The LTC®3530 is a wide VIN range, highly efficient, fixed frequency, buck-boost DC/DC converter that operates from input voltages above, below or equal to the output voltage. The topology incorporated in the IC provides a continuous transfer function through all operating modes, making the product ideal for single lithium-ion, two-cell alkaline or NiMH applications where the output voltage is within the battery voltage range.

The LTC3530 is pin compatible with the LTC3440 buck-boost DC/DC converter but adds programmable automatic Burst Mode operation and extends the VIN/VOUT range to 1.8V. Switching frequencies up to 2MHz are programmed with an external resistor. Automatic Burst Mode operation allows the user to program the load current threshold for Burst Mode operation using a single resistor from the BURST pin to GND.

Other features include 1μA shutdown, short circuit protection, programmable soft-start control, current limit and thermal shutdown. The LTC3530 is available in a thermally enhanced 10-lead (3mm × 3mm) DFN and 10-Lead MS Packages.

**APPLICATIONS**
- MP3 Players
- Handheld Instruments
- Digital Cameras
- Smart Phones
- Portable GPS Units
- Miniature Hard Disk Drive Power

**DESCRIPTION**

Regulated Output with Input Voltages Above, Below or Equal to the Output
- 1.8V to 5.5V Input and 1.8V to 5.25V Output Range
- 250mA Continuous Output Current from 1.8V VIN
- 600mA Continuous/1A Peak Output Current from Li-Ion
- Single Inductor
- Synchronous Rectification: Up to 96% Efficiency
- Programmable Automatic Burst Mode® Operation
- Output Disconnect in Shutdown
- Pin Compatible with the LTC3440
- Programmable Frequency from 300kHz to 2MHz
- <1μA Shutdown Current
- Small Thermally Enhanced 10-Lead (3mm × 3mm) DFN and 10-Lead MS Packages

**FEATURES**

- Regulated Output with Input Voltages Above, Below or Equal to the Output
- 1.8V to 5.5V Input and 1.8V to 5.25V Output Range
- 250mA Continuous Output Current from 1.8V VIN
- 600mA Continuous/1A Peak Output Current from Li-Ion
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**APPLICATIONS**
- MP3 Players
- Handheld Instruments
- Digital Cameras
- Smart Phones
- Portable GPS Units
- Miniature Hard Disk Drive Power

**TYPICAL APPLICATION**

![Typical Application Diagram]

**Efficiency**

- Burst Mode VIN = 3.6V
- VIN = 4.2V
- VIN = 3.6V
- VIN = 2.0V

Vin = 2.0V

Vin = 3.6V

Vin = 4.2V

Vin = 3.6V

**Vin = 2.0V**

**Vin = 3.6V**

**Vin = 4.2V**

**Vin = 3.6V**
LTC3530

**ABSOLUTE MAXIMUM RATINGS** *(Note 1)*

- \( V_{IN}, V_{OUT} \) Voltage \(-0.3\) to 6V
- SW1, SW2 Voltage
  - DC \(-0.3\) to 6V
  - Pulsed \(< 100\)ns \(-0.3\) to 7V
- \( V_C, R_T, FB, SHDN/SS, BURST \) Voltage \(-0.3\) to 6V
- Operating Temperature *(Note 2)* \(-40\)°C to 85°C
- Maximum Junction Temperature *(Note 4)* \(125\)°C
- Storage Temperature Range \(-65\)°C to 150°C

**PIN CONFIGURATION**

![TOP VIEW](image)

**ORDER INFORMATION**

<table>
<thead>
<tr>
<th>LEAD FREE FINISH</th>
<th>TAPE AND REEL</th>
<th>PART MARKING</th>
<th>PACKAGE DESCRIPTION</th>
<th>TEMPERATURE RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC3530EDD#PBF</td>
<td>LTC3530EDD#TRPBF</td>
<td>LCBH</td>
<td>10-Lead (3mm × 3mm) Plastic DFN</td>
<td>(-40)°C to 85°C</td>
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<tr>
<td>LTC3530EMS#PBF</td>
<td>LTC3530EMS#TRPBF</td>
<td>LTCBJ</td>
<td>10-Lead Plastic MSOP</td>
<td>(-40)°C to 85°C</td>
</tr>
</tbody>
</table>

Consult LTC Marketing for parts specified with wider operating temperature ranges.
Consult LTC Marketing for information on non-standard lead based finish parts.
For more information on lead free part marking, go to: [http://www.linear.com/leadfree/](http://www.linear.com/leadfree/)
For more information on tape and reel specifications, go to: [http://www.linear.com/tapeandreel/](http://www.linear.com/tapeandreel/)

**ELECTRICAL CHARACTERISTICS** The \( \bullet \) denotes the specifications which apply over the full operating temperature range, otherwise specifications are at \( T_A = 25\)°C. \( V_{IN} = V_{OUT} = 3.6V, R_T = 33.2k \), 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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<tbody>
<tr>
<td>Input Operating Range</td>
<td>( \bullet )</td>
<td>1.8</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Output Voltage Adjust Range</td>
<td>( \bullet )</td>
<td>1.8</td>
<td>5.25</td>
<td>V</td>
<td></td>
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<tr>
<td>Feedback Voltage</td>
<td></td>
<td>1.191</td>
<td>1.215</td>
<td>1.239</td>
<td>V</td>
</tr>
<tr>
<td>Feedback Input Current</td>
<td>( V_{FB} = 1.215V )</td>
<td>1</td>
<td>50</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>Quiescent Current, Burst Mode Operation</td>
<td>( V_{FB} = 1.215V, BURST = 0V ) <em>(Note 3)</em></td>
<td>40</td>
<td>60</td>
<td>( \mu A )</td>
<td></td>
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<tr>
<td>Quiescent Current, Shutdown</td>
<td>( SHDN = 0V, Not Including Switch Leakage )</td>
<td>0.1</td>
<td>1</td>
<td>( \mu A )</td>
<td></td>
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<tr>
<td>Quiescent Current, Active</td>
<td>( V_C = 0V, BURST = 3V ) <em>(Note 3)</em></td>
<td>700</td>
<td>1200</td>
<td>( \mu A )</td>
<td></td>
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<tr>
<td>Input Current Limit</td>
<td>( \bullet )</td>
<td>1</td>
<td>2</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>
**ELECTRICAL CHARACTERISTICS**

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ C$. $V_{IN} = V_{OUT} = 3.6V$, $R_T = 33.2k$, unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMOS Switch Leakage</td>
<td>Switches B and C</td>
<td>0.1</td>
<td>5</td>
<td>μA</td>
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<tr>
<td>PMOS Switch Leakage</td>
<td>Switches A and D</td>
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<td>μA</td>
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<tr>
<td>NMOS Switch On Resistance</td>
<td>Switches B and C</td>
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<td>Ω</td>
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<tr>
<td>PMOS Switch On Resistance</td>
<td>Switches A and D</td>
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<td></td>
<td>Ω</td>
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<tr>
<td>Maximum Duty Cycle</td>
<td>Boost (% Switch C On)</td>
<td>●</td>
<td>80</td>
<td>90</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Buck (% Switch A On)</td>
<td>●</td>
<td>100</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Minimum Duty Cycle</td>
<td></td>
<td>●</td>
<td>0</td>
<td></td>
<td>%</td>
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<td>Frequency</td>
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<td>●</td>
<td>0.7</td>
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<td>1.3</td>
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<td>Error Amp AVOL</td>
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<td></td>
<td>90</td>
<td></td>
<td>dB</td>
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<tr>
<td>Error Amp Source Current</td>
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<td></td>
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<td></td>
<td>μA</td>
</tr>
<tr>
<td>Error Amp Sink Current</td>
<td></td>
<td></td>
<td>300</td>
<td></td>
<td>μA</td>
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<tr>
<td>Burst Threshold</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Burst Input Current</td>
<td>$V_{BURST} = 5.5V$</td>
<td></td>
<td>2</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>SHDN/SS Threshold</td>
<td>When IC is Enabled</td>
<td>●</td>
<td>0.4</td>
<td>0.85</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>When EA is at Maximum Boost Duty Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHDN/SS Input Current</td>
<td>$V_{SHDN} = 5.5V$</td>
<td></td>
<td>0.01</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**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 LTC3530E is guaranteed to meet performance specifications from 0°C to 85°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlations with statistical process controls.

**Note 3:** Current measurements are performed when the outputs are not switching.

**Note 4:** This IC includes overtemperature protection that is intended to protect the device during momentary overload conditions. Junction temperature will exceed 125°C when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature may result in device degradation or failure.

**TYPICAL PERFORMANCE CHARACTERISTICS**

$T_A = 25^\circ C$, unless otherwise specified.
TYPICAL PERFORMANCE CHARACTERISTICS

Automatic Burst Mode Threshold vs \( R_{\text{BURST}} \)

Minimum Start Voltage vs Temperature

Average Input Current Limit vs Temperature

Frequency Change vs Temperature

Feedback Voltage vs Temperature

Switch Pins Before Entering Boost Mode

Switch Pins in Buck-Boost Mode

Switch Pins Entering Buck-Boost Mode

LTC3530 Output Ripple 500mA Load

\( T_A = 25^\circ\text{C}, \) unless otherwise specified.

\[ \begin{align*}
\text{VIN} &= 3.3V \\
\text{VOUT} &= 3.3V \text{ AT 500mA}
\end{align*} \]
TYPICAL PERFORMANCE CHARACTERISTICS

TA = 25°C, unless otherwise specified.

Load Transient Response in Fixed Frequency Mode, No Load to 300mA

Load Transient Response in Auto Burst Mode Operation, No Load to 500mA

Typical Burst Mode Waveforms

Transition from Burst Mode Operation to Fixed Frequency Mode

Maximum Output Current vs VIN

PIN FUNCTIONS

R_T (Pin 1): Programs the Frequency of the Internal Oscillator. Connect a resistor from R_T to ground.

f(kHz) = 33,170/R_T (kΩ)

BURST (Pin 2): Used to Set the Automatic Burst Mode Threshold. Connect a resistor and capacitor in parallel from this pin to ground. See the Applications Information section for component value selection. For manual control, ground the pin to force Burst Mode operation, connect to VIN to force fixed frequency PWM mode.

SW1 (Pin 3): Switch Pin Where the Internal Switches A and B are Connected. Connect inductor from SW1 to SW2. An optional Schottky diode can be connected from SW1 to ground for a moderate efficiency improvement. Minimize trace length to keep EMI down.

SW2 (Pin 4): Switch Pin Where the Internal Switches C and D are Connected. For applications with output voltages over 4.3V, a Schottky diode is required from SW2 to VOUT to ensure the SW pin does not exhibit excessive voltage.
**PIN FUNCTIONS**

**GND (Pin 5):** Ground for the IC.

**VOUT (Pin 6):** Output of the Synchronous Rectifier. A filter capacitor is placed from VOUT to GND. A ceramic bypass capacitor is recommended as close to the VOUT and GND pins as possible.

**VIN (Pin 7):** Input Supply Voltage. Internal VCC for the IC. A 10μF ceramic capacitor is recommended as close to the VIN and GND pins as possible.

**SHDN/SS (Pin 8):** Combined Soft-Start and Shutdown. Applied voltage <0.4V shuts down the IC. Tie to >1.4V to enable the IC and >1.6V to ensure the error amp is not clamped from soft-start. An R-C from the shutdown command signal to this pin will provide a soft-start function by limiting the rise time of VC.

**FB (Pin 9):** Feedback Pin. Connect resistor divider tap here. The output voltage can be adjusted from 1.8V to 5.25V. The feedback reference is typically 1.215V.

\[ V_{OUT} = 1.215V \cdot \left( 1 + \frac{R_1}{R_2} \right) \]

**VC (Pin 10):** Error Amp Output. An R-C network is connected from this pin to FB for loop compensation. Refer to “Closing the Feedback Loop” section for component selection guidelines. During Burst Mode operation, VC is internally clamped.

**Exposed Pad (Pin 11, DD Package Only):** Ground. This pin must be soldered to the PCB and electrically connected to ground.

**BLOCK DIAGRAM**

- **SW1, SW2:** Gate Drivers and Anticross Conduction
- **SW A, SW B, SW C:** Reverse Amp
- **VC:** Error Amp Output. An R-C network is connected from this pin to FB for loop compensation. Refer to “Closing the Feedback Loop” section for component selection guidelines. During Burst Mode operation, VC is internally clamped.
- **VOUT:** Output of the Synchronous Rectifier. A filter capacitor is placed from VOUT to GND. A ceramic bypass capacitor is recommended as close to the VOUT and GND pins as possible.
- **RSS:** SHDN/SS (Pin 8): Combined Soft-Start and Shutdown. Applied voltage <0.4V shuts down the IC. Tie to >1.4V to enable the IC and >1.6V to ensure the error amp is not clamped from soft-start. An R-C from the shutdown command signal to this pin will provide a soft-start function by limiting the rise time of VC.
- **CIN, COUT:** Input and Output Capacitors
- **L1:** Inductor
- **RT:** Oscillator
- **GND:** Ground

---

**3530b**
The LTC3530 provides high efficiency, low noise power for a wide variety of handheld electronic devices. The LTC proprietary topology allows input voltages above, below or equal to the output voltage by properly phasing the output switches. The error amp output voltage on $V_C$ determines the output duty cycle of the switches. Since $V_C$ is a filtered signal, it provides rejection of frequencies from well below the switching frequency. The low $R_{DS(ON)}$, low gate charge synchronous switches provide high frequency pulse width modulation control at high efficiency. High efficiency is achieved at light loads when Burst Mode operation is entered and the LTC3530’s quiescent current drops to a low 40μA.

**LOW NOISE FIXED FREQUENCY OPERATION**

**Oscillator**

The frequency of operation is programmed by an external resistor from $R_T$ to ground, according to the following equation:

$$f(\text{kHz}) = \frac{33,170}{R_T(\text{k}\Omega)}$$

**Error Amp**

The error amplifier is a voltage mode amplifier. The loop compensation components are configured around the amplifier (from FB to $V_C$) to obtain stability of the converter. For improved bandwidth, an additional R-C feed-forward network can be placed across the upper feedback divider resistor. The voltage on SHDN/SS clamps the error amp output, $V_C$, to provide a soft-start function.

**Internal Current Limit**

There are two different current limit circuits in the LTC3530. Each has internally fixed thresholds which vary inversely with $V_{IN}$.

The first circuit is a high speed peak current limit comparator that will shut off switch A once the current exceeds 2.5A typical. The delay to output of this comparator is typically 50ns.

A second amplifier will source current out of FB to drop the output voltage once the peak input current exceeds 2A typical. This method provides a closed loop means of clamping the input current. During conditions where $V_{OUT}$ is near ground, such as during a short-circuit or during startup, this threshold is cut to 670mA (typ), providing a foldback feature. For this current limit feature to be most effective, the Thevenin resistance from FB to ground should be greater than 100kΩ.

**Reverse Current Limit**

During fixed frequency operation, the LTC3530 operates in forced continuous conduction mode. The reverse current limit amplifier monitors the inductor current from the output through switch D. Once the negative inductor current exceeds 640mA typical, the LTC3530 will shut off switch D.

**Four-Switch Control**

Figure 1 shows a simplified diagram of how the four internal switches are connected to the inductor, $V_{IN}$, $V_{OUT}$ and GND. Figure 2 shows the regions of operation for the LTC3530 as a function of the internal control voltage, $V_{CI}$.
OPERATION

Depending on the control voltage, the IC will operate in either buck, buck/boost or boost mode. The $V_{CI}$ voltage is a level shifted voltage from the output of the error amp ($V_{C}$). The four power switches are properly phased so the transition between operating modes is continuous, smooth and transparent to the user. When $V_{IN}$ approaches $V_{OUT}$ the buck/boost region is reached where the conduction time of the four switch region is typically 150ns. Referring to Figures 1 and 2, the various regions of operation will now be described.

**Buck Region ($V_{IN} > V_{OUT}$)**

Switch D is always on and switch C is always off during this mode. When the internal control voltage, $V_{CI}$, is above voltage $V_1$, output A begins to switch. During the off-time of switch A, synchronous switch B turns on for the remainder of the time. Switches A and B will alternate similar to a typical synchronous buck regulator. As the control voltage increases, the duty cycle of switch A increases until the maximum duty cycle of the converter in buck mode reaches $D_{MAX\_BUCK}$, given by:

$$D_{MAX\_BUCK} = 100 - D_{4SW} \%$$

where $D_{4SW}$ = duty cycle % of the four switch range.

$$D_{4SW} = (150ns \times f) \times 100 \%$$

where $f$ = operating frequency, Hz.

Beyond this point the “four switch,” or buck/boost region is reached.

**Buck/Boost or Four Switch ($V_{IN} \approx V_{OUT}$)**

When the internal control voltage, $V_{CI}$, is above voltage $V_2$, switch pair AD remain on for duty cycle $D_{MAX\_BUCK}$, and the switch pair AC begins to phase in. As switch pair AC phases in, switch pair BD phases out accordingly. When the $V_{CI}$ voltage reaches the edge of the buck/boost range, at voltage $V_3$, the AC switch pair completely phase out the BD pair, and the boost phase begins at duty cycle $D_{4SW}$. The input voltage, $V_{IN}$, where the four switch region begins is given by:

$$V_{IN} = \frac{V_{OUT}}{1 - (150ns \times f)}$$

The point at which the four switch region ends is given by:

$$V_{IN} = V_{OUT}(1 - D) = V_{OUT}(1 - 150ns \times f) V$$

**Boost Region ($V_{IN} < V_{OUT}$)**

Switch A is always on and switch B is always off during this mode. When the internal control voltage, $V_{CI}$, is above voltage $V_3$, switch pair CD will alternately switch to provide a boosted output voltage. This operation is typical of a synchronous boost regulator. The maximum duty cycle of the converter is limited to 90% typical and is reached when $V_{CI}$ is above $V_4$.

**BURST MODE OPERATION**

Burst mode reduces the LTC3530’s quiescent current consumption at light loads and improves overall conversion efficiency, increasing battery life. During Burst Mode operation the LTC3530 delivers energy to the output until it is regulated and then goes into sleep mode where the outputs are off and quiescent current drops to 40μA (typ). In this mode the output ripple has a variable frequency component that depends upon load current, and will typically be about 2% peak-to-peak. Burst Mode operation ripple can be reduced slightly by using more output capacitance (47μF or greater). Another method of reducing Burst Mode operation ripple is to place a small feed-forward capacitor across the upper resistor in the $V_{OUT}$ feedback divider network (as in Type III compensation).

During the period where the device is delivering energy to the output, the peak switch current will be equal to 450mA typical and the inductor current will terminate at zero current for each cycle. In this mode the typical maximum average output current is given by:

$$I_{MAX\(BURST\)} = \frac{450mA}{2}; V_{OUT} < V_{IN}$$

$$I_{MAX\(BURST\)} = \frac{450mA}{2} \times \left( \frac{V_{IN}}{V_{OUT}} \right); V_{OUT} > V_{IN}$$

$$I_{MAX\(BURST\)} \text{ Buck-Boost} \approx 350mA; V_{OUT} \approx V_{IN}$$

Since the input and output are connected together for most of the cycle.
The efficiency below 1mA becomes dominated primarily by the quiescent current. The Burst Mode operation efficiency is given by:

\[ \text{EFFICIENCY} = \frac{\eta \cdot I_{\text{LOAD}}}{40 \mu A + I_{\text{LOAD}}} \]

where \( \eta \) is typically 90% during Burst Mode operation.

**Automatic Burst Mode Operation Control**

Burst Mode operation can be automatic or manually controlled with a single pin. In automatic mode, the IC will enter Burst Mode operation at light load and return to fixed frequency operation at heavier loads. The load current at which the mode transition occurs is programmed using a single external resistor from BURST to ground, according to the following equations:

- **Enter Burst Mode:** \( I_{\text{BURST}} = \frac{8.8}{R_{\text{BURST}}} \)
- **Leave Burst Mode:** \( I_{\text{BURST}} = \frac{11.2}{R_{\text{BURST}}} \)

where \( R_{\text{BURST}} \) is in k\( \Omega \) and \( I_{\text{BURST}} \) is the load transition current in Amps. Do not use values of \( R_{\text{BURST}} \) greater than 500k\( \Omega \).

For automatic operation, a filter capacitor must also be connected from BURST to ground. The equation for the minimum capacitor value is:

\[ C_{\text{BURST(MIN)}} \geq \frac{C_{\text{OUT}} \cdot V_{\text{OUT}}}{60,000} \]

where \( C_{\text{BURST(MIN)}} \) and \( C_{\text{OUT}} \) are in \( \mu F \).

In the event that a load transient causes FB to drop by more than 4% from the regulation value while in Burst Mode operation, the IC will immediately switch to fixed frequency mode and an internal pull-up will be momentarily applied to BURST, rapidly charging \( C_{\text{BURST}} \). This prevents the IC from immediately re-entering Burst Mode operation once the output achieves regulation.

**Manual Burst Mode Operation**

For manual control of Burst Mode operation, the RC network connected to BURST can be eliminated. To force fixed frequency mode, BURST should be connected to \( V_{\text{IN}} \). To force Burst Mode operation, BURST should be grounded. When commanding Burst Mode operation manually, the circuit connected to BURST should be able to sink up to 2mA.

For optimum transient response with large dynamic loads, the operating mode should be controlled manually by the host. By commanding fixed frequency operation prior to a sudden increase in load, output voltage droop can be minimized. Note that if the load current applied during forced Burst Mode operation (BURST pin is grounded) exceeds the current that can be supplied, the output voltage will start to droop and the IC will automatically come out of Burst Mode operation and enter fixed frequency mode, raising \( V_{\text{OUT}} \). Once regulation is achieved, the IC will then enter Burst Mode operation once again, and the cycle will repeat, resulting in about 4% output ripple.

**Burst Mode Operation to Fixed Frequency Transient Response**

In Burst Mode operation, the compensation network is not used and \( V_C \) is disconnected from the error amplifier. During long periods of Burst Mode operation, leakage currents in the external components or on the PC board could cause the compensation capacitor to charge (or discharge), which could result in a large output transient when returning to fixed frequency mode of operation, even at the same load current. To prevent this, the LTC3530 incorporates an active clamp circuit that holds the voltage on \( V_C \) at an optimal voltage during Burst Mode operation. This minimizes any output transient when returning to fixed frequency mode operation. For optimum transient response, Type 3 compensation is also recommended to broad band the control loop and roll off past the two pole response of the output LC filter. See Closing the Feedback Loop under Applications Information.
Soft-Start

The soft-start function is combined with shutdown. When the SHDN/SS pin is brought above 1V typical, the IC is enabled but the EA duty cycle is clamped from V_C. A detailed diagram of this function is shown in Figure 3. The components RSS and C_SS provide a slow ramping voltage on SHDN/SS to provide a soft-start function. To ensure that V_C is not being clamped, SHDN/SS must be raised above 1.6V.

COMPONENT SELECTION

Inductor Selection

The high frequency operation of the LTC3530 allows the use of small surface mount inductors. The inductor ripple current is typically set to 20% to 40% of the maximum inductor current. For a given ripple the inductance terms are given as follows:

\[ L_{BOOST} > \frac{V_{IN(MIN)} \cdot (V_{OUT} - V_{IN(MIN)})}{f \cdot \Delta I_{L} \cdot V_{OUT}} \text{H} \]

\[ L_{BUCK} > \frac{V_{OUT} \cdot (V_{IN(MAX)} - V_{OUT})}{f \cdot \Delta I_{L} \cdot V_{IN(MAX)}} \text{H} \]

Output Capacitor Selection

The bulk value of the output filter capacitor is set to reduce the ripple due to charge into the capacitor each cycle. The steady state ripple due to charge is given by:

\[ \% \text{Ripple}_{Boost} = \frac{I_{OUT(MAX)} \cdot (V_{OUT} - V_{IN(MIN)}) \cdot 100}{C_{OUT} \cdot V_{OUT}^2 \cdot f} \%
\]

\[ \% \text{Ripple}_{Buck} = \frac{1 \cdot (V_{IN(MAX)} - V_{OUT}) \cdot 100}{8Lcf^2 \cdot V_{IN(MAX)}} \%
\]

where f = operating frequency, Hz
\[ \Delta I_{L} = \text{maximum allowable inductor ripple current, A} \]
\[ V_{IN(MIN)} = \text{minimum input voltage, V} \]
\[ V_{IN(MAX)} = \text{maximum input voltage, V} \]
\[ V_{OUT} = \text{output voltage, V} \]
\[ I_{OUT(MAX)} = \text{maximum output load current} \]

For high efficiency, choose a ferrite inductor with a high frequency core material to reduce core loses. 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 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 shielded inductor. See Table 1 for a suggested list of inductor suppliers.

Table 1. Inductor Vendor Information

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PHONE</th>
<th>FAX</th>
<th>WEB SITE</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>CoEv Magnetics</td>
<td>(800) 227-7040</td>
<td>(650) 361-2508</td>
<td><a href="http://www.circuitprotection.com/magnetics.asp">www.circuitprotection.com/magnetics.asp</a></td>
</tr>
<tr>
<td>Murata</td>
<td>(814) 237-1431</td>
<td>(814) 238-0409</td>
<td><a href="http://www.murata.com">www.murata.com</a></td>
</tr>
<tr>
<td>Sumida</td>
<td>USA: (847) 956-0666</td>
<td>USA: (847) 956-0702</td>
<td><a href="http://www.sumida.com">www.sumida.com</a></td>
</tr>
<tr>
<td></td>
<td>Japan: 81(3) 3607-5111</td>
<td>Japan: 81(3) 3607-5144</td>
<td></td>
</tr>
<tr>
<td>TDK</td>
<td>(847) 803-6100</td>
<td>(847) 803-6296</td>
<td><a href="http://www.component.tdk.com">www.component.tdk.com</a></td>
</tr>
<tr>
<td>TOKO</td>
<td>(847) 297-0070</td>
<td>(847) 699-7864</td>
<td><a href="http://www.tokoam.com">www.tokoam.com</a></td>
</tr>
</tbody>
</table>
The output capacitance is usually many times larger than the minimum value in order to handle the transient response requirements of the converter. For a rule of thumb, the ratio of the operating frequency to the unity-gain bandwidth of the converter is the amount the output capacitance will have to increase from the above calculations in order to maintain the desired transient response.

The other component of ripple is due to the ESR (equivalent series resistance) of the output capacitor. Low ESR capacitors should be used to minimize output voltage ripple. For surface mount applications, Taiyo Yuden or TDK ceramic capacitors, AVX TPS series tantalum capacitors or Sanyo POSCAP are recommended. See Table 2 for contact information.

**Input Capacitor Selection**

Since $V_{IN}$ is the supply voltage for the IC, as well as the input to the power stage of the converter, it is recommended to place at least a 10μF, low ESR ceramic bypass capacitor close to the $V_{IN}$ and GND pins. It is also important to minimize any stray resistance from the converter to the battery or other power source.

**Optional Schottky Diodes**

Schottky diodes across the synchronous switches B and D are not required ($V_{OUT} < 4.3V$), but provide a lower drop during the break-before-make time (typically 15ns) improving efficiency. Use a surface mount Schottky diode such as an MBRM120T3 or equivalent. Do not use ordinary rectifier diodes, since the slow recovery times will compromise efficiency. For applications with an output voltage above 4.3V, a Schottky diode is required from SW2 to $V_{OUT}$.

**Output Voltage < 1.8V**

The LTC3530 can operate as a buck converter with output voltages as low as 0.4V. Synchronous switch D is powered from $V_{OUT}$ and the $R_{DS(ON)}$ will increase at low output voltages, therefore a Schottky diode is required from SW2 to $V_{OUT}$ to provide the conduction path to the output. Note that Burst Mode operation is inhibited at output voltages below 1V typical. Note also that if $V_{OUT}$ is less than 1V, the current limit will be 670mA (typ).

**Output Voltage > 4.3V**

A Schottky diode from SW2 to $V_{OUT}$ is required for output voltages over 4.3V. The diode must be located as close to the pins as possible in order to reduce the peak voltage on SW2 due to the parasitic lead and trace inductance.

**Input Voltage > 4.5V**

For applications with input voltages above 4.5V which could exhibit an overload or short-circuit condition, a $2Ω/1nF$ series snubber is required between SW1 and GND. A Schottky diode from SW1 to $V_{IN}$ should also be added as close to the pins as possible. For the higher input voltages, $V_{IN}$ bypassing becomes more critical; therefore, a ceramic bypass capacitor as close to the $V_{IN}$ and GND pins as possible is also required.

**Operating Frequency Selection**

Higher operating frequencies allow the use of a smaller inductor and smaller input and output filter capacitors, thus reducing board area and component height. However, higher operating frequencies also increase the IC’s total quiescent current due to the gate charge of the four switches, as given by:

\[
\begin{align*}
\text{Buck:} & \quad I_q = (0.6 \cdot V_{IN} \cdot f) \text{ mA} \\
\text{Boost:} & \quad I_q = (0.8 \cdot (V_{IN} + V_{OUT}) \cdot f) \text{ mA} \\
\text{Buck/Boost:} & \quad I_q = [f \cdot (1.4 \cdot V_{IN} + 0.4 \cdot V_{OUT})] \text{ mA}
\end{align*}
\]

---

Table 2. Capacitor Vendor Information

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PHONE</th>
<th>FAX</th>
<th>WEB SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVX</td>
<td>(803) 448-9411</td>
<td>(803) 448-1943</td>
<td><a href="http://www.avxcorp.com">www.avxcorp.com</a></td>
</tr>
<tr>
<td>Murata</td>
<td>(814) 237-1431</td>
<td>(814) 238-0409</td>
<td><a href="http://www.murata.com">www.murata.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>
<tr>
<td>TDK</td>
<td>(847) 803-6100</td>
<td>(847) 803-6296</td>
<td><a href="http://www.component.tdk.com">www.component.tdk.com</a></td>
</tr>
</tbody>
</table>
where \( f \) = switching frequency in MHz. Therefore frequency selection is a compromise between the optimal efficiency and the smallest solution size.

**Closing the Feedback Loop**

The LTC3530 incorporates voltage mode PWM control. The control to output gain varies with operation region (buck, boost, buck/boost), but is usually no greater than 15. The output filter exhibits a double pole response, as given by:

\[
\frac{1}{2\pi \sqrt{L \cdot C_{OUT}}} \text{Hz (in buck mode)}
\]

\[
\frac{V_{IN}}{2\pi V_{OUT} \sqrt{L \cdot C_{OUT}}} \text{Hz (in boost mode)}
\]

where \( L \) is in henries and \( C_{OUT} \) is in farads.

The output filter zero is given by:

\[
\frac{1}{2\pi \cdot R_{ESR} \cdot C_{OUT}} \text{Hz}
\]

where \( R_{ESR} \) is the equivalent series resistance of the output capacitor.

A troublesome feature in boost mode is the right-half plane zero (RHP), given by:

\[
\frac{V_{IN}^2}{2\pi \cdot I_{OUT} \cdot L \cdot V_{OUT}} \text{Hz}
\]

where resistance is in ohms and capacitance is in farads.

The loop gain is typically rolled off before the RHP zero frequency.

A simple Type I compensation network can be incorporated to stabilize the loop, but at a cost of reduced bandwidth and slower transient response. To ensure proper phase margin using Type I compensation, the loop must be crossed over a decade before the LC double pole. The unity-gain frequency of the error amplifier with the Type I compensation is given by:

\[
\frac{1}{2\pi \cdot R_{1} \cdot C_{P1}} \text{Hz (referring to Figure 4)}
\]

Most applications demand an improved transient response to allow a smaller output filter capacitor. To achieve a higher bandwidth, Type III compensation is required, providing two zeros to compensate for the double-pole response of the output filter. Referring to Figure 5, the location of the poles and zeros are given by:

\[
\frac{1}{2\pi \cdot R \cdot C_{Z1}} \text{Hz}
\]

\[
\frac{1}{2\pi \cdot R \cdot C_{Z2}} \text{Hz}
\]

\[
\frac{1}{2\pi \cdot R \cdot C_{P2}} \text{Hz}
\]

where \( Z \) is in ohms and \( C \) is in farads.
TYPICAL APPLICATIONS

1MHz Li-Ion to 3.3V at 500mA Converter with Manual Mode Control

1MHz Li-Ion to 3.3V/600mA Converter with USB Power Input Option, Li Battery Charger and Power Path Management.
**High Efficiency Li-Ion Powered Constant Current Lumiled Driver**

- **VIN** = 3.6V
- **VOUT**
- **FB**
- **VC**
- **BURST**
- **LTC3530**

**R2** = R1/1.5

\[ I_{LED} = \frac{12 \times (R1+R2+R3+R4)}{R1 \times R3} \]

D1 = BAT54

**CIN** = TAIYO YUDEN JMK212BJ106MG

**COUT** = TAIYO YUDEN JMK325BJ475MM

**ILED** = 500mA

**Lumiled Driver Efficiency vs LED Current**

- **VIN** = 3.6V
- **1MHz**

Efficiency (%) vs LED Current (A)
PACKAGE DESCRIPTION

**DD Package**
10-Lead Plastic DFN (3mm × 3mm)
(Reference LTC DWG # 05-08-1695)

**Note:**
1. Drawing to be made a JEDEC Package Outline MO-229 Variation of (WEED-2).
2. Check the LTC website data sheet for current status of variation assignment.
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**

**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. Lea lead coplanarity (bottom of leads after forming) shall be 0.102mm (.004") max.
LTC3530

TYPICAL APPLICATION

USB to 5V Converter with Output Disconnect

PART NUMBER DESCRIPTION COMMENTS

LTC3400/LTC3400B 600mA (I_{SW}), 1.2MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 0.85V to 5V, \( V_{OUT(\text{MAX})} = 5V \),\n\( I_{Q} = 19\mu A/300\mu A, I_{SD} < 1\mu A \), ThinSOT Package

LTC3401/LTC3402 1A/2A (I_{SW}), 3MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 0.5V to 5V, \( V_{OUT(\text{MAX})} = 5V \), \( I_{Q} = 38mA \),\n\( I_{SD} < 1\mu A \), MS Package

LTC3406/LTC3406B 600mA (I_{OUT}), 1.5MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MIN})} = 0.6V \), \( I_{Q} = 20\mu A \),\n\( I_{SD} < 1\mu A \), ThinSOT Package

LTC3407 600mA (I_{OUT}), 1.5MHz Dual Synchronous Step-Up DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MIN})} = 0.6V \), \( I_{Q} = 40\mu A \),\n\( I_{SD} < 1\mu A \), MS Package

LTC3411 1.25A (I_{OUT}), 4MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MIN})} = 0.8V \), \( I_{Q} = 60\mu A \),\n\( I_{SD} < 1\mu A \), MS Package

LTC3412 2.5A (I_{OUT}), 4MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MIN})} = 0.8V \), \( I_{Q} = 60\mu A \),\n\( I_{SD} < 1\mu A \), TSSOP16E Package

LTC3421 3A (I_{SW}), 3MHz Synchronous Step-Up DC/DC Converter

V_{IN}: 0.5V to 4.5V, \( V_{OUT(\text{MAX})} = 5.25V \), \( I_{Q} = 12\mu A \),\n\( I_{SD} < 1\mu A \), QFN Package

LTC3425 5A (I_{SW}), 8MHz Multiphase Synchronous Step-Up DC/DC Converter

V_{IN}: 0.5V to 4.5V, \( V_{OUT(\text{MAX})} = 5.25V \), \( I_{Q} = 12\mu A \),\n\( I_{SD} < 1\mu A \), QFN Package

LTC3429 600mA (I_{SW}), 500kHz Synchronous Step-Up DC/DC Converter

V_{IN}: 0.5V to 4.35V, \( V_{OUT(\text{MAX})} = 5V \), \( I_{Q} = 20\mu A \),\n\( I_{SD} < 1\mu A \), QFN Package

LTC3440 600mA (I_{OUT}), 2MHz Synchronous Buck-Boost DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MAX})} = 5.5V \), \( I_{Q} = 25\mu A \),\n\( I_{SD} < 1\mu A \), MS, DFN Package

LTC3441 600mA (I_{OUT}), 2MHz Synchronous Buck-Boost DC/DC Converter

V_{IN}: 2.5V to 5.5V, \( V_{OUT(\text{MAX})} = 5.5V \), \( I_{Q} = 25\mu A \),\n\( I_{SD} < 1\mu A \), DFN Package

LTC3442/LTC3443 1.2A (I_{OUT}), Synchronous Buck-Boost DC/DC Converters,\nLTC3442 (1MHz), LTC3443 (600kHz)

V_{IN}: 2.4V to 5.5V, \( V_{OUT(\text{MAX})} = 5.25V \), \( I_{Q} = 28\mu A \),\n\( I_{SD} < 1\mu A \), MS Package

LTC3444 500mA (I_{OUT}), 1.5MHz Synchronous Buck-Boost DC/DC Converter with\nWide V_{OUT} Range

V_{IN}: 2.7V to 5.5V, \( V_{OUT} = 0.5V \) to 5.25V, 3mm x 3mm\nDFN Package, Ideal for WCDMA PA Bias

LTC3532 500mA (I_{OUT}), 2MHz Synchronous Buck-Boost DC/DC Converter

V_{IN}: 2.4V to 5.5V, \( V_{OUT(\text{MAX})} = 5.25V \), \( I_{SD} < 1\mu A \), DFN Package

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