as 1.5V from a single cell. An applied voltage of at least 2.7V to the VDD pin is required to power the internal control circuitry.

The devices include a 0.16W N-channel MOSFET switch and a 0.21W P-channel synchronous rectifier. The LTC3423 is intended for applications requiring less than 0.75W of output power and the LTC3424 for 1.5W or less. Switching frequencies up to 3MHz are programmed with an external timing resistor and the oscillator can be synchronized to an external clock.

Quiescent current is only 38μA in Burst Mode operation, maximizing battery life in portable applications. Burst Mode operation is user controlled and can be enabled by driving the MODE/SYNC pin high. If the MODE/SYNC pin has either a clock or is driven low then the operation is at constant fixed frequency.

Other features include a 1μA shutdown, thermal shutdown and current limit. The LTC3423 and LTC3424 are available in the 10-pin MSOP package. For applications requiring an output voltage greater than 2.6V, the LTC3401 and LTC3402 are recommended without the need of a separate voltage for the VDD pin.
### Absolute Maximum Ratings

**V\textsubscript{IN}, V\textsubscript{OUT}, V\textsubscript{DD} Voltages**

\(-0.5\text{V} to 6\text{V}\)

**SW Voltage**

\(-0.5\text{V} to 6\text{V}\)

**V\textsubscript{C}, R\textsubscript{t} Voltages**

\(-0.5\text{V} to (V\textsubscript{OUT} + 0.3\text{V})\)

**SHDN, FB, MODE Voltages**

\(-0.5\text{V} to 6\text{V}\)

**Operating Temperature Range**

\(-40\text{°C} to 85\text{°C}\)

**Storage Temperature Range**

\(-65\text{°C} to 125\text{°C}\)

**Lead Temperature**

(Soldering, 10 sec)\(.................300\text{°C}\)

### Package/Order Information

<table>
<thead>
<tr>
<th>ORDER PART NUMBER</th>
<th>LTC3423EMS</th>
<th>LTC3424EMS</th>
</tr>
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<tbody>
<tr>
<td>MS PACKAGE MARKING</td>
<td>MS PACKAGE</td>
<td>MS PACKAGE</td>
</tr>
<tr>
<td>LTC3423EMS</td>
<td>LTC3424EMS</td>
<td></td>
</tr>
<tr>
<td>LTQM</td>
<td>LTQN</td>
<td></td>
</tr>
</tbody>
</table>

Consult LTC Marketing for parts specified with wider operating temperature ranges.

### Electrical Characteristics

The \(\bullet\) denotes specifications that apply over the full operating temperature range, otherwise specifications are at \(T\textsubscript{A} = 25\text{°C}\).

\(V\textsubscript{IN} = 1.2\text{V}, V\textsubscript{DD} = 3.3\text{V}, V\textsubscript{OUT} = 1.8\text{V},\) unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V\textsubscript{DD}) Input Voltage Range</td>
<td>2.7 5.5 V</td>
</tr>
<tr>
<td>(V\textsubscript{IN}) Operating Voltage Range</td>
<td>0.5 5.5 V</td>
</tr>
<tr>
<td>Output Voltage Adjust Range</td>
<td>1.5 5.5 V</td>
</tr>
<tr>
<td>Feedback Voltage</td>
<td>1.22 1.25 1.28 V</td>
</tr>
<tr>
<td>Feedback Input Current</td>
<td>1 50 nA</td>
</tr>
<tr>
<td>Quiescent Current—Burst Mode Operation</td>
<td>1 50 nA</td>
</tr>
<tr>
<td>Quiescent Current—SHDN</td>
<td>0.1 1 μA</td>
</tr>
<tr>
<td>Quiescent Current—Active</td>
<td>440 800 μA</td>
</tr>
<tr>
<td>NMOS Switch Leakage</td>
<td>0.1 5 μA</td>
</tr>
<tr>
<td>PMOS Switch Leakage</td>
<td>0.1 10 μA</td>
</tr>
<tr>
<td>NMOS Switch On Resistance</td>
<td>0.16 Ω</td>
</tr>
<tr>
<td>PMOS Switch On Resistance</td>
<td>0.21 Ω</td>
</tr>
<tr>
<td>NMOS Current Limit</td>
<td>LTC3423 1 1.6 A</td>
</tr>
<tr>
<td>LTC3424 2 2.8 A</td>
<td></td>
</tr>
<tr>
<td>Maximum Duty Cycle</td>
<td>80 85 %</td>
</tr>
<tr>
<td>Minimum Duty Cycle</td>
<td>0 %</td>
</tr>
<tr>
<td>Frequency Accuracy</td>
<td>1.6 2 2.4 MHz</td>
</tr>
<tr>
<td>MODE/SYNC Input High</td>
<td>1.4 V</td>
</tr>
<tr>
<td>MODE/SYNC Input Low</td>
<td>0.4 V</td>
</tr>
<tr>
<td>MODE/SYNC Input Current</td>
<td>(V\textsubscript{MODE/SYNC} = 5.5\text{V}) 0.01 1 μA</td>
</tr>
<tr>
<td>Error Amp Transconductance</td>
<td>(\Delta I = -5μ\text{A} to 5μ\text{A}, V\textsubscript{C} = V\textsubscript{FB}) 85 μmhos</td>
</tr>
</tbody>
</table>
**ELECTRICAL CHARACTERISTICS**

The ● denotes specifications that apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ\text{C}$.

$V_{IN} = 1.2\text{V}, \; V_{OUT} = 3.3\text{V}$ unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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</thead>
<tbody>
<tr>
<td>SHDN Input High</td>
<td>$V_{SHDN} = V_{IN} = V_{OUT}$</td>
<td>1</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>SHDN Input Low</td>
<td></td>
<td></td>
<td>0.4</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>SHDN Input Current</td>
<td>$V_{SHDN} = 5.5\text{V}$</td>
<td>0.01</td>
<td></td>
<td>1</td>
<td>$\mu\text{A}$</td>
</tr>
</tbody>
</table>

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** The LTC3423/LTC3424 are guaranteed to meet performance specifications from $0^\circ\text{C}$ to $70^\circ\text{C}$. Specifications over the $-40^\circ\text{C}$ to $85^\circ\text{C}$ operating temperature range are assured by design, characterization and correlation with statistical process controls.

**Note 3:** Current is measured into $V_{DD}$ since the supply current is bootstrapped to the $V_{DD}$ pin. The outputs are not switching.

**Note 4:** Once the output is started, the IC is not dependant upon the $V_{IN}$ supply.

---

**TYPICAL PERFORMANCE CHARACTERISTICS**

**Switching Waveform on SW Pin**

$V_{LOAD} = 500\text{mA}$

$I_{OUT} = 150\text{mA}$ to $450\text{mA}$

$V_{OUT} = 1.8\text{V}$

$C_{OUT} = 44\text{mF}$

$f_{OSC} = 1\text{MHz}$

**Transient Response 150mA to 450mA**

$V_{OUT}$

$C_{OUT} = 44\text{mF}$

$L = 2.2\mu\text{H}$

$f_{OSC} = 1\text{MHz}$

**Burst Mode Operation at 500mA Load**

$V_{IN} = 1.2\text{V}$

$V_{OUT} = 1.8\text{V}$

$C_{OUT} = 44\text{mF}$

MODE/SYNC PIN = HIGH

**Burst Mode Operation at 10mA Load**

$V_{IN} = 1.2\text{V}$

$V_{OUT} = 1.8\text{V}$

$C_{OUT} = 44\text{mF}$

MODE/SYNC PIN = HIGH
TYPICAL PERFORMANCE CHARACTERISTICS

Converter Efficiency 1.2V to 1.8V

LTC3424 Current Limit

LTC3423 Current Limit

EA FB Voltage

Oscillator Frequency Accuracy

NMOS R_{DS(ON)}

Efficiency Loss Without Schottky vs Frequency

PMOS R_{DS(ON)}

TEMPERATURE (°C)

VOLTAGE (V)

RESISTANCE (Ω)

FREQUENCY (MHz)

CURRENT (A)

EFFICIENCY (%)
TYPICAL PERFORMANCE CHARACTERISTICS

PIN FUNCTIONS

Rt (Pin 1): Timing Resistor to Program the Oscillator Frequency.

\[ f_{\text{osc}} = \frac{3 \times 10^{10}}{R_t} \text{ Hz} \]

MODE/SYNC (Pin 2): Burst Mode Select and Oscillator Synchronization.

- MODE/SYNC = High. Enable Burst Mode operation. The inductor peak inductor current will be 400mA and return to zero current on each cycle. During Burst Mode operation the operation is variable frequency, providing a significant efficiency improvement at light loads. It is recommended the Burst Mode operation only be entered once the part has started up.
- MODE/SYNC = Low. Disable Burst Mode operation and maintain low noise, constant frequency operation.
- MODE/SYNC = External CLK. Synchronization of the internal oscillator and Burst Mode operation disable. A clock pulse width of 100ns to 2μs is required to synchronize.

VIN (Pin 3): Voltage Sense for Internal Circuitry.

SW (Pin 4): Switch Pin. Connect inductor and optional Schottky diode here. Minimize trace length to keep EMI down.

GND (Pin 5): Signal and Power Ground for the IC.

VDD (Pin 6): Power Source for the IC. Typically derived from a higher voltage power converter. Requires an input of 2.7V to 5.5V. A 2.2μF ceramic bypass capacitor is recommended as close to the pins as possible.

VOUT (Pin 7): Output of the Synchronous Rectifier.

FB (Pin 8): Feedback Pin. Connect resistor divider tap here. The output voltage can be adjusted from 1.5V to 5.5V. The feedback reference voltage is typically 1.25V.

VC (Pin 9): Error Amp Output. A frequency compensation network is connected to this pin to compensate the loop. See the section “Compensating the Feedback Loop” for guidelines.

SHDN (Pin 10): Shutdown. Grounding this pin shuts down the IC. Tie to >1V to enable (VDD or digital gate output). During shutdown the output voltage will hold up to VIN minus a diode drop due to the body diode of the PMOS synchronous switch. If the application requires a complete disconnect during shutdown then refer to section “Output Disconnect”.

Shutdown Threshold

Burst Mode Operation Current
APPLICATIONS INFORMATION

DETAILED DESCRIPTION

The LTC3423/LTC3424 provides high efficiency, low noise power for applications such as portable instrumentation and are ideal for applications that require an output voltage between 1.5V and 2.6V from a single cell. These products are an addition to the LTC3401 and LTC3402 family of synchronous boost converters, with the differences being the omission of the power good function (PGOOD) and the addition of a V\text{DD} input to provide internal power. The IC will not start up until the applied voltage on the V\text{DD} pin is above 2.7V.

The current mode architecture with adaptive slope compensation provides ease of loop compensation with excellent transient load response. The low R\text{DS(ON)}, low gate charge synchronous switches provides the pulse width modulation control at high efficiency.

Zero Current Amp. The zero current amplifier monitors the inductor current to the output and shuts off the synchronous rectifier once the current is below 50mA, preventing negative inductor current.

Burst Mode Operation

Burst Mode operation is when the IC delivers energy to the output until it is regulated and then goes into a sleep mode where the outputs are off and the IC is consuming only 38\(\mu\)A. In this mode, the output ripple has a variable frequency component with load current and the steady state ripple will be typically below 3%.

During the period where the device is delivering energy to the output, the peak current will be equal to 400mA and the inductor current will terminate at zero current for each cycle. In this mode the maximum output current is given by:

\[
I_{\text{OUT(MAXBURST)}} = \frac{V_{\text{IN}}}{6 \cdot V_{\text{OUT}}} \text{Amps}
\]

Burst Mode operation is user controlled by driving the MODE/SYNC pin high to enable and low to disable. It is recommended that Burst Mode operation be entered after the part has started up.

COMPONENT SELECTION

Inductor Selection

The high frequency operation of the LTC3423/LTC3424 allows the use of small surface mount inductors. The minimum inductance value is proportional to the operating frequency and is limited by the following constraints:

\[
L > \frac{k}{f} \mu\text{H} \quad \text{and} \quad L > \frac{V_{\text{IN(MIN)}} \cdot \left(V_{\text{OUT(MAX)}} - V_{\text{IN(MIN)}}\right)}{f \cdot \text{Ripple} \cdot V_{\text{OUT(MAX)}}} \text{H}
\]

where

\[
k = 3 \text{ for LTC3423, 2 for LTC3424}
\]

\[
f = \text{Operating Frequency} \ (\text{Hz})
\]

\[
\text{Ripple} = \text{Allowable Inductor Current Ripple} \ (\text{A})
\]

\[
V_{\text{IN(MIN)}} = \text{Minimum Input Voltage} \ (\text{V})
\]

\[
V_{\text{OUT(MAX)}} = \text{Maximum Output Voltage} \ (\text{V})
\]
The inductor current ripple is typically set to 20% to 40% of the maximum inductor current.

For high efficiency, choose an inductor with a high frequency core material, such as ferrite, to reduce core losses. The inductor should have low ESR (equivalent series resistance) to reduce the I^2R losses and must be able to handle the peak inductor current at full load without saturating. Molded chokes or chip inductors usually do not have enough core to support the peak inductor currents in the 1A to 2A region. To minimize radiated noise, use a toroid, pot core or shielded bobbin inductor. See Table 1 for a list of component suppliers.

Table 1. Inductor Vendor Information

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PHONE</th>
<th>FAX</th>
<th>WEBSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coilcraft</td>
<td>(847) 639-6400</td>
<td>(847) 639-1469</td>
<td><a href="http://www.coilcraft.com">www.coilcraft.com</a></td>
</tr>
<tr>
<td>Coiltronics</td>
<td>(516) 241-7876</td>
<td>(516) 241-9339</td>
<td><a href="http://www.coiltronics.com">www.coiltronics.com</a></td>
</tr>
<tr>
<td>Murata</td>
<td>(814) 237-1431</td>
<td>(800) 831-9172</td>
<td><a href="http://www.murata.com">www.murata.com</a></td>
</tr>
<tr>
<td>Sumida USA:</td>
<td>(847) 956-0666</td>
<td>(847) 956-0702</td>
<td><a href="http://www.japanlink.com">www.japanlink.com</a></td>
</tr>
<tr>
<td>Sumida Japan:</td>
<td>81-3-3607-5111</td>
<td>81-3-3607-5144</td>
<td>sumida</td>
</tr>
</tbody>
</table>

The ESR is usually the most dominant factor for ripple in most power converters. The ripple due to capacitor ESR is simply given by:

\[ V_{R_{CESR}} = I_P \cdot R_{ESR} \text{ Volts} \]

where

\[ R_{ESR} = \text{Capacitor Series Resistance} \]

Low ESR capacitors should be used to minimize output voltage ripple. For surface mount applications, AVX TPS series tantalum capacitors and Sanyo POSCAP or Taiyo-Yuden ceramic capacitors are recommended. For through-hole applications Sanyo OS-CON capacitors offer low ESR in a small package size. See Table 2 for a list of component suppliers.

Table 2. Capacitor Vendor Information

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PHONE</th>
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<th>WEBSITE</th>
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<tbody>
<tr>
<td>AVX</td>
<td>(803) 440-9411</td>
<td>(803) 448-1943</td>
<td><a href="http://www.avxcorp.com">www.avxcorp.com</a></td>
</tr>
<tr>
<td>Sanyo</td>
<td>(619) 661-6322</td>
<td>(619) 661-1055</td>
<td><a href="http://www.sanyovideo.com">www.sanyovideo.com</a></td>
</tr>
<tr>
<td>Taiyo Yuden</td>
<td>(408) 573-4150</td>
<td>(408) 573-4159</td>
<td><a href="http://www.t-yuden.com">www.t-yuden.com</a></td>
</tr>
</tbody>
</table>

Input Capacitor Selection

The input filter capacitor reduces peak currents drawn from the input source and reduces input switching noise. In most applications a 3.3 \( \mu F \) is sufficient.

Output Diode

The Schottky diode across the synchronous PMOS switch is not required, but provides a lower drop during the break-before-make time (typically 20ns) of the NMOS to PMOS transition. The addition of the Schottky diode will improve peak efficiency (see graph “Efficiency Loss Without Schottky vs Frequency”). Use of a Schottky diode such as a MBRM120T3, 1N5817 or equivalent. Since slow recovery times will compromise efficiency, do not use ordinary rectifier diodes.
Applications Information

Operating Frequency Selection

There are several considerations in selecting the operating frequency of the converter. The first is determining the sensitive frequency bands that cannot tolerate any spectral noise. For example, in products incorporating RF communications, the 455kHz IF frequency is sensitive to any noise, therefore switching above 600kHz is desired. Some communications have sensitivity to 1.1MHz. In this case, converter frequencies up to 3MHz may be employed.

The second consideration is the physical size of the converter. As the operating frequency goes up, the inductor and filter caps go down in value and size. The trade off is in efficiency since the switching losses due to gate charge are going up proportional with frequency.

Another operating frequency consideration is whether the application can allow “pulse skipping.” In this mode, the minimum on time of the converter cannot support the duty cycle, so the converter ripple will go up and there will be a low frequency component of the output ripple. In many applications where physical size is the main criterion then running the converter in this mode is acceptable. In applications where it is preferred not to enter this mode, then the maximum operating frequency is given by:

$$f_{\text{MAX\_NOSKIP}} = \frac{V_{\text{OUT}} - V_{\text{IN}}}{V_{\text{OUT}} \cdot t_{\text{ON(MIN)}}} \text{ Hz}$$

where $t_{\text{ON(MIN)}} = \text{minimum on time} = 140\text{ns}$

Reducing Output Capacitance with a Load Feed Forward Signal

In many applications the output filter capacitance can be reduced for the desired transient response by having the device commanding the change in load current, (i.e. system microcontroller), inform the power converter of the changes as they occur. Specifically, a “load feed forward” signal coupled into the $V_C$ pin gives the inner current loop a head start in providing the change in output current. The transconductance of the LTC3423 converter at the $V_C$ pin with respect to the inductor current is typically 130mA/100mV, and the LTC3424 is typically 170mA/100mV, so the amount of signal injected is proportional to the anticipated change of inductor current with load. The outer voltage loop performs the remainder of the correction, but because of the load feed forward signal, the range over which it must slew is greatly reduced. This results in an improved transient response. A logic level feed forward signal, $V_{\text{FF}}$, is coupled through components C5 and R6. The amount of feed forward signal is attenuated with resistor R6 and is given by the following relationship:

$$R_6 = \left( \frac{V_{\text{FF}} \cdot R_5 \cdot V_{\text{IN}} \cdot 1.5}{V_{\text{OUT}} \cdot \Delta I_{\text{OUT}}} \right) - R_5$$

where $\Delta I_{\text{OUT}} = \text{load current change}$.

Closing the Feedback Loop

The LTC3423/LTC3424 uses current mode control with internal adaptive slope compensation. Current mode control eliminates the 2nd order filter due to the inductor and output capacitor exhibited in voltage mode controllers, and simplifies it to a single-pole filter response. The product of the modulator control to output DC gain plus the error amp open-loop gain equals the DC gain of the system.
The typical error amp compensation is shown in Figure 3. The equations for the loop dynamics are as follows:

\[ f_{\text{POLE1}} = \frac{1}{2 \cdot \pi \cdot 2 \cdot 10^6 \cdot C_1} \text{Hz} \]

which is extremely close to DC

\[ f_{\text{ZERO1}} = \frac{1}{2 \cdot \pi \cdot R_z \cdot C_1} \text{Hz} \]

\[ f_{\text{POLE2}} = \frac{1}{2 \cdot \pi \cdot R_z \cdot C_2} \text{Hz} \]

Refer to Application Note AN76 for more closed loop examples.
TYPICAL APPLICATION

Single Cell to 1.8V at 300mA, 1.8mm High

PACKAGE DESCRIPTION

MS Package
10-Lead Plastic MSOP
(Reference LTC DWG # 05-08-1661)

NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

RECOMMENDED SOLDER PAD LAYOUT

NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.
RELATED PARTS

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT1306</td>
<td>Sync, Fixed Frequency, Step-Up DC/DC Converter</td>
<td>Internal 2A Switches, ( V_{IN} ) As Low As 1.8V</td>
</tr>
<tr>
<td>LT1308A/LT1308B</td>
<td>High Current, Micropower, Single Cell 600kHz DC/DC Converter</td>
<td>5V at 1A from Single Li-Ion Cell</td>
</tr>
<tr>
<td>LT1317/LT1317B</td>
<td>Micropower 600kHz PWM DC/DC Converter</td>
<td>( V_{IN} ) As Low As 1.5V, ( I_{Q} ) = 100( \mu )A</td>
</tr>
<tr>
<td>LT1610</td>
<td>1.7MHz, Single Cell Micropower DC/DC Converter</td>
<td>3V at 30mA from 1V, 5V at 200mA from 3.3V</td>
</tr>
<tr>
<td>LT1613</td>
<td>1.4MHz, Single Cell DC/DC Converter in ThinSOT™</td>
<td>( V_{IN} ) As Low As 1.1V, 3V at 30mA from Single Cell</td>
</tr>
<tr>
<td>LT1615</td>
<td>Micropower Step-Up DC/DC Converter in ThinSOT</td>
<td>( I_{Q} ) = 20( \mu )A, 1( \mu )A Shutdown Current, ( V_{IN} ) As Low As 1V</td>
</tr>
<tr>
<td>LT1949</td>
<td>600kHz, 1A Switch PWM DC/DC Converter</td>
<td>1.1A, 0.5V/30V Internal Switch, ( V_{IN} ) As Low As 1.8V</td>
</tr>
<tr>
<td>LTC3400/LTC3400B</td>
<td>ThinSOT, 600mA, 1.2MHz Boost Converter</td>
<td>92% Efficiency, 0.85V ( \leq V_{IN} ) 2.6V ( \leq V_{OUT} ) ( \leq 5V )</td>
</tr>
<tr>
<td>LTC3401</td>
<td>Single Cell, High Current (1A) Micropower, Synchronous 3MHz Step-Up DC/DC Converter</td>
<td>( V_{IN} ) = 0.5V to 5.5V, Up to 97% Efficiency Synchronizable Oscillator from 100kHz to 3MHz</td>
</tr>
<tr>
<td>LTC3402</td>
<td>Single Cell, High Current (2A) Micropower, Synchronous 3MHz Step-Up DC/DC Converter</td>
<td>( V_{IN} ) = 0.5V to 5.5V, Up to 97% Efficiency Synchronizable Oscillator from 100kHz to 3MHz</td>
</tr>
</tbody>
</table>

ThinSOT is a trademark of Linear Technology Corporation.