LTC3355-1
20V 1A Buck DC/DC with Integrated SCAP Charger and Backup Regulator

FEATURES
- $V_{IN}$ Voltage Range: 3V to 20V
- $V_{OUT}$ Voltage Range: 2.7V to 5V
- 1A Current Mode Buck Main Regulator
- 5A Boost Backup Regulator Powered from Single Supercapacitor
- Boost Regulator Operates Down to 0.5V for Maximum Utilization of Supercapacitor Energy
- Programmable Supercapacitor Charge Current to 1A with Overvoltage Protection
- Charger Supports Single Cell CC/CV Battery Charging
- Programmable $V_{IN}$ Current Limit
- Programmable Boost Current Limit
- Compact 20-Lead 4mm × 4mm QFN Package

DESCRIPTION
The LTC®3355-1 is a complete input power interrupt ride-through DC/DC system. The part charges a supercapacitor while delivering load current to $V_{OUT}$, and uses energy from the supercapacitor to provide continuous $V_{OUT}$ backup power when $V_{IN}$ power is lost. The LTC3355-1 contains a nonsynchronous constant frequency current mode monolithic 1A buck switching regulator to provide a 2.7V to 5V regulated output voltage from an input supply of up to 20V.

A 1A programmable CC/CV linear charger charges the supercapacitor from $V_{OUT}$. When the $V_{IN}$ supply drops below the PFI threshold, the devices’ constant frequency nonsynchronous current mode 5A boost switching regulator delivers power from the supercapacitor to $V_{OUT}$. A thermal regulation loop maximizes charge current while limiting the die temperature to 110°C. The IC has boost, charger and $V_{IN}$ programmable current limits. The LTC3355-1 is available in a 20-lead 4mm × 4mm QFN surface mount package.

APPLICATIONS
- Ride-Through “Dying Gasp” Supplies
- Power Meters/Industrial Alarms/Solid State Drives

TYPICAL APPLICATION
Supercapacitor Charger and Ride-Through Power Supply

Backup Operation

All registered trademarks and trademarks are the property of their respective owners.
**ABSOLUTE MAXIMUM RATINGS**

(Note 1)

- \( V_{IN}, V_{INS}, V_{INM5} \) .......................................................... 22V
- \( V_{IN} - V_{INS} \) .......................................................... \( \pm 0.1V \)
- \( V_{SW1} \) .......................................................... \( -0.4V \) to 22V
- \( V_{SW2} \) .......................................................... \( -0.4V \) to 6V
- \( V_{OUT}, INTV_{CC}, V_{CAP} \) ........................................... \( -0.3V \) to 6V
- \( PFI, EN\_CHG, FB \) .................................................. \( -0.3V \) to 6V
- \( CFB \) .......................................................... \( -0.3V \) to \( INTV_{CC} \) + 0.3V

Operating Junction Temperature Range
(Notes 2, 3) .................................................. \( -40°C \) to 125°C

Storage Temperature Range .................. \( -65°C \) to 150°C

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**PIN CONFIGURATION**

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**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>LTC3355EUF-1#PBF</td>
<td>LTC3355EUF-1#TRPBF</td>
<td>33551</td>
<td>20-Lead (4mm × 4mm) Plastic QFN</td>
<td>–40°C to 125°C</td>
</tr>
<tr>
<td>LTC3355IUF-1#PBF</td>
<td>LTC3355IUF-1#TRPBF</td>
<td>33551</td>
<td>20-Lead (4mm × 4mm) Plastic QFN</td>
<td>–40°C to 125°C</td>
</tr>
</tbody>
</table>

Contact the factory for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container. Tape and reel specifications. Some packages are available in 500 unit reels through designated sales channels with #TRMPBF suffix.
## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at $T_A = 25^\circ C$. $V_{IN} = 12V$ unless otherwise noted. (Note 2)

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$</td>
<td>$V_{IN}$ Operating Voltage Range</td>
<td>●</td>
<td>3</td>
<td>20</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$i_Q$</td>
<td>$V_{IN}$ Quiescent Current</td>
<td>●</td>
<td>60</td>
<td>120</td>
<td>215</td>
<td>µA</td>
</tr>
<tr>
<td>$V_{OUT}$ Quiescent Current</td>
<td>●</td>
<td>110</td>
<td>265</td>
<td>420</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$V_{FB}$</td>
<td>FB Reference Voltage</td>
<td>●</td>
<td>0.775</td>
<td>0.825</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FB Line Regulation</td>
<td>$V_{OUT} = 2.7V$ to $5V$</td>
<td>0.1</td>
<td>%/V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{FB}$</td>
<td>FB Input Bias Current</td>
<td>–20</td>
<td>20</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>$V_{OUT}$ Voltage Range</td>
<td>●</td>
<td>2.7</td>
<td>5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buck or Boost Enabled</td>
<td>5.4</td>
<td>5.65</td>
<td>5.95</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boost Enabled</td>
<td>1.8</td>
<td>2</td>
<td>2.2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{IM5}$</td>
<td>$V_{IN} - V_{IM5}$</td>
<td>$V_{IN} &gt; 7V$</td>
<td>4.65</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{INTVC}$</td>
<td>$I_{INTVC}$ Internal Voltage Power Supply</td>
<td>2</td>
<td>5</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{CAP}$</td>
<td>$V_{CAP}$ Voltage Range</td>
<td>0</td>
<td>5</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{VCAP}$</td>
<td>$V_{CAP}$ Current Accuracy</td>
<td>$V_{CAP} = 2V, V_{OUT} = 3.3V, I_{VCAP} = 1A$</td>
<td>–10</td>
<td>10</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{CAP}$ Programmable Current Range</td>
<td>$EN_CHG = High$</td>
<td>0.1</td>
<td>1</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>$V_{ICHG}$</td>
<td>$I_{ICHG}$ Reference Voltage</td>
<td>$EN_CHG = High$</td>
<td>0.78</td>
<td>0.82</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$R_{ICHG}$</td>
<td>$I_{ICHG}$ Set Resistor Range</td>
<td>60.4</td>
<td>604</td>
<td>kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{CFB}$</td>
<td>CFB Input Bias Current</td>
<td>–20</td>
<td>20</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{CFB}$</td>
<td>CFB Reference Voltage</td>
<td>$EN_CHG = High$</td>
<td>0.78</td>
<td>0.8</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CFB Hysteresis</td>
<td>$EN_CHG = High$</td>
<td>30</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CFB Overvoltage Hysteresis Comparator Switch Point</td>
<td>CFB Rising</td>
<td>$V_{CFB} + 0.035$</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CFB Falling</td>
<td>$V_{CFB}$</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{ICL}$</td>
<td>$V_{IN}$ Input Current Limit</td>
<td>$V_{INS} - V_{IN}$ to Disable Charger</td>
<td>37</td>
<td>43</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$V_{INS} - V_{IN}$ to Disable Buck</td>
<td>42</td>
<td>50</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>$V_{INS(CMI)}$</td>
<td>$V_{INS}$ Common Mode Range</td>
<td>3.0</td>
<td>20</td>
<td>V</td>
<td></td>
<td></td>
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<tr>
<td>$f_{SW}$</td>
<td>Switching Frequency</td>
<td>$FB \geq 0.5V$</td>
<td>0.75</td>
<td>1</td>
<td>1.25</td>
<td>MHz</td>
</tr>
<tr>
<td></td>
<td>Foldback Frequency (Buck Only)</td>
<td>$FB \leq 0.3V$</td>
<td>100</td>
<td>kHz</td>
<td></td>
<td></td>
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<tr>
<td>$V_{PFI}$</td>
<td>PFI Falling Threshold</td>
<td>●</td>
<td>0.775</td>
<td>0.8</td>
<td>0.825</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>PFI Hysteresis</td>
<td>17</td>
<td>mV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{PFI}$</td>
<td>PFI Leakage Current</td>
<td>–20</td>
<td>20</td>
<td>nA</td>
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</table>

### 1A Buck Regulator

<table>
<thead>
<tr>
<th>SYMBOL</th>
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<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{SW1}$</td>
<td>SW1 Peak Current</td>
<td>(Note 5)</td>
<td>1.3</td>
<td>1.65</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>$I_{SS}$</td>
<td>Soft-Start Time</td>
<td>1000</td>
<td>µs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Max</td>
<td>Maximum Duty Cycle</td>
<td>$FB = 0V$</td>
<td>100</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{PMOS}$</td>
<td>PMOS On-Resistance</td>
<td>0.5</td>
<td>1</td>
<td>Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{LEAKP}$</td>
<td>PMOS Leakage Current</td>
<td>Buck Disabled</td>
<td>–2</td>
<td>2</td>
<td>µA</td>
<td></td>
</tr>
</tbody>
</table>
**ELECTRICAL CHARACTERISTICS** The * denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at $T_A = 25^\circ C$, $V_{IN} = 12V$ unless otherwise noted. (Note 2)

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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ISW2$</td>
<td>SW2 Peak Current</td>
<td>$R_{BSTPK} = 200k$</td>
<td>4.5</td>
<td>5</td>
<td>5.5</td>
<td>A</td>
</tr>
<tr>
<td>$R_{NMOS}$</td>
<td>NMOS On-Resistance</td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td>mΩ</td>
</tr>
<tr>
<td>$I_{LEAKN}$</td>
<td>NMOS Leakage Current</td>
<td>Boost Disabled</td>
<td>–5</td>
<td>5</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>DC Max</td>
<td>Boost Maximum Duty Cycle</td>
<td></td>
<td>88</td>
<td>92</td>
<td>98</td>
<td>%</td>
</tr>
<tr>
<td>$V_{SBOST}$</td>
<td>Boost Input Supply Voltage Range</td>
<td>$V_{OUT(MAX)} = 4V$</td>
<td>0.75</td>
<td>5</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$AV$</td>
<td>Boost Error Amplifier Voltage Gain</td>
<td>(Note 5)</td>
<td>850</td>
<td></td>
<td></td>
<td>V/V</td>
</tr>
<tr>
<td>$g_m$</td>
<td>Boost Error Amplifier Transconductance</td>
<td></td>
<td>27</td>
<td></td>
<td></td>
<td>µS</td>
</tr>
<tr>
<td>$V_{IBSTPK}$</td>
<td>$IBSTPK$ Reference Voltage</td>
<td></td>
<td>0.775</td>
<td>0.825</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$R_{IBSTPK}$</td>
<td>$IBSTPK$ Set Resistor Range</td>
<td></td>
<td>200</td>
<td>1000</td>
<td></td>
<td>kΩ</td>
</tr>
</tbody>
</table>

**Logic (EN, CHG)**

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IL}$</td>
<td>Input Low Logic Voltage</td>
<td></td>
<td>0.4</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$V_{IH}$</td>
<td>Input High Logic Voltage</td>
<td></td>
<td>1.2</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$I_{IL}, I_{IH}$</td>
<td>Input Low/High Current</td>
<td></td>
<td>-1</td>
<td>1</td>
<td></td>
<td>µA</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 LTC3355-1 is tested under pulsed load conditions such that $T_J = T_A$. The LTC3355-1E is guaranteed to meet specifications from 0°C to 85°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 LTC3355-1I is guaranteed over the –40°C to 125°C operating junction temperature range. Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with board layout, the rated package thermal impedance and other environmental factors. The junction temperature ($T_J$, in °C) is calculated from the ambient temperature ($T_A$, in °C) and power dissipation ($P_D$, in Watts) according to the formula:

$$T_J = T_A + (P_D \cdot \theta_{JA})$$

where $\theta_{JA} = 47^\circ C/W$ for the UF package.

**Note 3:** The LTC3355-1 has a thermal regulation loop that limits the maximum junction temperature to 110°C by limiting the charger current.

**Note 4:** The current limit features of this part are intended to protect the IC from short-term or intermittent fault conditions. Continuous operation above the maximum specified pin current may result in device degradation or failure.

**Note 5:** Guaranteed by design and/or correlation to static test.

**Note 6:** The LTC3355-1 has a thermal shutdown that will shut down the part when the die temperature reaches 155°C.
TYPICAL PERFORMANCE CHARACTERISTICS

**Buck Efficiency**

- **VOUT = 4V**
- **VOUT = 3.3V**
- **VOUT = 5V**

**Boost Efficiency**

- **VOUT = 4V**
- **VOUT = 3.3V**
- **VOUT = 5V**

**Maximum Buck Load Current**

- **VOUT = 4V**
- **L = 6.8µH**
- **INPUT CURRENT SET RESISTOR = 0.05Ω**

**Buck Switch Voltage Drop**

- **VS = 200mV**
- **VS = 400mV**
- **VS = 600mV**

**Oscillator Frequency vs Temperature**

- **FB = 0V**
- **FB = 0.1V**
- **FB = 0.2V**

**Buck Frequency vs Feedback Voltage**

- **VOUT = 3.3V**
- **L = 6.8µH**
- **INPUT CURRENT SET RESISTOR = 0.05Ω**

**Typical Minimum Buck Input Voltage (VOUT = 3.3V)**

- **VOUT = 3.3V**
- **L = 6.8µH**
- **INPUT CURRENT SET RESISTOR = 0.05Ω**

**Typical Minimum Buck Input Voltage (VOUT = 5V)**

- **VOUT = 5V**
- **L = 6.8µH**
- **INPUT CURRENT SET RESISTOR = 0.05Ω**

**T_A = 25°C unless otherwise noted**

For more information [www.analog.com](http://www.analog.com)
TYPICAL PERFORMANCE CHARACTERISTICS

$T_A = 25^\circ C$ unless otherwise noted

- **Boost Switch Current Limit vs Temperature**
- **Buck Switch Current Limit vs Temperature**
- **$V_{OUT}$ vs $V_{INS-VIN}$**
- **Charge Current vs $V_{INS-VIN}$**
- **Charge Current vs $V_{OUT-VCAP}$**
- **Charge Current vs Junction Temperature**
- **Buck Load Regulation**
- **Buck Line Regulation**
- **Boost Load Regulation**

For more information [www.analog.com](http://www.analog.com)
TYPICAL PERFORMANCE CHARACTERISTICS

TA = 25°C unless otherwise noted

**Boost Line Regulation**

![Graph showing Boost Line Regulation](image1)

**Logic Input Threshold vs Temperature (EN_CHG)**

![Graph showing Logic Input Threshold](image2)

**PFi Threshold vs Temperature**

![Graph showing PFi Threshold](image3)

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**Buck Load Step PWM**

![Graph showing Buck Load Step PWM](image4)

**Boost Load Step PWM**

![Graph showing Boost Load Step PWM](image5)

**Boost Error Amplifier Voltage Gain vs Temperature**

![Graph showing Boost Error Amplifier Voltage Gain](image6)

**Boost Error Amplifier Transconductance vs Temperature**

![Graph showing Boost Error Amplifier Transconductance](image7)

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For more information [www.analog.com](http://www.analog.com)
PIN FUNCTIONS

PFI (Pin 1): Input to the Power-Fail Comparator. The input voltage below which a power-fail occurs can be programmed by connecting this pin to an external resistor divider between VIN and ground.

FB (Pin 2): Sets the VOUT voltage for both the buck and boost voltage control loops via an external resistor divider. The reference voltage is 0.8V.


VINS (Pin 4): Input Current Limit Sense Voltage Pin. Connect a sense resistor from VINS to VIN. Must be locally bypassed with a low ESR ceramic capacitor. Connect to VIN if input current limit is not needed.

VIN (Pin 5): Input Power Pin Supplies Current to the Internal Regulator and Buck Power Switch. Must be locally bypassed with a low ESR ceramic capacitor.

VINM5 (Pin 6): This pin is used to filter an internal supply regulator which generates a voltage of VIN – 4.65V. Connect a 1µF ceramic capacitor from VINM5 to VIN.

SW1 (Pin 7): Buck Output of the Internal Power Switch. Connect this pin to the catch diode and inductor. Minimize trace area at this pin to reduce EMI.

EN_CHG (Pin 8): A high on this pin enables the supercapacitor charger.

NC (Pin 9): No Connect.

NC (Pin 10): No Connect.

CFB (Pin 11): This pin is used to program the VCAP voltage via an external resistor divider. The reference voltage is 0.8V.

ICHG (Pin 12): This pin programs the VCAP charge current by connecting a resistor to ground.

NC (Pin 13): No Connect.

VCAP (Pin 14): This pin is the constant current, constant voltage linear charger output and connects to the supercapacitor.

VOUT (Pin 15): The Output Voltage Supply. The buck powers this supply from VIN when the input voltage is present and the boost powers this supply from VCAP when the input voltage has dropped out.

SW2 (Pin 16, 17): Boost Output of the Internal Power Switch. Connect these pins to the rectifier diode and inductor. Minimize trace area at these pins to reduce EMI.

INTVCC (Pin 18): This pin is used to filter an internal supply. Connect a 1µF ceramic capacitor from this pin to ground. INTVCC is 2.5V during start-up until VOUT exceeds 2.5V then INTVCC follows VOUT.

VCBST (Pin 19): This pin is the output of the boost internal error amplifier. The voltage on this pin controls the peak switch current for the boost regulator. Connect an RC series network from this pin to ground to compensate the boost control loop.

IBSTPK (Pin 20): This pin programs the boost peak current limit by connecting a resistor to ground.

GND (Exposed Pad Pin 21): Ground. The exposed pad must be connected to a continuous ground plane on the second layer of the printed circuit board by several vias directly under the part to achieve optimum thermal conduction.
Figure 1. LTC3355-1 Block Diagram
The LTC3355-1 is a 1A buck regulator with a built-in backup boost converter to allow temporary backup, or ride-through, of V\textsubscript{OUT} during a sudden loss of V\textsubscript{IN} power. The device contains all functions necessary to provide seamless charging of a supercapacitor (or other storage element), monitoring of V\textsubscript{IN}, V\textsubscript{OUT}, and V\textsubscript{CAP}, and automatic switch-over to backup power. When the buck is disabled an internal circuit blocks reverse current between V\textsubscript{OUT} and V\textsubscript{IN}.

**Start-Up**

When the part first starts up the only voltage available is V\textsubscript{IN}, since V\textsubscript{OUT} and V\textsubscript{CAP} are at zero volts. An internal 2.5V regulator powers INTV\textsubscript{CC} from V\textsubscript{IN} during start-up. INTV\textsubscript{CC} powers all of the low voltage circuits. The buck regulator is enabled and will drive V\textsubscript{OUT} positive through an inductor until the feedback voltage at FB equals 0.8V. When V\textsubscript{OUT} exceeds 2.5V, INTV\textsubscript{CC} will exactly track V\textsubscript{OUT} and the current for the internal low voltage circuits will now be supplied from V\textsubscript{OUT} instead of from V\textsubscript{IN}. A 1µF external ceramic capacitor is required for INTV\textsubscript{CC} to filter internal switching noise.

**Buck Switching Regulator**

The LTC3355-1 uses a 1MHz constant frequency peak current mode nonsynchronous monolithic buck regulator with internal slope compensation to control the voltage at V\textsubscript{OUT} when V\textsubscript{IN} is available. An error amplifier compares the divided output voltage at FB with a reference voltage of 0.8V and adjusts the peak inductor current accordingly. The buck operates only in PWM mode. The buck is internally compensated and can operate over an input voltage range of 3V to 20V. An internal soft-start ramp limits inrush current during start-up. Frequency foldback protection helps to prevent inductor current runaway during start-up or short-circuit conditions.

**Input Current Limit**

The (optional) input current limit is programmed via an external sense resistor connected between V\textsubscript{INS} and V\textsubscript{IN}. As the input current limit is reached the charge current will be reduced. If the charge current has been reduced to zero and the input current continues to increase the buck regulator current drive capability will be reduced. The maximum sense voltage is 50mV. The input current limit includes the LTC3355-1 quiescent current for high accuracy over a wide current range.

**Boost Switching Regulator**

When V\textsubscript{IN} is not available, a monolithic 1MHz constant frequency peak current mode boost regulator with internal slope compensation is enabled and the buck regulator is disabled via the PFI pin. The boost regulator uses the voltage stored at V\textsubscript{CAP} as an input supply and regulates the V\textsubscript{OUT} voltage. An error amplifier compares the divided output voltage at FB with a reference voltage of 0.8V and adjusts the peak inductor current accordingly. The IB\textsubscript{STPK} pin sets the peak boost current over a range of 1A to 5A allowing for lower current backup applications. The boost switching regulator is compensated by adding a series RC network from the V\textsubscript{CBST} pin to ground. The boost regulator can operate over an input voltage range (V\textsubscript{CAP}) of 0.5V to 5V. The boost regulator uses the same feedback pin and error amplifier as the buck and regulates to the same V\textsubscript{OUT} voltage. The boost operates only in PWM mode. In PWM mode as the load current is decreased, the switch turns on for a shorter period each cycle. If the load current is further decreased, the boost converter will skip cycles to maintain output voltage regulation.

**Charger**

The supercapacitor is charged by an internal 1A constant current/constant voltage linear charger that supplies current from V\textsubscript{OUT} to V\textsubscript{CAP}. The charger will be enabled when V\textsubscript{IN} is above a programmable voltage via the PFI pin, when the EN\textsubscript{CHG} pin is high, and when V\textsubscript{OUT} is in regulation. The value of the resistor on the I\textsubscript{CHG} pin determines the charger current. An internal amplifier servos the I\textsubscript{CHG} voltage to 0.8V to create the reference current for the charge. The V\textsubscript{CAP} voltage is divided down by an external resistor divider that is connected to the CFB pin. A hysteretic comparator compares the CFB voltage to a 0.8V reference voltage and turns the charger off when these voltages are the same. The V\textsubscript{CAP} voltage represents the fully charged supercapacitor voltage available to supply the boost regulator when V\textsubscript{IN} has dropped out. When
OPERATION

CFB decays to 30mV below the CFB reference voltage the charger will be turned on. The LTC3355-1 includes a soft-start circuit to minimize the inrush current at the start of charge. When the charger is enabled, the charge current ramps from zero to full-scale over a period of approximately 1ms. This has the effect of minimizing the transient load current on VOUT.

The VCAP output also has an overvoltage protection circuit which monitors the CFB voltage. If the CFB voltage increases above the CFB reference voltage by 35mV a hysteretic comparator switches in an 8k resistor from VCAP to ground. This will bleed any excess charge from the supercapacitor. When the CFB voltage decays to the CFB reference voltage the comparator will remove the 8k bleed resistor. Excess charge can come from leakage currents associated with the boost rectifier diode.

VIN Status Monitor

The PFI input always monitors the VIN voltage and determines when VIN is in dropout. VIN is divided down by an external resistor divider and this voltage is then compared to a reference voltage of 0.8V. If the PFI voltage is below the reference voltage the buck regulator and the charger will be disabled and the boost regulator will be enabled.

Thermal Regulation

As the die temperature increases due to internal power dissipation, a thermal regulator will limit the die temperature to 110°C by reducing the charger current. The thermal regulation protects the LTC3355-1 from excessive temperature and allows the user to push the limits of the power handling capability of a given circuit board without the risk of damaging the LTC3355-1. Another feature is that the charge current can be set according to typical, rather than worst-case ambient temperatures for a given application with the assurance that the charger will automatically reduce the charge current in worst-case conditions.

Thermal Shutdown

The LTC3355-1 includes a thermal shutdown circuit in addition to the thermal regulator. If for any reason, the die temperature exceeds 155°C, the entire part shuts down. The part will resume normal operation once the temperature drops about 15°C, to approximately 140°C.

VOUT Overvoltage, Undervoltage Lockout

The LTC3355-1 includes an overvoltage protection circuit to ensure that VOUT does not exceed 5.65V (nominal). An internal resistor divider from VOUT is connected to an amplifier that will regulate VOUT as the overvoltage limit is reached. The LTC3355-1 includes undervoltage lockout which disabling the boost when VOUT is < 2V typical.
FB Resistor Network
The \( V_{\text{OUT}} \) voltage is programmed with a resistor divider between the \( V_{\text{OUT}} \) pin and the FB pin. Choose the resistor values according to:

\[
R_1 = R_2 \left( \frac{V_{\text{OUT}}}{0.8V} - 1 \right)
\]

Reference designators refer to Figure 1. 1% resistors are recommended to maintain output voltage accuracy.

CFB Resistor Network
The \( V_{\text{CAP}} \) voltage is programmed with a resistor divider between the \( V_{\text{CAP}} \) pin and the CFB pin. Choose the resistor values according to:

\[
R_3 = R_4 \left( \frac{V_{\text{CAP}}}{0.8V} - 1 \right)
\]

Reference designators refer to Figure 1. 1% resistors are recommended to maintain the capacitor float voltage accuracy.

\( I_{\text{CHG}} \) Set Resistor
The charge current at \( V_{\text{CAP}} \) is set by connecting a resistor from \( I_{\text{CHG}} \) to ground. Choose the resistor value according to:

\[
\text{Charger Current (Amps)} = \frac{60400}{R_5}
\]

Reference designators refer to Figure 1. 1% resistors are recommended to maintain charge current accuracy.

\( I_{\text{BSTPK}} \) Set Resistor
The boost peak current limit is set by connecting a resistor from \( I_{\text{BSTPK}} \) to ground. Choose the resistor value according to:

\[
\text{Boost Peak Current Limit (Amps)} = \frac{1E6}{R_6}
\]

Reference designators refer to Figure 1. 1% resistors are recommended to maintain boost peak current accuracy.

PFI Resistor Network
The \( V_{\text{IN}} \) dropout voltage is programmed with a resistor divider between the \( V_{\text{IN}} \) pin and the PFI pin. Choose the resistor values according to:

\[
R_7 = R_8 \left( \frac{V_{\text{IN}}}{0.8V} - 1 \right)
\]

Reference designators refer to Figure 1. 1% resistors are recommended to maintain the PFI threshold voltage accuracy.

Input Voltage Range
The minimum input voltage is determined by the dropout of the buck regulator. The dropout is dependent on the maximum load current and the buck internal switch resistance. The minimum input voltage due to buck dropout is:

\[
V_{\text{IN(MIN)}} = V_{\text{OUT}} + (I_{\text{SW(PEAK)}} \cdot 1\Omega)
\]

Buck Inductor \( L_1 \) Selection and Maximum Output Current
A good starting point for the inductor value is:

\[
L = (V_{\text{OUT}} + V_D) \cdot \frac{1.8}{f_{\text{SW}}}
\]

where \( f_{\text{SW}} \) is the switching frequency in MHz, \( V_{\text{OUT}} \) is the buck output voltage, \( V_D \) is the catch diode drop (~0.5V) and \( L \) is the inductor value in \( \mu \text{H} \).

The inductor’s RMS current rating must be greater than the maximum load current and its saturation current should be 30% higher. To keep the efficiency high, the series resistance (DCR) should be less than 0.1\( \Omega \), and the core material should be intended for high frequency applications. Table 1 lists several inductor vendors.

For robust operation and fault conditions (start-up or short-circuit) and high input voltage (>15V), the saturation current should be chosen high enough to ensure that the inductor peak current does not exceed 2.2A.
The current in the inductor is a triangle wave with an average value equal to the load current. The peak inductor and switch current is:

\[ I_{SW(PEAK)} = I_L(PEAK) = I_{OUT(MAX)} + \frac{\Delta I_L}{2} \]

where \( I_L(PEAK) \) is the peak inductor current, \( I_{OUT(MAX)} \) is the maximum output load current and \( \Delta I_L \) is the inductor ripple current. The LTC3355-1 limits the switch current in order to protect the part. Therefore, the maximum output current that the buck will deliver depends on the switch current limit, the inductor value, and the input and output voltages.

When the switch is off, the potential across the inductor is the output voltage plus the catch diode drop. This gives the peak-to-peak ripple current in the inductor:

\[ \Delta I_L = (1-DC) \frac{V_{OUT} + V_D}{L \cdot f_{SW}} \]

where \( f_{SW} \) is the switching frequency of the buck, DC is the duty cycle and \( L \) is the value of the inductor.

To maintain output regulation, the inductor peak current must be less than the buck switch current limit. The maximum output current is:

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

Choosing an inductor value so that the ripple current is small will allow a maximum output current near the switch current limit.

One approach to choosing the inductor is to start with the simple rule above, look at the available inductors, and choose one to meet cost or space goals. Then use the equations to check that the buck will be able to deliver the required output current. These equations assume that the inductor current is continuous. Discontinuous operation occurs when \( I_{OUT} \) is less than \( \Delta I_L/2 \).

**Buck Input Capacitor**

Bypass \( V_{IN} \) and \( V_{INS} \) with a ceramic capacitor of X7R or X5R type. A 10µF to 22µF ceramic capacitor is adequate for bypassing. Note that a larger \( V_{INS} \) bypass capacitor may be required if the input power supply source impedance is high or there is significant inductance due to long wires or cables. This can be provided with a lower performance electrolytic capacitor in parallel with the ceramic capacitor.

Buck regulators draw current from the input supply in pulses with very fast rise and fall times. The input capacitors are required to reduce the resulting voltage ripple at \( V_{INS} \) and \( V_{IN} \) and to force this very high frequency switching into a tight local loop, minimizing EMI. The capacitors must be placed close to the LTC3355-1 pins.

**Output Capacitor and Output Ripple**

The output capacitor has two essential functions. Along with the inductor, it filters the square wave generated by the buck regulator to produce the DC output. In this role it determines the output ripple, and low impedance at the switching frequency is important. The second function is to store energy in order to satisfy transient loads and stabilize the buck regulator control loop. Ceramic capacitors have very low equivalent series resistance (ESR) and provide the best ripple performance. A good starting value is:

\[ C_{OUT} = f_{SW} \left( \frac{100}{V_{OUT}} \right) \]

where \( f_{SW} \) is in MHz 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.
APPLICATIONS INFORMATION

When choosing a capacitor look carefully through the data sheet to find out what the actual capacitance is under operating conditions (applied voltage and temperature). A physically larger capacitor, or one with a higher voltage rating, may be required. High performance tantalum or electrolytic capacitors can be used for the output capacitor.

Low ESR is important, so choose one that is intended for use in switching regulators. The ESR should be specified by the supplier, and should be 0.05Ω or less. Table 2 lists several capacitor vendors.

Table 2. Capacitor Vendors

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>URL</th>
<th>PART SERIES</th>
<th>COMMANDS</th>
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<tbody>
<tr>
<td>Panasonic</td>
<td><a href="http://www.panasonic.com">www.panasonic.com</a></td>
<td>Ceramic, Polymer,</td>
<td>EEF Series,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tantalum</td>
<td>POSCAP</td>
</tr>
<tr>
<td>Kemet</td>
<td><a href="http://www.kemet.com">www.kemet.com</a></td>
<td>Ceramic, Tantalum</td>
<td>T494, T495</td>
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<tr>
<td>Murata</td>
<td><a href="http://www.murata.com">www.murata.com</a></td>
<td>Ceramic</td>
<td></td>
</tr>
<tr>
<td>AVX</td>
<td><a href="http://www.avxcorp.com">www.avxcorp.com</a></td>
<td>Ceramic, Tantalum</td>
<td>TPS Series</td>
</tr>
<tr>
<td>Taiyo Yuden</td>
<td><a href="http://www.taiyo-yuden.com">www.taiyo-yuden.com</a></td>
<td>Ceramic</td>
<td></td>
</tr>
</tbody>
</table>

Buck Catch Diode Selection

The catch diode (D1 in Figure 1) conducts current only during the switch-off time. The average forward current in normal operation can be calculated from:

\[ I_{D\text{(AVG)}} = I_{OUT}(1 - DC) \]

where DC is the duty cycle. The only reason to consider a diode with a larger current rating than necessary for nominal operation is for the case of shorted or overloaded output conditions. For the worst case of shorted output the diode average current will then increase to a value that depends on the switch current limit.

If operating at high temperatures select a Schottky diode with low reverse leakage current.

Buck Soft-Start

When the buck is enabled soft-start is engaged. Soft-start reduces the inrush current by taking more time to reach the final output voltage. This is achieved by limiting the buck output current over a 1ms period.

Boost Rectifier Diode

A Schottky rectifier diode (D2 in Figure 1) is recommended for the boost rectifier diode. The diode should have low forward drop at the peak operating current, low reverse current and fast reverse recovery times. The current rating should take into account power dissipation as well as output current requirements. The diode current rating should be equal to or greater than the average forward current which is normally equal to the output current. The reverse breakdown voltage should be greater than the \( V_{OUT} \) voltage plus the peak ringing voltage that is generated at the SW2 pin. Generally higher reverse breakdown diodes will have lower reverse currents. Refer to Table 3 for Schottky diode vendors.

Table 3. Schottky Diode Vendors

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>( V_R ) (V)</th>
<th>( I_{AVE} ) (A)</th>
<th>( V_F ) AT 1A (mV)</th>
<th>( V_F ) AT 2A (mV)</th>
<th>( I_R ) AT 5V 85°C (µA)</th>
</tr>
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<tbody>
<tr>
<td>Diodes Inc.</td>
<td></td>
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<tr>
<td>B130</td>
<td>30</td>
<td>1</td>
<td>460</td>
<td>430</td>
<td>20</td>
</tr>
<tr>
<td>B230</td>
<td>30</td>
<td>2</td>
<td></td>
<td></td>
<td>100</td>
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<tr>
<td>Rohm</td>
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<tr>
<td>RSX201VA-30</td>
<td>30</td>
<td>1</td>
<td>360</td>
<td></td>
<td>600</td>
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<tr>
<td>Vishay</td>
<td></td>
<td></td>
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<tr>
<td>VS-20MQ060</td>
<td>60</td>
<td>2.1</td>
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</table>

Boost Inductor L2 Selection and Maximum Output Current

The boost inductor L2 should be 3.3\( \mu \)H to ensure fast transfer of power from the buck to the boost after a \( V_{IN} \) power outage. Refer to Table 1 for inductor vendors.

Boost Frequency Compensation

The LTC3355-1 boost switching regulator uses current mode control to regulate \( V_{OUT} \). This simplifies loop compensation and ceramic output capacitors can be used. The boost regulator does not require the ESR of the output capacitor for stability. Frequency compensation is provided by the components connected to the \( V_{CBST} \) pin. Generally a capacitor (\( C_C \)) and resistor (\( R_C \)) in series to ground are used as shown in Figure 1.
APPLICATIONS INFORMATION

Loop compensation determines the stability and transient performance. Optimizing the design of the compensation network depends on the application and type of output capacitor. A practical approach is to start with one of the circuits in this data sheet that is similar to your application and tune the compensation network to optimize the performance. Stability should then be checked across all operating conditions, including load current, input voltage, and temperature. Figure 2 shows an equivalent circuit for the boost regulator control loop. The error amplifier is a transconductance amplifier with a finite output impedance. The power section consisting of a modulator, power switch, and inductor, is modeled as a transconductance amplifier generating an output current proportional to the voltage at the \( V_{\text{CBST}} \) pin. Note that the output capacitor integrates this current, and that the capacitor on the \( V_{\text{CBST}} \) pin (\( C_C \)) integrates the error amplifier output current, resulting in two poles in the loop. In most cases a zero is required and comes from either the ESR of the output capacitor or from a resistor \( R_C \) in series with \( C_C \). This simple model works well as long as the inductor value is not too high and the loop crossover frequency is much lower than the switching frequency. A phase lead capacitor across the feedback divider may improve the transient response. A small capacitor from \( V_{\text{CBST}} \) to ground may have to be added if phase lead is used.

PCB Layout

For proper operation and minimum EMI, care must be taken during printed circuit board layout. Large switched currents flow in the \( V_{\text{IN}} \), \( SW1 \), \( SW2 \), and paddle ground pins, in the buck catch diode, in the boost rectifier diode, and in the input capacitor. The loops formed by these components should be as small as possible. These components, along with the inductors and output capacitor, should be placed on the same side of the circuit board, and their connections should be made on that layer. All connections to GND should be made at a common star ground point or directly to a local, unbroken ground plane below these components. \( SW1 \) and \( SW2 \) nodes should be laid out carefully to avoid interference. Keep the FB, PFI, \( I_{\text{CHG}} \), \( I_{\text{BSTPK}} \), \( V_{\text{CBST}} \), and CFB nodes small so that the ground traces will shield them from the switching nodes. To keep thermal resistance low, extend the ground plane as much as possible and add thermal vias under and near the paddle. Keep in mind that the thermal design must keep the junctions of the LTC3355-1 below the specified absolute maximum temperature.

Figure 2. Model for Boost Loop Response
**APPLICATIONS INFORMATION**

### High Temperature Considerations

The PCB must provide heat sinking to keep the LTC3355-1 cool. The exposed pad on the bottom of the package may be soldered to a copper area which should be tied to large copper layers below with thermal vias; these layers will spread the heat dissipated by the LTC3355-1. Place additional vias to reduce thermal resistance further. With these steps, the thermal resistance from the die (or junction) to ambient can be reduced to $\theta_{JA} = 47°C/W$ or less. With 100 LFPM airflow, this resistance can fall by another 25%.

The LTC3355-1 has two thermal circuits. The first thermal circuit is operational when the buck and charger are enabled. If the die temperature exceeds 110°C the charge current will be reduced. When the LTC3355-1 is in boost mode the high current thermal shutdown will turn the boost off when the die temperature reaches 155°C. The high temperature shutdown is active in all modes of operation.

---

**TYPICAL APPLICATIONS**

**Tantalum Capacitor Charger and Ride-Through Backup Supply**

[Diagram of Tantalum Capacitor Charger and Ride-Through Backup Supply]
PACKAGE DESCRIPTION

UF Package
20-Lead Plastic QFN (4mm × 4mm)
(Reference LTC DWG # 05-08-1710 Rev A)

NOTE:
1. DRAWING IS PROPOSED TO BE MADE A JEDEC PACKAGE OUTLINE MO-220 VARIATION (WGGD-1)—TO BE APPROVED
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
APPLY SOLDER MASK TO AREAS THAT ARE NOT SOLDERED

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TYPICAL APPLICATION

NiMH Trickle Charger and Ride-Through Backup Supply

RELATION PARTS

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC3225/</td>
<td>150mA Supercapacitor Charger</td>
<td>Low Noise, Constant Frequency Charging of Two Series Supercapacitors. Automatic Cell Balancing Prevents Capacitor Overvoltage During Charging. Programmable Charge Current (Up to 150mA). 2mm × 3mm DFN Package</td>
</tr>
<tr>
<td>LTC3225-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTC3226</td>
<td>2-Cell Supercapacitor Charger with Backup PowerPath™ Controller</td>
<td>1×/2× Multimode Charge Pump Supercapacitor Charger Ideal Diode Main PowerPath™ Controller, Internal 2A LDO Back-Up Supply, 16-Lead (3mm × 3mm) QFN Package</td>
</tr>
<tr>
<td>LTC3355</td>
<td>20V 1A Buck DC/DC with Integrated SCAP Charger and Backup Regulator</td>
<td>Full-Featured LTC3355-1 with Addition of MODE, PFOB, RSTB, and CPGOOD Pins and Functions</td>
</tr>
<tr>
<td>LT3485</td>
<td>Photo-flash Capacitor Chargers with Output Voltage Monitor and Integrated IGBT Drive</td>
<td>Integrated IGBT Driver; Voltage Output Monitor; Uses Small Transformers: 5.8mm × 5.8mm × 3mm. Operates from Two AA Batteries, Single Cell Li-Ion or Any Supply from 1.8V Up to 10V. No Output Voltage Divider Needed; No External Schottky Diode Required. Charges Any Size Photo-flash Capacitor; 10-Lead (3mm × 3mm) DFN Package</td>
</tr>
<tr>
<td>LTC3625/</td>
<td>1A High Efficiency 2-Cell Supercapacitor Charger with Automatic Cell Balancing</td>
<td>High Efficiency Step-Up/Step-Down Charging of Two Series Supercapacitors. Automatic Cell Balancing Prevents Capacitor Overvoltage During Charging. Programmable Charging Current Up to 500mA (Single Inductor), 1A (Dual Inductor). Vin = 2.7V to 5.5V, Low No-Load Quiescent Current: 23µA, 12-lead 3mm × 4mm DFN Package</td>
</tr>
<tr>
<td>LTC3625-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT3750</td>
<td>Capacitor Charger Controller</td>
<td>Charges Any Size Capacitor; Easily Adjustable Output Voltage. Drives High Current NMOS FETs; Primary-Side Sense—No Output Voltage Divider Necessary. Wide Input Range: 3V to 24V; Drives Gate to VCC – 2V. 10-Lead MS Package</td>
</tr>
<tr>
<td>LT3751</td>
<td>High Voltage Capacitor Charger Controller with Regulation</td>
<td>Charges Any Size Capacitor; Low Noise Output in Voltage Regulation Mode. Stable Operation Under a No-Load Condition; Integrated 2A MOSFET Gate Driver with Rail-to-Rail Operation for VCC ≤ 8V. Wide Input VCC Voltage Range (5V to 24V). 20-Pin QFN 4mm × 5mm and 20-Lead TSSOP Packages</td>
</tr>
<tr>
<td>LTC4425</td>
<td>Supercapacitor Charger with Current Limited Ideal Diode</td>
<td>Constant-Current/Constant-Voltage Linear Charger for 2-cell Series Supercapacitor Stack. VIN: Li-Ion/Polymer Battery, a USB Port, or a 2.7V to 5.5V Current-Limited Supply. 2A Charge Current, Auto Cell Balancing, 20µA Quiescent Current, Shutdown Current &lt;2µA. Low Profile 12-Pin 3mm × 3mm DFN or a 12-Lead MSOP Package</td>
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