1.1A Step-Up DC/DC Converter in ThinSOT™ with Integrated Soft-Start

June 2003

FEATURES

- **1.3MHz Switching Frequency**
- **Low V_{CESAT} Switch: 330mV at 1.1A**
- **High Output Voltage: Up to 40V**
- **Wide Input Range: 2.4V to 16V**
- **Dedicated Soft-Start Pin**
- 5V at 540mA from 3.3V Input
- 12V at 270mA from 5V Input
- Uses Small Surface Mount Components
- Low Shutdown Current: <1µA
- Pin-for-Pin Compatible with the LT1930 and LT1613
- Low Profile (1mm) SOT-23 Package

APPLICATIONS

- Digital Cameras
- White LED Power Supply
- Cellular Phones
- Medical Diagnostic Equipment
- Local 5V or 12V Supply
- TFT-LCD Bias Supply
- xDSL Power Supply

DESCRIPTION

The LT®3467 SOT-23 switching regulator combines a 42V, 1.1A switch with a soft-start function. Pin compatible with the LT1930, its low V_{CESAT} bipolar switch enables the device to deliver high current outputs in a small footprint. The LT3467 switches at 1.3MHz, allowing the use of tiny, low cost and low height inductors and capacitors. High inrush current at start-up is eliminated using the programmable soft-start function. A single external capacitor sets the current ramp rate. A constant frequency current mode PWM architecture results in low, predictable output noise that is easy to filter.

The high voltage switch on the LT3467 is rated at 42V, making the device ideal for boost converters up to 40V as well as SEPIC and flyback designs. The LT3467 can generate 5V at up to 540mA from a 3.3V supply or 5V at 450mA from four alkaline cells in a SEPIC design. The LT3467 is available in a low profile (1mm) 6-lead SOT-23 package.

TYPICAL APPLICATION

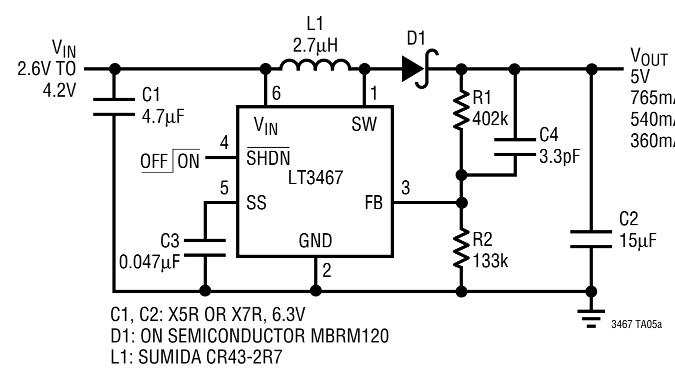
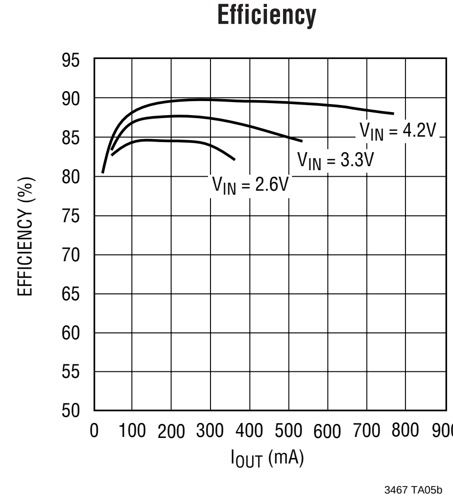


Figure 1. Single Li-Ion Cell to 5V Boost Converter



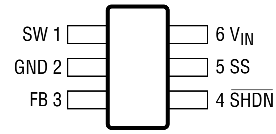
ABSOLUTE MAXIMUM RATINGS

(Note 1)

V_{IN} Voltage 16V
SW Voltage ....−0.4V to 42V
FB Voltage 2.5V
Current Into FB Pin .... ±1mA
$\overline{SHDN}$ Voltage 16V
Maximum Junction Temperature .... 125°C
Operating Temperature Range (Note 2) .. −40°C to 85°C
Storage Temperature Range .... −65°C to 150°C
Lead Temperature (Soldering, 10 sec) .... 300°C

PACKAGE/ORDER INFORMATION

TOP VIEW



S6 PACKAGE
6-LEAD PLASTIC TSOT-23

$T_{JMAX} = 125°C$, $\theta_{JA} = 256°C/W$

ORDER PART NUMBER
LT3467ES6
S6 PART MARKING
LTACH

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

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are T_A = 25°C. V_{IN} = 3V, $V_{\overline{SHDN}}$ = V_{IN} unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Minimum Operating Voltage				2.2	2.4	V
Maximum Operating Voltage					16	V
Feedback Voltage			1.230	1.255	1.270	V
		●	1.220		1.280	V
FB Pin Bias Current	(Note 3)	●		10	50	nA
Quiescent Current	$V_{\overline{SHDN}}$ = 2.4V, Not Switching			1.2	2	mA
Quiescent Current in Shutdown	$V_{\overline{SHDN}}$ = 0.5V, V_{IN} = 3V			0.01	1	µA
Reference Line Regulation	2.6V ≤ V_{IN} ≤ 16V			0.01	0.05	%/V
Switching Frequency			1	1.3	1.6	MHz
Maximum Duty Cycle			88	94		%
		●	87			
Minimum Duty Cycle				10		%
Switch Current Limit	At Minimum Duty Cycle		1.4	1.8	2.5	A
	At Maximum Duty Cycle (Note 4)		0.8	1.2	1.9	
Switch V_{CESAT}	I_{SW} = 1.1A			330	500	mV
Switch Leakage Current	V_{SW} = 5V			0.01	1	µA
$\overline{SHDN}$ Input Voltage High			2.4			V
$\overline{SHDN}$ Input Voltage Low					0.5	V
$\overline{SHDN}$ Pin Bias Current	$V_{\overline{SHDN}}$ = 3V			16	32	µA
	$V_{\overline{SHDN}}$ = 0V			0	0.1	µA
SS Charging Current	V_{SS} = 0.5V		2	3	4.5	µA

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

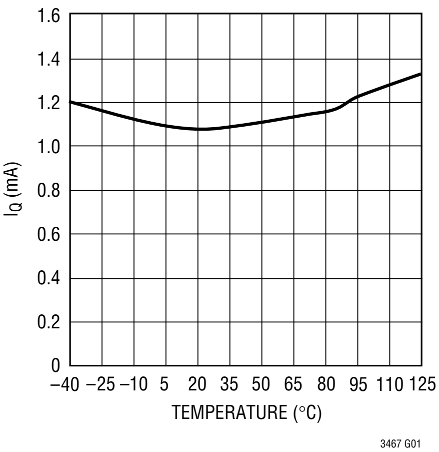
Note 2: The LT3467E is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the −40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.

Note 3: Current flows out of the pin.

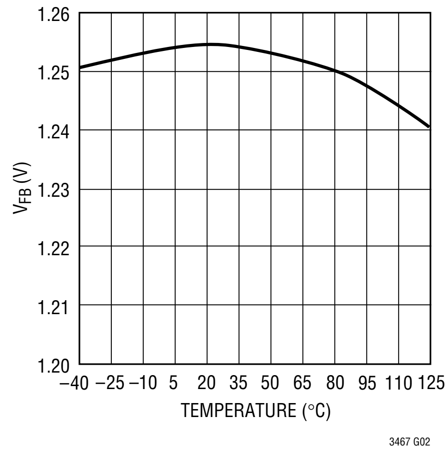
Note 4: See Typical Performance Characteristics for guaranteed current limit vs duty cycle.

TYPICAL PERFORMANCE CHARACTERISTICS

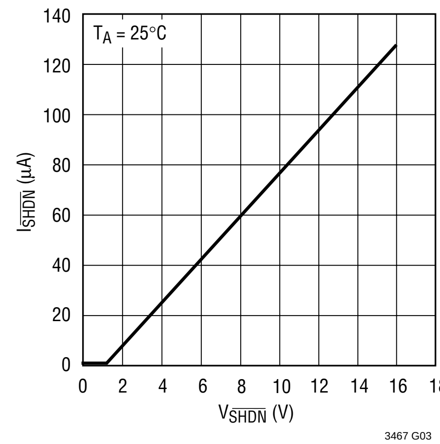
Quiescent Current vs Temperature



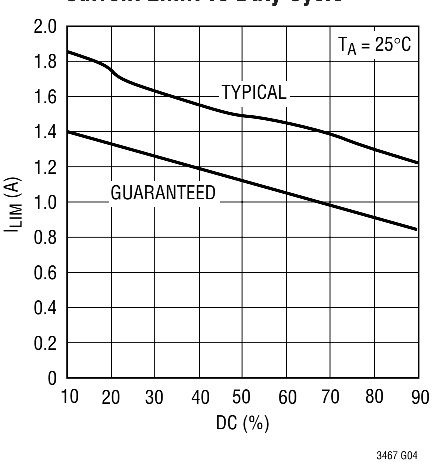
FB Pin Voltage vs Temperature



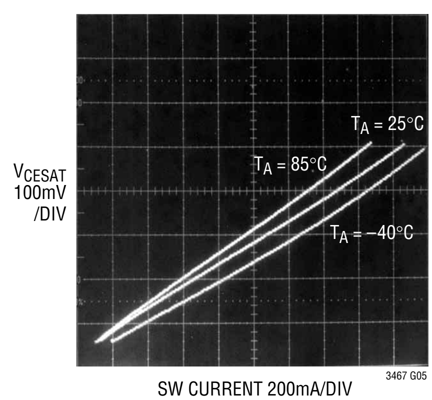
$\overline{SHDN}$ Current vs $\overline{SHDN}$ Voltage



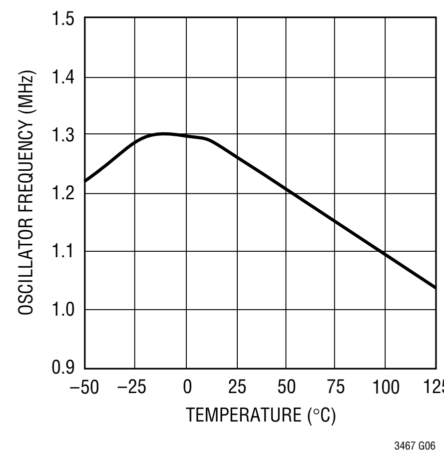
Current Limit vs Duty Cycle



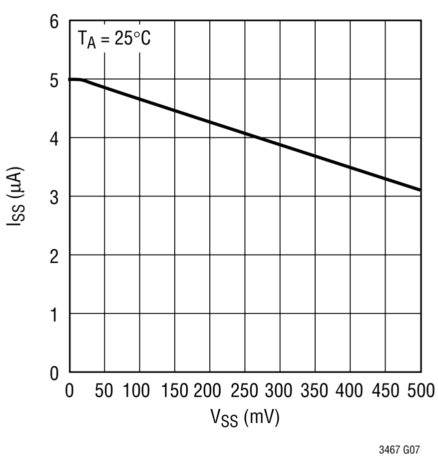
Switch Saturation Voltage vs Switch Current



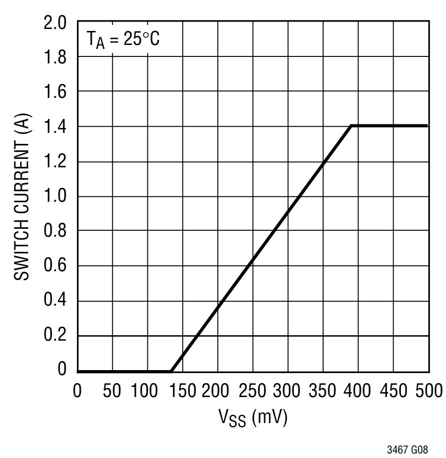
Oscillator Frequency vs Temperature



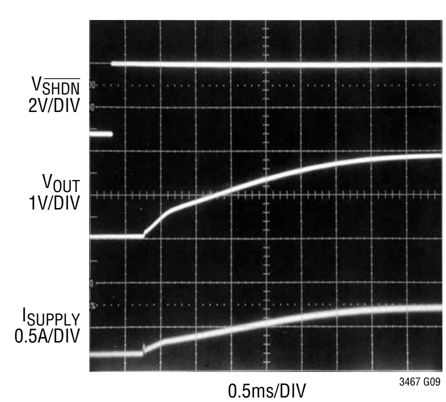
Soft-Start Current vs Soft-Start Voltage



Peak Switch Current vs Soft-Start Voltage



Start-Up Waveform (Figure 1 Circuit)



PIN FUNCTIONS

SW (Pin 1): Switch Pin. (Collector of internal NPN power switch) Connect inductor/diode here and minimize the metal trace area connected to this pin to minimize EMI.

GND (Pin 2): Ground. Tie directly to local ground plane.

FB (Pin 3): Feedback Pin. Reference voltage is 1.255V. Connect resistive divider tap here. Minimize trace area at FB. Set V_{OUT} = 1.255V(1 + R1/R2).

$\overline{\text{SHDN}}$ (Pin 4): Shutdown Pin. Tie to 2.4V or more to enable device. Ground to shut down.

SS(Pin 5): Soft-Start Pin. Place a soft-start capacitor here. Upon start-up, 4μA of current charges the capacitor to 1.255V. Use a larger capacitor for slower start-up. Leave floating if not in use.

V_{IN} (Pin 6): Input Supply Pin. Must be locally bypassed.

BLOCK DIAGRAM

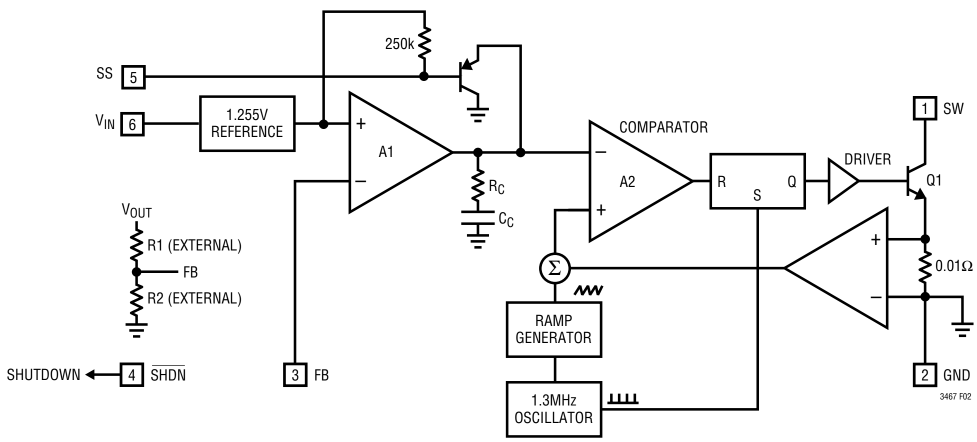


Figure 2. Block Diagram

OPERATION

The LT3467 uses a constant frequency, current-mode control scheme to provide excellent line and load regulation. Refer to the Block Diagram above. At the start of each oscillator cycle, the SR latch is set which turns on the power switch Q1. A voltage proportional to the switch current is added to a stabilizing ramp and the resulting sum is fed into the positive terminal of the PWM comparator A2. When this voltage exceeds the level at the negative input of A2, the SR latch is reset, turning off the power switch. The level at the negative input of A2 is set by the error amplifier A1, and is simply an amplified version of the difference between the feedback voltage and the reference voltage of 1.255V. In this manner, the error amplifier sets the correct peak current level to keep the output in regulation. If the error amplifier's output increases, more current is delivered to the output. Similarly, if the error decreases, less current is delivered. The soft-start feature of the LT3467 allows for clean start-up conditions by limiting the rate of voltage rise at the output of comparator A1 which, in turn, limits the peak switch current. The soft-start pin is connected to a reference voltage of 1.255V through a 250k resistor, providing 4μA of current to charge the soft-start capacitor. Typical values for the soft-start capacitor range from 10nF to 200nF. The LT3467 has a current limit circuit not shown in the Block Diagram. The switch current is constantly monitored and not allowed to exceed the maximum switch current (typically 1.4A). If the switch current reaches this value, the SR latch is reset regardless of the state of comparator A2. This current limit protects the power switch as well as the external components connected to the LT3467.

APPLICATIONS INFORMATION

Duty Cycle

The typical maximum duty cycle of the LT3467 is 94%. The duty cycle for a given application is given by:

$$DC = \frac{|V_{OUT}| + |V_D| - |V_{IN}|}{|V_{OUT}| + |V_D| - |V_{CESAT}|}$$

Where V_D is the diode forward voltage drop and V_{CESAT} is in the worst case 330mV (at 1.1A)

The LT3467 can be used at higher duty cycles, but it must be operated in the discontinuous conduction mode so that the actual duty cycle is reduced.

Setting Output Voltage

R1 and R2 determine the output voltage.

Vout = 1.255V (1+ R1/R2)

Switching Frequency and Inductor Selection

The LT3467 switches at 1.3 MHz, allowing for small valued inductors to be used. 4.7µH or 10µH will usually suffice. Choose an inductor that can handle at least 1.2A without saturating, and ensure that the inductor has a low DCR (copper-wire resistance) to minimize I^2R power losses. Note that in some applications, the current handling requirements of the inductor can be lower, such as in the SEPIC topology where each inductor only carries one half of the total switch current. For better efficiency, use similar valued inductors with a larger volume. Many different sizes and shapes are available from various manufacturers. Choose a core material that has low losses at 1.3 MHz, such as ferrite core.

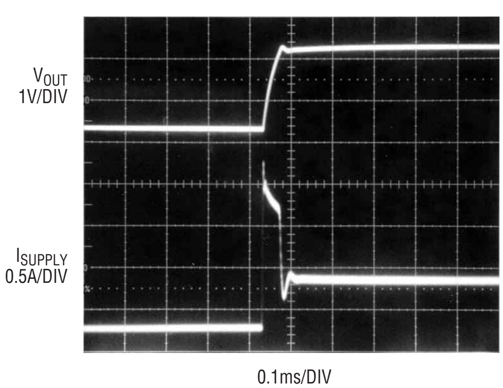
Table 1. Inductor Manufacturers.

Sumida	(847) 956-0666	www.sumida.com
TDK	(847) 803-6100	www.tdk.com
Murata	(714) 852-2001	www.murata.com

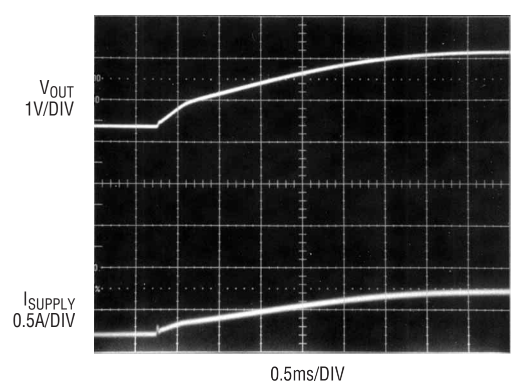
Soft-Start

The soft-start feature provides a way to limit the inrush current drawn from the supply upon startup. An internal 250k resistor charges the external soft start capacitor to 1.255V. After the capacitor reaches 0.15V the rate of voltage rise at the output of the comparator A1 tracks the rate of voltage rise of the soft-start capacitor. This limits the inrush current drawn from the supply during startup. Once the part is shut down, the soft start capacitor is quickly discharged to 0.4V, then slowly discharged through the 250k resistor to ground. If the part is to be shut down and re-enabled in a short period of time while soft-start is used, you must ensure that the soft-start capacitor has enough time to discharge before re-enabling the part. Typical values of the soft-start capacitor range from 10nF to 200nF.

Supply Current of Figure 1 During Startup without Soft-Start Capacitor



Supply Current of Figure 1 During Startup with 47nF Soft-Start Capacitor



APPLICATIONS INFORMATION

CAPACITOR SELECTION

Low ESR (equivalent series resistance) capacitors should be used at the output to minimize the output ripple voltage. Multi-layer ceramic capacitors are an excellent choice, as they have extremely low ESR and are available in very small packages. X5R dielectrics are preferred, followed by X7R, as these materials retain the capacitance over wide voltage and temperature ranges. A 4.7µF to 15µF output capacitor is sufficient for most applications, but systems with very low output currents may need only a 1µF or 2.2µF output capacitor. Solid tantalum or OSCON capacitors can be used, but they will occupy more board area than a ceramic and will have a higher ESR. Always use a capacitor with a sufficient voltage rating.

Ceramic capacitors also make a good choice for the input decoupling capacitor, which should be placed as close as possible to the LT3467. A 1µF to 4.7µF input capacitor is sufficient for most applications. Table 2 shows a list of several ceramic capacitor manufacturers. Consult the manufacturers for detailed information on their entire selection of ceramic parts.

Table 2. Ceramic Capacitor Manufacturers

Taiyo Yuden	(408) 573-4150	www.t-yuden.com
AVX	(803) 448-9411	www.avxcorp.com
Murata	(714) 852-2001	www.murata.com

The decision to use either low ESR (ceramic) capacitors or the higher ESR (tantalum or OSCON) capacitors can affect the stability of the overall system. The ESR of any capacitor, along with the capacitance itself, contributes a zero to the system. For the tantalum and OSCON capacitors, this zero is located at a lower frequency due to the higher value of the ESR, while the zero of a ceramic capacitor is at a much higher frequency and can generally be ignored.

A phase lead zero can be intentionally introduced by placing a capacitor (C4) in parallel with the resistor (R1) between V_{OUT} and V_{FB} as shown in Figure 1. The frequency of the zero is determined by the following equation.

$$f_Z = \frac{1}{2\pi \cdot R1 \cdot C4}$$

By choosing the appropriate values for the resistor and capacitor, the zero frequency can be designed to improve the phase margin of the overall converter. The typical target value for the zero frequency is between 35kHz to 55kHz. Figure 3 shows the transient response of the step-up converter from Figure 8 without the phase lead capacitor C4. Although adequate for many applications, phase margin is not ideal as evidenced by 2-3 "bumps" in both the output voltage and inductor current. A 22pF capacitor for C4 results in ideal phase margin, which is revealed in Figure 4 as a more damped response and less overshoot.

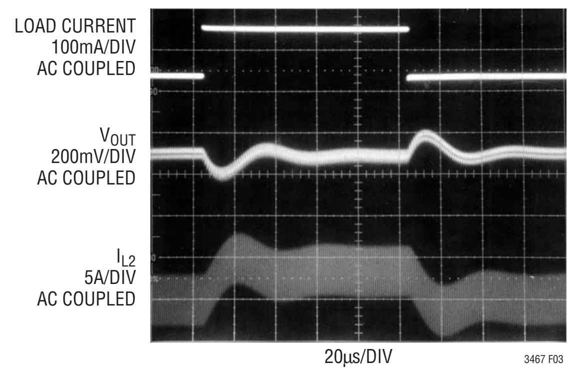


Figure 3. Transient Response of Figure 8's Step-Up Converter without Phase Lead Capacitor

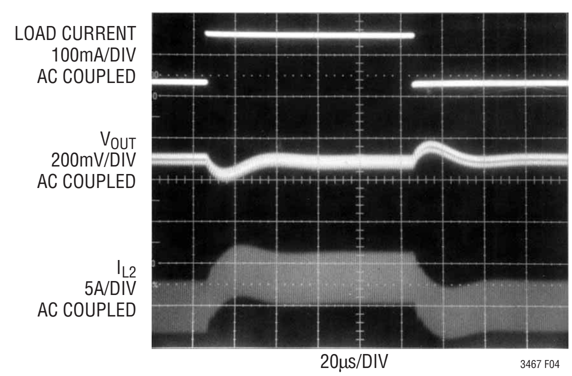


Figure 4. Transient Response of Figure 8's Step-Up Converter with 22pF Phase Lead Capacitor

APPLICATIONS INFORMATION

DIODE SELECTION

A Schottky diode is recommended for use with the LT3467. The Philips PMEG 2005 is a very good choice. Where the switch voltage exceeds 20V, use the PMEG 3005 (a 30V diode). Where the switch voltage exceeds 30V, use the PMEG 4005 (a 40V diode). These diodes are rated to handle an average forward current of 0.5A. In applications where the average forward current of the diode exceeds 0.5A, a Philips PMEG 2010 rated at 1A is recommended. For higher efficiency, use a diode with better thermal characteristics such as the On Semiconductor MBRM120 (a 20V diode) or the MBRM140 (a 40V diode).

SETTING OUTPUT VOLTAGE

To set the output voltage, select the values of R1 and R2 (see Figure 1) according to the following equation.

$$R1 = R2\left(\frac{V_{OUT}}{1.255V} - 1\right)$$

A good value for R2 is 13.3k which sets the current in the resistor divider chain to 1.255V/13.3k = 94μA.

LAYOUT HINTS

The high speed operation of the LT3467 demands careful attention to board layout. You will not get advertised performance with careless layout. Figure 5 shows the recommended component placement.

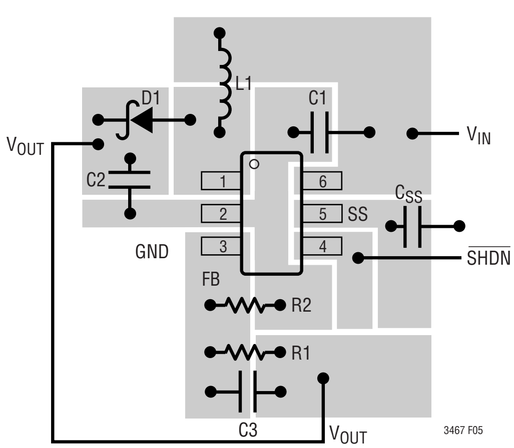


Figure 5. Suggested Layout

Compensation—Theory

Like all other current mode switching regulators, the LT3467 needs to be compensated for stable and efficient operation. Two feedback loops are used in the LT3467: a fast current loop which does not require compensation, and a slower voltage loop which does. Standard Bode plot analysis can be used to understand and adjust the voltage feedback loop.

As with any feedback loop, identifying the gain and phase contribution of the various elements in the loop is critical. Figure 6 shows the key equivalent elements of a boost converter. Because of the fast current control loop, the power stage of the IC, inductor and diode have been replaced by the equivalent transconductance amplifier g_{mp}. g_{mp} acts as a current source where the output current is proportional to the V_C voltage. Note that the maximum output current of g_{mp} is finite due to the current limit in the IC.

From Figure 6, the DC gain, poles and zeroes can be calculated as follows:

$$\text{Output Pole: } P1 = \frac{2}{2 \bullet \pi \bullet R_L \bullet C_{OUT}}$$

$$\text{Error Amp Pole: } P2 = \frac{1}{2 \bullet \pi \bullet R_O \bullet C_C}$$

$$\text{Error Amp Zero: } Z1 = \frac{1}{2 \bullet \pi \bullet R_C \bullet C_C}$$

$$\text{DC GAIN: } A = \frac{1.255}{V_{OUT}} \bullet g_{ma} \bullet R_O \bullet g_{mp} \bullet R_L \bullet \frac{1}{2}$$

$$\text{ESR Zero: } Z2 = \frac{1}{2 \bullet \pi \bullet R_{ESR} \bullet C_{OUT}}$$

$$\text{RHP Zero: } Z3 = \frac{V_{IN}^2 \bullet R_L}{2 \bullet \pi \bullet V_{OUT}^2 \bullet L}$$

$$\text{High Frequency Pole: } P3 > \frac{f_S}{3}$$

$$\text{Phase Lead Zero: } Z4 = \frac{1}{2 \bullet \pi \bullet R1 \bullet C_{PL}}$$

$$\text{Phase Lead Pole: } P4 = \frac{1}{2 \bullet \pi \bullet C_{PL} \bullet \frac{R1 \bullet R2}{R1 + R2}}$$

APPLICATIONS INFORMATION

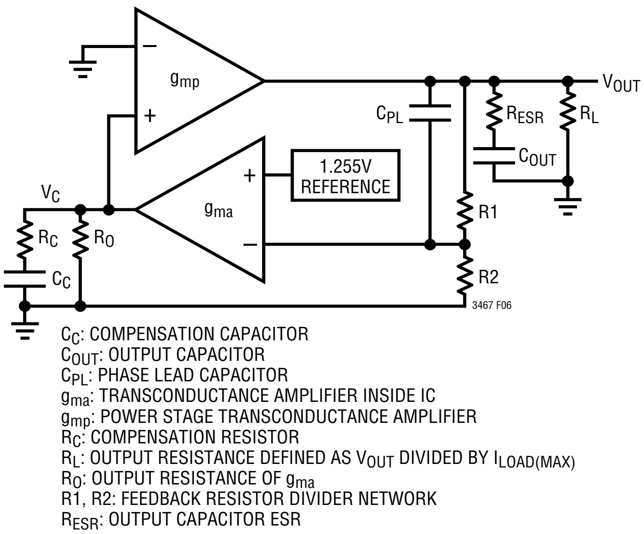


Figure 6. Boost Converter Equivalent Model

The Current Mode zero is a right half plane zero which can be an issue in feedback control design, but is manageable with proper external component selection.

Using the circuit of Figure 1 as an example, the following table shows the parameters used to generate the Bode plot shown in Figure 7.

Table 3. Bode Plot Parameters

Parameter	Value	Units	Comment
R_L	10.4	Ω	Application Specific
C_{OUT}	15	µF	Application Specific
R_{ESR}	10	mΩ	Application Specific
R_O	0.4	MΩ	Not Adjustable
C_C	60	pF	Not Adjustable
C_{PL}	3.3	pF	Adjustable
R_C	100	kΩ	Not Adjustable
R1	402	kΩ	Adjustable
R2	133	kΩ	Adjustable
V_{OUT}	5	V	Application Specific
V_{IN}	3.3	V	Application Specific
g_{ma}	35	µmho	Not Adjustable
g_{mp}	7.5	mho	Not Adjustable
L	2.7	µH	Application Specific
f_S	1.3	MHz	Not Adjustable

From Figure 7, the phase is –138° when the gain reaches 0dB giving a phase margin of 42°. This is more than adequate. The crossover frequency is 37kHz.

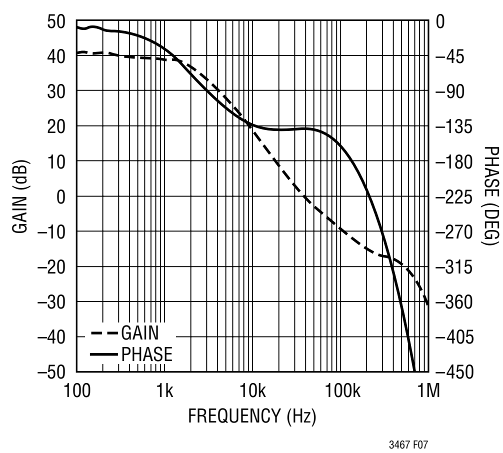
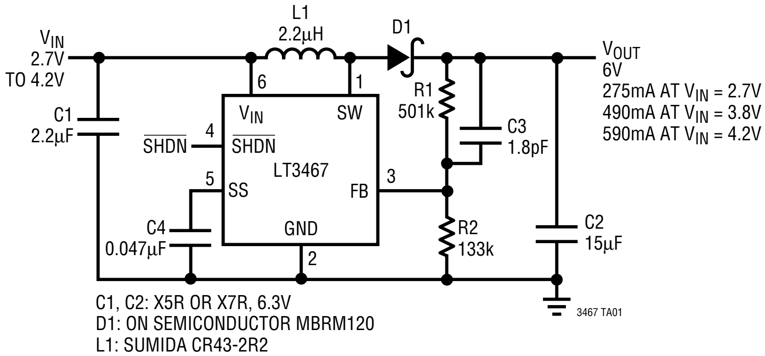


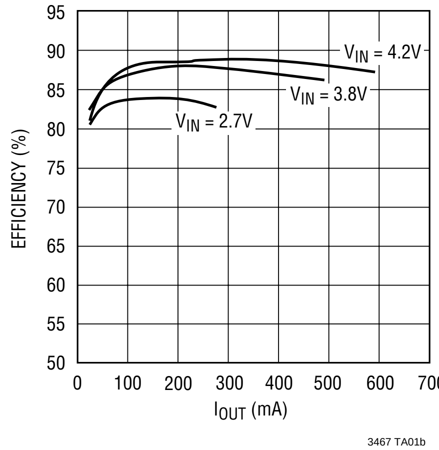
Figure 7.Bode Plot of 3.3V to 5V Application

TYPICAL APPLICATIONS

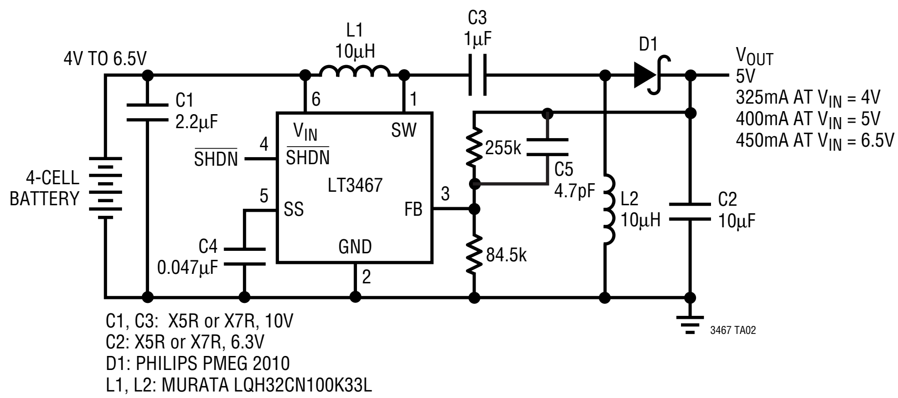
Lithium-Ion to 6V Step-Up DC/DC Converter



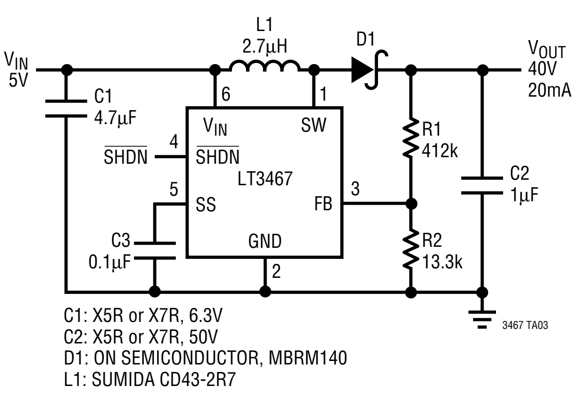
Li-Ion to 6V



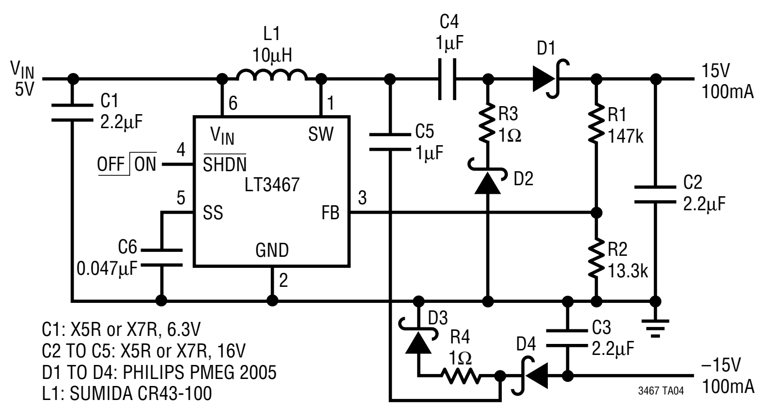
4-Cell to 5V SEPIC Converter



5V to 40V Boost Converter

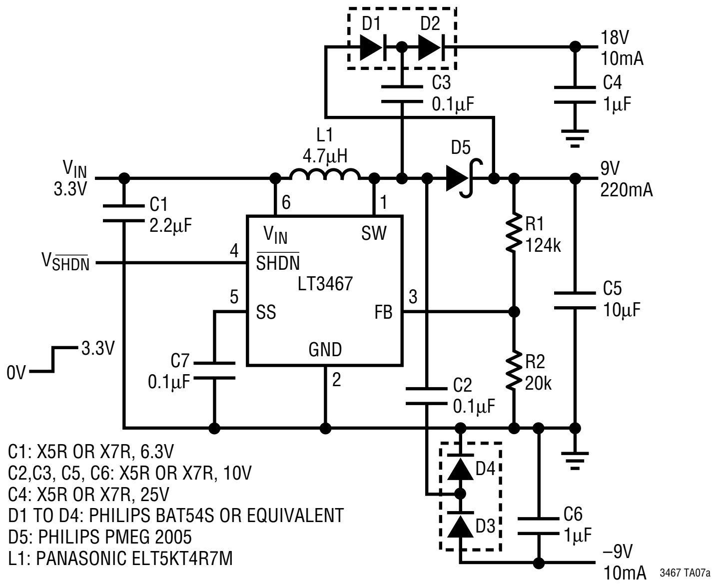


±15V Dual Output Converter with Output Disconnect

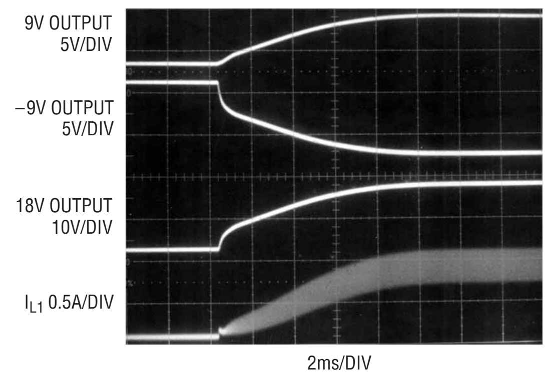


TYPICAL APPLICATIONS

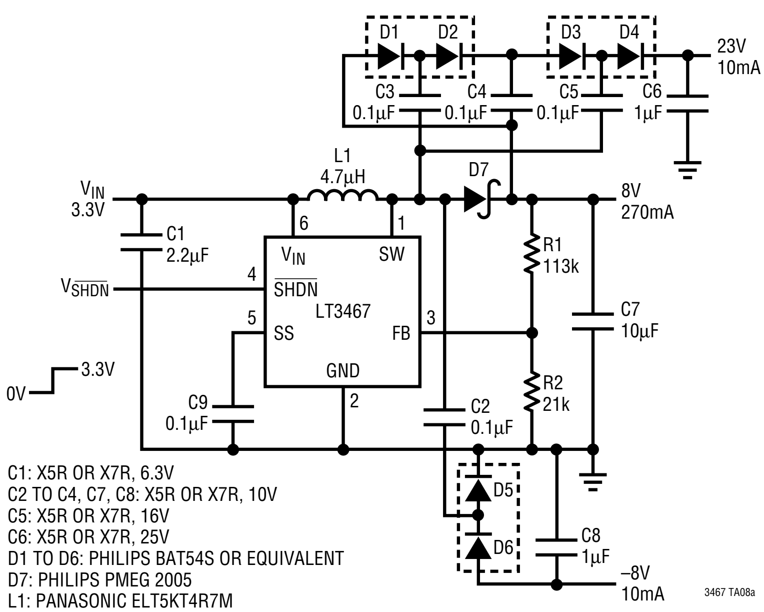
9V, 18V, –9V Triple Output TFT-LCD Bias Supply with Soft-Start



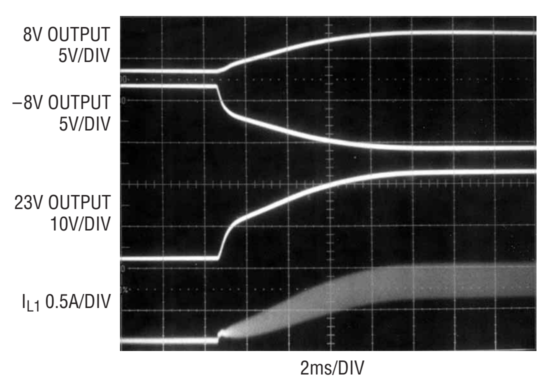
Start-Up Waveforms



8V, 23V, –8V Triple Output TFT-LCD Bias Supply with Soft-Start

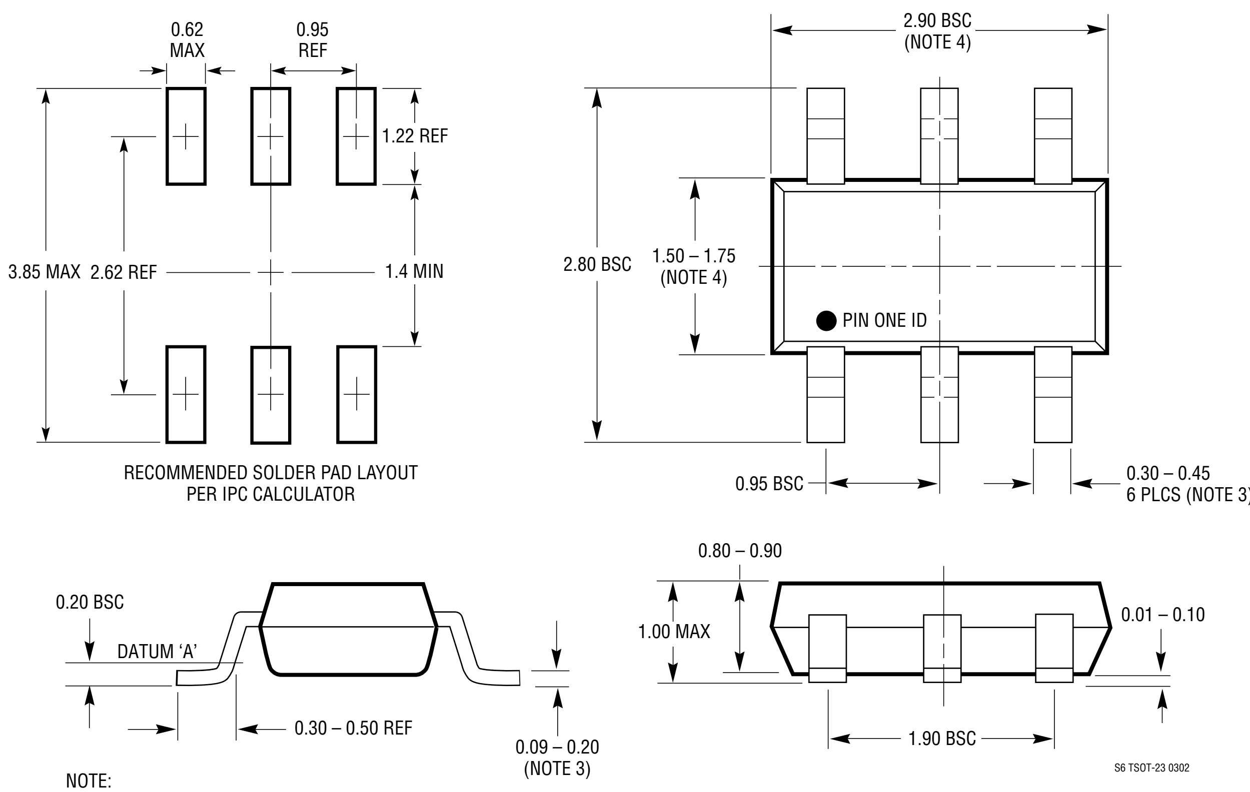


Start-Up Waveforms



PACKAGE DESCRIPTION

S6 Package
6-Lead Plastic TSOT-23
(Reference LTC DWG # 05-08-1636)



NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. JEDEC PACKAGE REFERENCE IS MO-193

TYPICAL APPLICATIONS

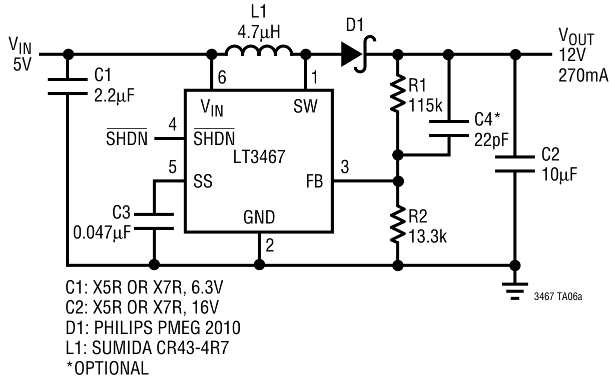
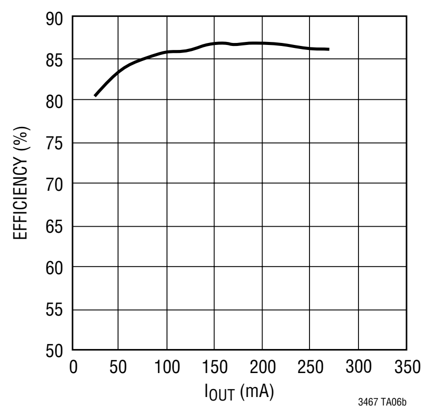


Figure 8. 5V to 12V, 270mA Step-Up Converter

5V to 12V Efficiency



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1371/LT1371HV	3A (I_{SW}), 500kHz, High Efficiency Step-Up DC/DC Converter	V_{IN}: 2.7V to 30V, $V_{OUT(MAX)}$: 35V/42V, I_Q: 4mA, I_{SD}: <12µA, DD,TO220-7, S20 Package
LT1613	550mA (I_{SW}), 1.4MHz, High Efficiency Step-Up DC/DC Converter	90% Efficiency, V_{IN}: 0.9V to 10V, $V_{OUT(MAX)}$: 34V, I_Q: 3mA, I_{SD}: <1µA, ThinSOT Package
LT1615/LT1615-1	300mA/80mA (I_{SW}), High Efficiency Step-Up DC/DC Converter	V_{IN} = 1V to 15V, $V_{OUT(MAX)}$: 34V, I_Q: 20µA, I_{SD}: <1µA, ThinSOT Package
LT1618	1.5A (I_{SW}), 1.25MHz, High Efficiency Step-Up DC/DC Converter	90% Efficiency, V_{IN}: 1.6V to 18V, $V_{OUT(MAX)}$: 35V, I_Q: 1.8mA, I_{SD}: <1µA, MS Package
LTC1700	No R_{SENSE}™, 530kHz, Synchronous Step-Up DC/DC Controller	95% Efficiency, V_{IN}: 0.9V to 5V, I_Q: 200µA, I_{SD}: <10µA, MS Package
LTC1871	Wide Input Range, 1MHz, No R_{SENSE} Current Mode Boost, Flyback and SEPIC Controller	92% Efficiency, V_{IN}: 2.5V to 36V, I_Q: 250µA, I_{SD}: <10µA, MS Package
LT1930/LT1930A	1A (I_{SW}), 1.2MHz/2.2MHz, High Efficiency Step-Up DC/DC Converter	High Efficiency, V_{IN}: 2.6V to 16V, $V_{OUT(MAX}$: 34V, I_Q: 4.2mA/5.5mA, I_{SD}: <1µA, ThinSOT Package
LT1946/LT1946A	1.5A (I_{SW}), 1.2MHz/2.7MHz, High Efficiency Step-Up DC/DC Converter with Soft-Start	High Efficiency, V_{IN}: 2.45V to 16V, $V_{OUT(MAX)}$: 34V, I_Q: 3.2mA, I_{SD}: <1µA, MS8 Package
LT1961	1.5A (I_{SW}), 1.25MHz, High Efficiency Step-Up DC/DC Converter	90% Efficiency, V_{IN}: 3V to 25V, $V_{OUT(MAX)}$: 35V, I_Q: 0.9mA, I_{SD}: 6µA, MS8E Package
LTC3400/LTC3400B	600mA (I_{SW}), 1.2MHz, Synchronous Step-Up DC/DC Converter	92% Efficiency, V_{IN}: 0.85V to 5V, $V_{OUT(MAX)}$: 5V, I_Q: 19µA/300µA, I_{SD}: <1µA, ThinSOT Package
LTC3401	1A (I_{SW}), 3MHz, Synchronous Step-Up DC/DC Converter	97% Efficiency, V_{IN}: 0.5V to 5V, $V_{OUT(MAX)}$: 5.5V, I_Q: 38µA, I_{SD}: <1µA, MS Package
LTC3402	2A (I_{SW}), 3MHz, Synchronous Step-Up DC/DC Converter	97% Efficiency, V_{IN}: 0.5V to 5V, $V_{OUT(MAX)}$: 5.5V, I_Q: 38µA, I_{SD}: <1µA, MS Package
LTC3464	85mA (I_{SW}), High Efficiency Step-Up DC/DC Converter with Integrated Schottky and PNP Disconnect	V_{IN}: 2.3V to 10V, $V_{OUT(MAX)}$: 34V, I_Q: 25µA, I_{SD}: <1µA, ThinSOT Package

No R_{SENSE} is a trademark of Linear Technology Corporation.

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