

ABSOLUTE MAXIMUM RATINGS

(Note 1)

V_{IN} , V_{OUT} Voltages	–0.5V to 6V
SW Voltage	–0.5V to 6V
V_C , R_t Voltages	–0.5V to ($V_{OUT} + 0.3V$)
PGOOD, SHDN, FB, MODE Voltages	–0.5V to 6V
Operating Temperature Range (Note 2) ..	–40°C to 85°C
Storage Temperature Range	–65°C to 125°C
Lead Temperature (Soldering, 10 sec)	300°C

Order Options Tape and Reel: Add #TR
 Lead Free: Add #PBF Lead Free Tape and Reel: Add #TRPBF
 Lead Free Part Marking: <http://www.linear.com/leadfree/>

PACKAGE/ORDER INFORMATION

MS PACKAGE 10-LEAD PLASTIC MSOP $T_{JMAX} = 125^{\circ}C$ $\theta_{JA} = 130^{\circ}C/W$ 1 LAYER BOARD $\theta_{JA} = 100^{\circ}C/W$ 4 LAYER BOARD	ORDER PART NUMBER
	LTC3402EMS
	MS PART MARKING
	LTSK

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

ELECTRICAL CHARACTERISTICS

The ● denotes specifications that apply over the full operating temperature range, otherwise specifications are at $T_A = 25^{\circ}C$. $V_{IN} = 1.2V$, $V_{OUT} = 3.3V$ unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Minimum Start-Up Voltage	I _{LOAD} = <1mA			0.85	1.0	V
Minimum Operating Voltage	(Note 4)	●			0.5	V
Output Voltage Adjust Range		●	2.6		5.5	V
Feedback Voltage		●	1.22	1.25	1.28	V
Feedback Input Current	V _{FB} = 1.25V			1	50	nA
Quiescent Current—Burst Mode Operation	V _C = 0V, MODE/SYNC = 3.3V (Note 3)			38	65	μA
Quiescent Current—SHDN	SHDN = 0V, Not Including Switch Leakage			0.1	1	μA
Quiescent Current—Active	V _C = 0V, MODE/SYNC = 0V, R _t = 300k (Note 3)			440	800	μA
NMOS Switch Leakage				0.1	5	μA
PMOS Switch Leakage				0.1	10	μA
NMOS Switch On Resistance				0.16		Ω
PMOS Switch On Resistance				0.18		Ω
NMOS Current Limit		●	2	2.5		A
NMOS Burst Current Limit				0.66		A
Maximum Duty Cycle	R _t = 15k	●	80	85		%
Minimum Duty Cycle		●			0	%
Switching Frequency	R _t = 15k	●	1.6	2	2.4	MHz
MODE/SYNC Input High			1.4			V
MODE/SYNC Input Low					0.4	V
MODE/SYNC Input Current	V _{MODE/SYNC} = 5.5V			0.01	1	μA
Error Amp Transconductance	ΔI = −5μA to 5μA, V _C = V _{FB}			85		μmhos
PGOOD Threshold	Referenced to Feedback Voltage		−6	−9	−12	%

ELECTRICAL CHARACTERISTICS

The ● denotes specifications that apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ\text{C}$. $V_{IN} = 1.2\text{V}$, $V_{OUT} = 3.3\text{V}$ unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
PGOOD Low Voltage	$I_{PGOOD} = 1\text{mA}$ $V_{OUT} = 1\text{V}$, $I_{PGOOD} = 20\mu\text{A}$		0.1	0.2	V
			0.1	0.4	V
PGOOD Leakage	$V_{PGOOD} = 5.5\text{V}$		0.01	1	μA
SHDN Input High	$V_{IN} = V_{SHDN}$	1			V
SHDN Input Low				0.4	V
SHDN Input Current	$V_{SHDN} = 5.5\text{V}$		0.01	1	μA

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 LTC3402E 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

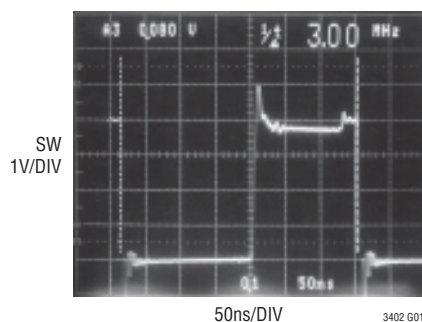
with statistical process controls.

Note 3: Current is measured into the V_{OUT} pin since the supply current is bootstrapped to the output pin and in the application will reflect to the input supply by $(V_{OUT}/V_{IN}) \cdot I/\text{Efficiency}$. The outputs are not switching.

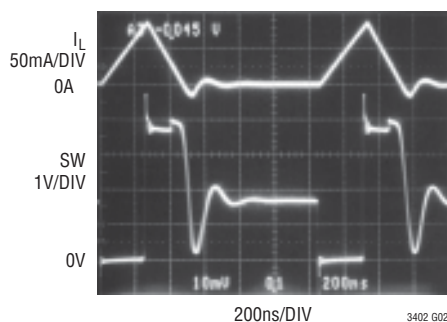
Note 4: Once the output is started, the IC is not dependent upon the V_{IN} supply.

TYPICAL PERFORMANCE CHARACTERISTICS ($T_A = 25^\circ\text{C}$ unless otherwise noted)

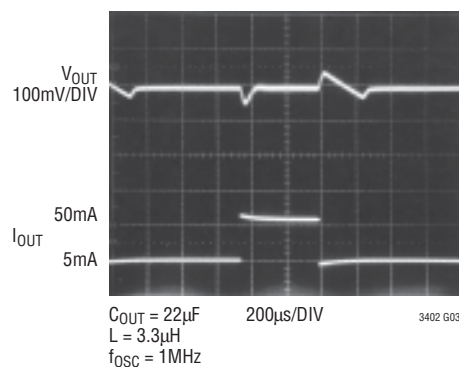
Switching Waveform on SW Pin



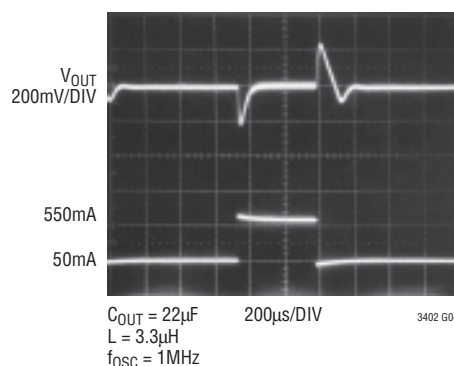
SW Pin and Inductor Current (I_L) in Discontinuous Mode. Ringing Control Circuitry Eliminates High Frequency Ringing



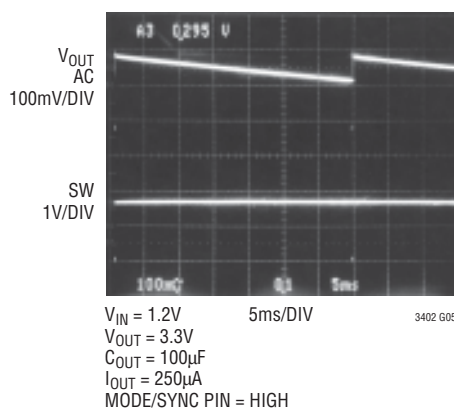
Transient Response 5mA to 50mA



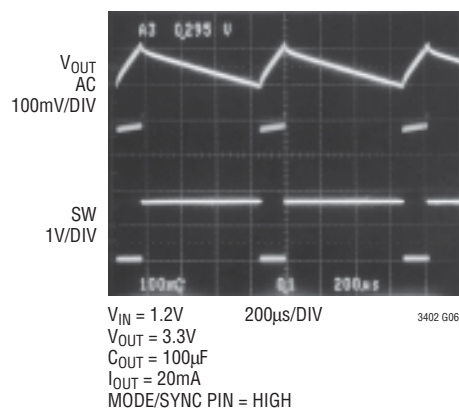
Transient Response 50mA to 500mA



Burst Mode Operation

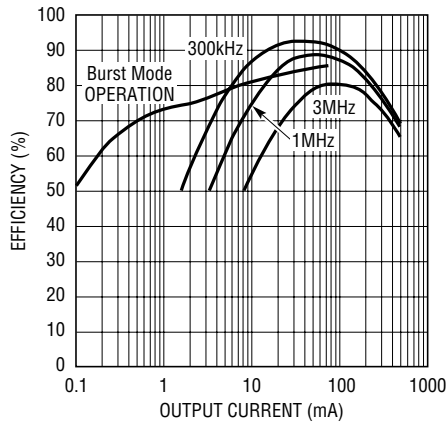


Burst Mode Operation

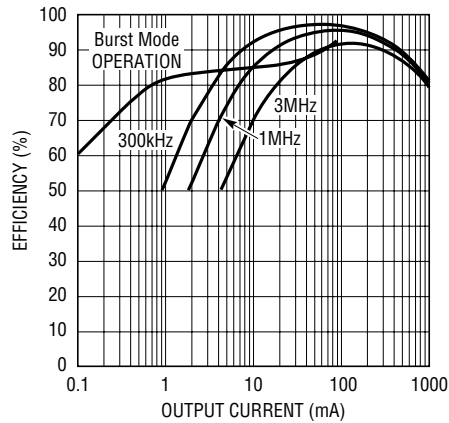


3402fb

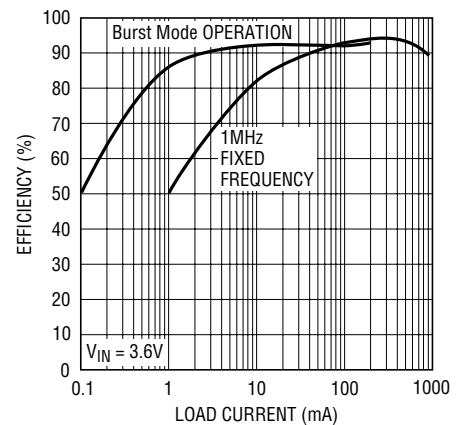
TYPICAL PERFORMANCE CHARACTERISTICS ($T_A = 25^\circ\text{C}$ unless otherwise noted)

Converter Efficiency 1.2V to 3.3V


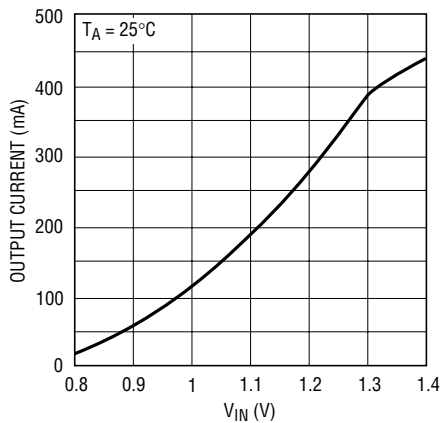
3402 G07

Converter Efficiency 2.4V to 3.3V


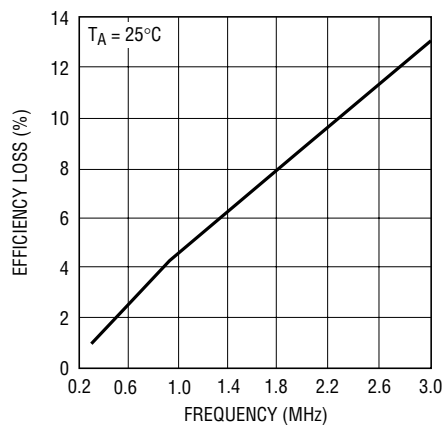
3402 G08

Converter Efficiency 3.6V to 5V


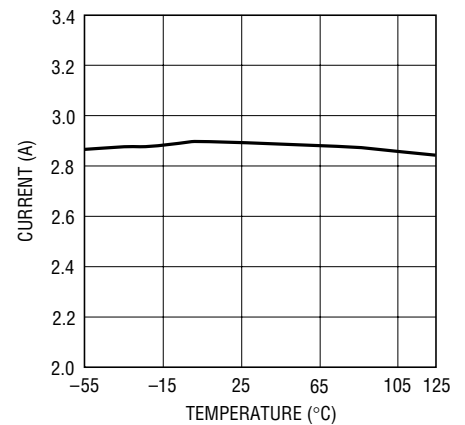
3402 G10

Start-Up Voltage vs I_{OUT}


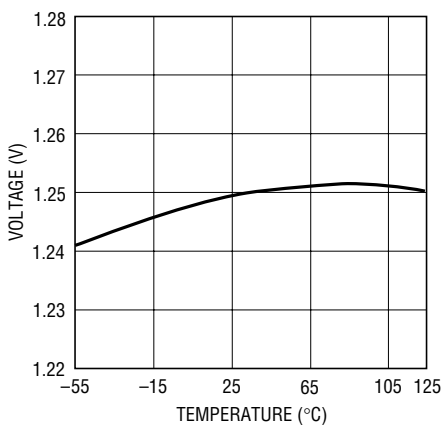
3402 G09

Efficiency Loss Without Schottky vs Frequency


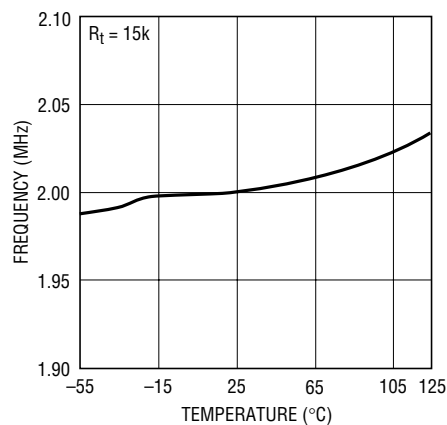
3402 G11

Current Limit


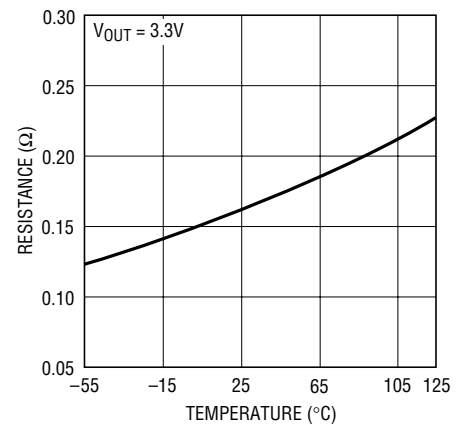
3402 G12

EA FB Voltage


3402 G13

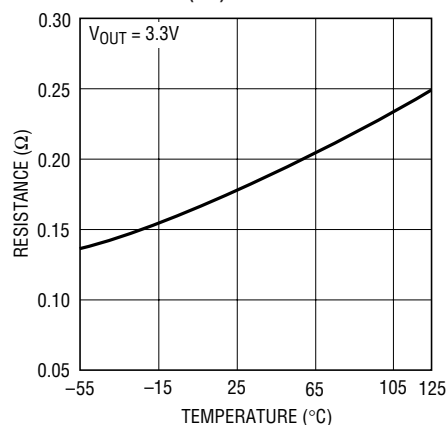
Oscillator Frequency Accuracy


3402 G14

NMOS $R_{DS(ON)}$


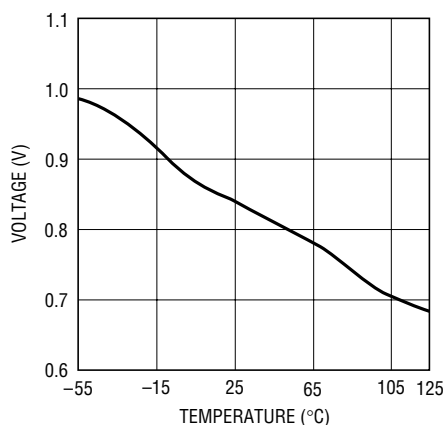
3402 G22

TYPICAL PERFORMANCE CHARACTERISTICS ($T_A = 25^\circ\text{C}$ unless otherwise noted)

PMOS $R_{DS(ON)}$ 

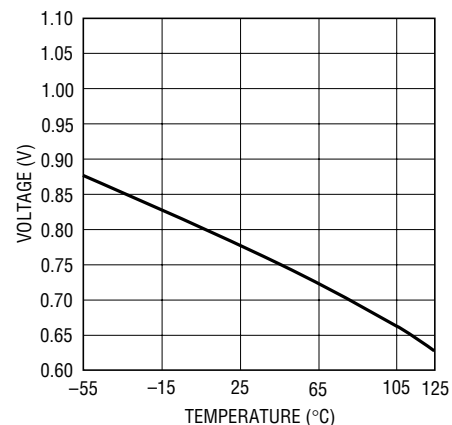
3402 G16

Start-Up Voltage



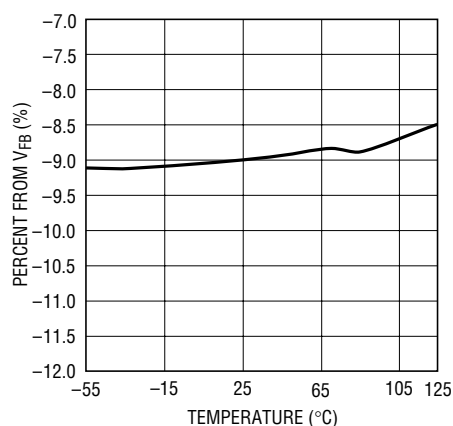
3402 G17

Shutdown Threshold



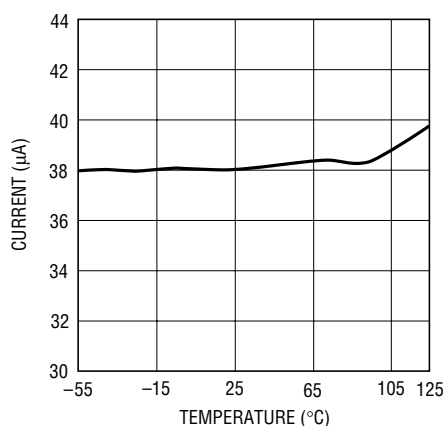
3402 G18

PGOOD Threshold

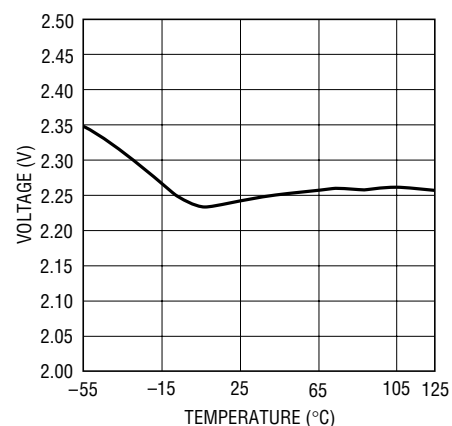


3402 G19

Burst Mode Operation Current



3402 G20

 V_{OUT} Turn-Off Voltage

3402 G21

PIN FUNCTIONS

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

$$f_{\text{osc}} = \frac{3 \cdot 10^{10}}{R_t} \text{ Hz}$$

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

MODE/SYNC = High. Enable Burst Mode operation. The inductor peak inductor current will be 1/3 the current limit value and return to zero current on each cycle. During Burst Mode operation the operation is variable frequency, providing a significant efficiency improvement at light loads. It is recommended the Burst Mode operation only be entered once the part has started up.

MODE/SYNC = Low. Disable Burst Mode operation and maintain low noise, constant frequency operation.

MODE/SYNC = External CLK. Synchronization of the internal oscillator and Burst Mode operation disable. A clock pulse width of 100ns to 2μs is required to synchronize.

V_{IN} (Pin 3): Input Supply Pin.

SW (Pin 4): Switch Pin. Connect inductor and Schottky diode here. For applications with output voltages over 4.3V, a Schottky diode is required to ensure that the SW pin voltage does not exceed its absolute maximum rating. Minimize trace length to keep EMI and high ringing down. For discontinuous inductor current, a controlled impedance is placed from SW to V_{IN} from the

IC to eliminate high frequency ringing due to the resonant tank of the inductor and SW node capacitance, therefore reducing EMI radiation.

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

PGOOD (Pin 6): Power Good Comparator Output. This open-drain output is low when V_{FB} < -9% from its regulation voltage.

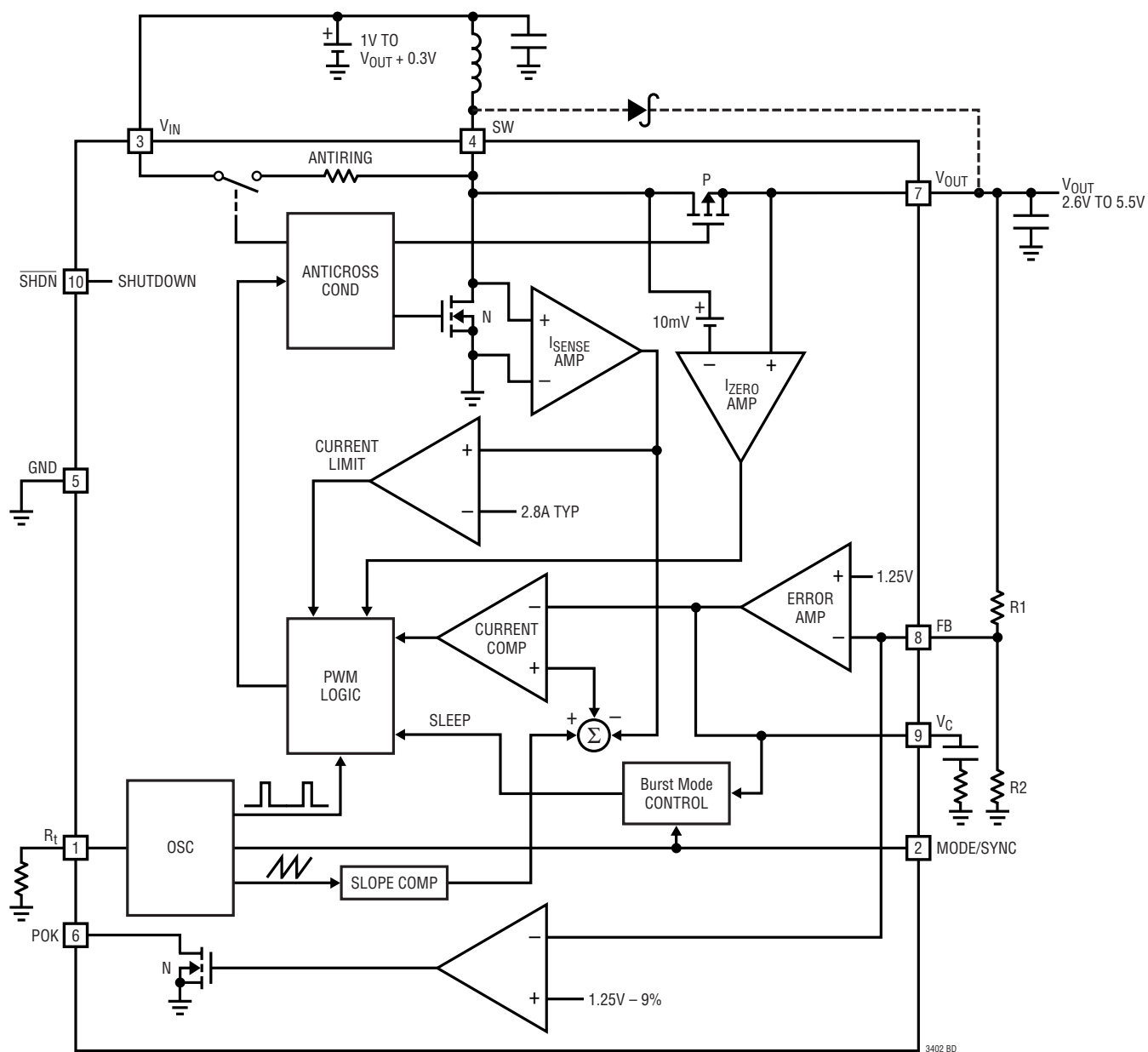
V_{OUT} (Pin 7): Output of the Synchronous Rectifier and Bootstrapped Power Source for the IC. A ceramic capacitor of at least 1μF is required and should be located as close to the V_{OUT} and GND pins as possible (Pins 7 and 5).

FB (Pin 8): Feedback Pin. Connect resistor divider tap here. The output voltage can be adjusted from 2.6V to 5V. The feedback reference voltage is typically 1.25V.

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

SHDN (Pin 10): Shutdown. Grounding this pin shuts down the IC. Tie to >1V to enable (V_{IN} or digital gate output). To operate with input voltages below 1V once the converter has started, a 1M resistor from SHDN to V_{IN} and a 5M resistor from SHDN to V_{OUT} will provide sufficient hysteresis. During shutdown, the output voltage will hold up to V_{IN} minus a diode drop due to the body diode of the PMOS synchronous switch. If the application requires a complete disconnect during shutdown, refer to the section "Output Disconnect Circuits."

BLOCK DIAGRAM



APPLICATIONS INFORMATION

DETAILED DESCRIPTION

The LTC3402 provides high efficiency, low noise power for applications such as portable instrumentation. The current mode architecture with adaptive slope compensation provides ease of loop compensation with excellent transient load response. The low $R_{DS(ON)}$, low gate charge synchronous switches provide the pulse width modulation control at high efficiency.

The Schottky diode across the synchronous PMOS switch provides a lower drop during the break-before-make time (typically 20ns) of the NMOS to PMOS transition. The addition of the Schottky diode will improve efficiency (see graph "Efficiency Loss Without Schottky vs Frequency"). While the IC's quiescent current is a low 38 μ A, high efficiency is achieved at light loads when Burst Mode operation is entered.

Low Voltage Start-Up

The LTC3402 is designed to start up at input voltages of typically 0.85V. The device can start up under some load, (see graph Start-Up vs Input Voltage). Once the output voltage exceeds a threshold of 2.3V, then the IC powers itself from V_{OUT} instead of V_{IN} . At this point, the internal circuitry has no dependency on the input voltage, eliminating the requirement for a large input capacitor. The input voltage can drop below 0.5V without affecting the operation, but the limiting factor for the application becomes the availability of the power source to supply sufficient energy to the output at the low voltages.

Low Noise Fixed Frequency Operation

Oscillator. The frequency of operation is set through a resistor from the R_t pin to ground where $f = 3 \cdot 10^{10}/R_t$. An internally trimmed timing capacitor resides inside the IC. The oscillator can be synchronized with an external clock inserted on the MODE/SYNC pin. When synchronizing the oscillator, the free running frequency must be set to approximately 30% lower than the desired synchronized frequency. Keeping the sync pulse width below 2 μ s will ensure that Burst Mode operation is disabled.

Current Sensing. Lossless current sensing converts the peak current signal to a voltage to sum in with the internal slope compensation. This summed signal is compared to

the error amplifier output to provide a peak current control command for the PWM. The slope compensation in the IC is adaptive to the input and output voltage. Therefore, the converter provides the proper amount of slope compensation to ensure stability and not an excess causing a loss of phase margin in the converter.

Error Amp. The error amplifier is a transconductance amplifier with $g_m = 0.1$ ms. A simple compensation network is placed from the V_C pin to ground.

Current Limit. The current limit amplifier will shut the NMOS switch off once the current exceeds its threshold. The current amplifier delay to output is typically 50ns.

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

Antiringing Control. The antiringing control will place an impedance across the inductor to damp the ringing on the SW pin during discontinuous mode operation. The LC_{SW} ringing (L = inductor, C_{SW} = capacitance on the switch pin) is low energy, but can cause EMI radiation.

Burst Mode Operation

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

During the period where the device is delivering energy to the output, the peak current will be equal to 1/6 the current limit value and the inductor current will terminate at zero current for each cycle. In this mode the maximum output current is given by:

$$I_{OUT(MAXBURST)} \approx \frac{V_{IN}}{6 \cdot V_{OUT}} \text{ Amps}$$

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

APPLICATIONS INFORMATION

COMPONENT SELECTION

Inductor Selection

The high frequency operation of the LTC3402 allows the use of small surface mount inductors. The minimum inductance value is proportional to the operating frequency and is limited by the following constraints:

$$L > \frac{3}{f} \mu\text{H} \text{ and } L > \frac{V_{\text{IN(MIN)}} \cdot V_{\text{OUT(MAX)}} - V_{\text{IN(MIN)}}}{f \cdot \text{Ripple} \cdot V_{\text{OUT(MAX)}}} \text{H}$$

where

f = Operating Frequency (Hz)

Ripple = Allowable Inductor Current Ripple (A)

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

$V_{\text{OUT(MAX)}}$ = Maximum Output Voltage (V)

The inductor current ripple is typically set to 20% to 40% of the maximum inductor current.

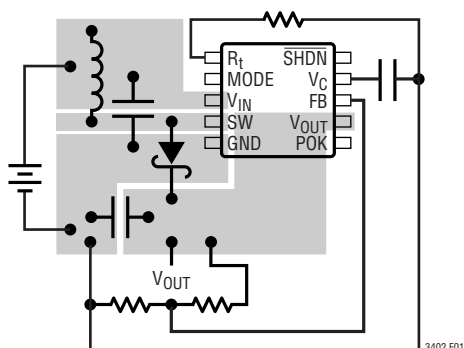


Figure 1. Recommended Component Placement. Traces Carrying High Current Are Direct. Trace Area FB and V_C Pins Are Kept Low. Lead Length to Battery Should be Kept Short

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

Table 1. Inductor Vendor Information

SUPPLIER	PHONE	FAX	WEBSITE
Coilcraft	(847) 639-6400	(847) 639-1469	www.coilcraft.com
Coiltronics	(516) 241-7876	(516) 241-9339	www.coiltronics.com
Murata	(814) 237-1431 (800) 831-9172	(814) 238-0490	www.murata.com
Sumida	USA: (847) 956-0666 Japan: 81-3-3607-5111	(847) 956-0702 81-3-3607-5144	www.japanlink.com sumida

Output Capacitor Selection

The output voltage ripple has several components. The bulk value of the capacitor is set to reduce the ripple due to charge into the capacitor each cycle. The max ripple due to charge is given by:

$$V_{\text{R(BULK)}} = \frac{I_P \cdot V_{\text{IN}}}{C_{\text{OUT}} \cdot V_{\text{OUT}} \cdot f} V$$

where

I_P = Peak Inductor Current

The ESR can be a significant factor for ripple in most power converters. The ripple due to capacitor ESR is simply given by:

$$V_{\text{R(ESR)}} = I_P \cdot R_{\text{ESR}} V$$

where

R_{ESR} = Capacitor Series Resistance

Low ESR capacitors should be used to minimize output voltage ripple. For surface mount applications, AVX TPS series tantalum capacitors and Sanyo POSCAP or Taiyo-Yuden ceramic X5R or X7R type capacitors are recommended. For through-hole applications Sanyo OS-CON capacitors offer low ESR in a small package size. See Table 2 for a list of component suppliers. In some layouts it may be required to place a $1\mu\text{F}$ low ESR capacitor as close to the V_{OUT} and GND pins as possible.

Table 2. Capacitor Vendor Information

SUPPLIER	PHONE	FAX	WEBSITE
AVX	(803) 448-9411	(803) 448-1943	www.avxcorp.com
Sanyo	(619) 661-6322	(619) 661-1055	www.sanyovideo.com
Taiyo Yuden	(408) 573-4150	(408) 573-4159	www.t-yuden.com

3402fb

APPLICATIONS INFORMATION

Input Capacitor Selection

The input filter capacitor reduces peak currents drawn from the input source and reduces input switching noise. Since the IC can operate at voltages below 0.5V once the output is regulated, then demand on the input capacitor is much less and in most applications a 4.7 μ F is recommended.

Output Diode

For applications with output voltages over 4.3V, a Schottky diode is required to ensure that the SW pin voltage does not exceed its absolute maximum rating. The Schottky diode across the synchronous PMOS switch provides a lower drop during the break-before-make time (typically 20ns) of the NMOS to PMOS transition. The Schottky diode improves peak efficiency (see graph “Efficiency Loss Without Schottky vs Frequency”). Use of a Schottky diode such as a MBR0520L, 1N5817 or equivalent. Since slow recovery times will compromise efficiency, do not use ordinary rectifier diodes.

Operating Frequency Selection

There are several considerations in selecting the operating frequency of the converter. The first is determining the sensitive frequency bands that cannot tolerate any spectral noise. For example, in products incorporating RF communications, the 455kHz IF frequency is sensitive to any noise, therefore switching above 600kHz is desired. Some communications have sensitivity to 1.1MHz. In this case, a 2MHz converter frequency may be employed.

The second consideration is the physical size of the converter. As the operating frequency goes up, the inductor and filter caps go down in value and size. The trade off is in efficiency since the switching losses due to gate charge are going up proportional with frequency. For example in Figure 2, for a 2.4V to 3.3V converter, the efficiency at 100mA is 5% less at 2MHz compared to 300kHz.

Another operating frequency consideration is whether the application can allow “pulse skipping.” In this mode, the minimum on time of the converter cannot support the duty cycle, so the converter ripple will go up and there will be a low frequency component of the output ripple. In many

applications where physical size is the main criterion then running the converter in this mode is acceptable. In applications where it is preferred not to enter this mode, then the maximum operating frequency is given by:

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

where $t_{\text{ON(MIN)}}$ = minimum on time = 120ns.

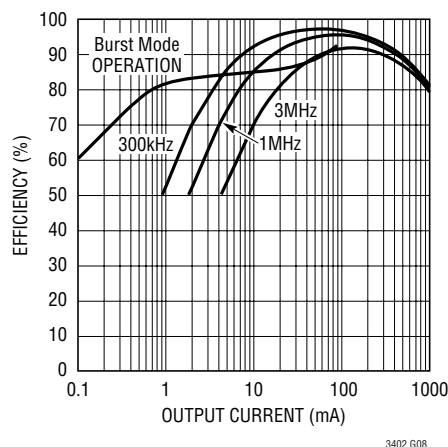


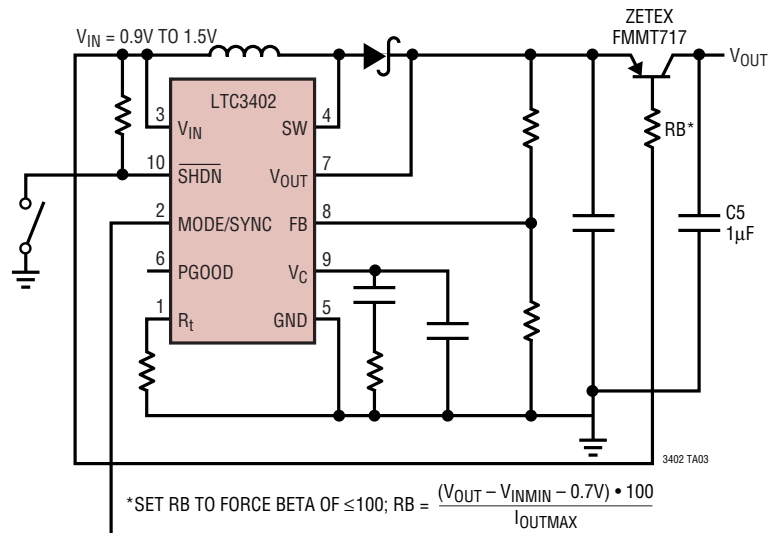
Figure 2. Converter Efficiency 2.4V to 3.3V

Reducing Output Capacitance with a Load Feed Forward Signal

In many applications the output filter capacitance can be reduced for the desired transient response by having the device commanding the change in load current, (i.e. system microcontroller), inform the power converter of the changes as they occur. Specifically, a “load feed forward” signal coupled into the V_C pin gives the inner current loop a head start in providing the change in output current. The transconductance of the LTC3402 converter at the V_C pin with respect to the inductor current is typically 170mA/100mV, so the amount of signal injected is proportional to the anticipated change of inductor current with load. The outer voltage loop performs the remainder of the correction, but because of the load feed forward signal, the range over which it must slew is greatly reduced. This results in an improved transient response. A logic level feed forward signal, V_{FF} , is coupled through components C5 and R6. The amount of feed forward

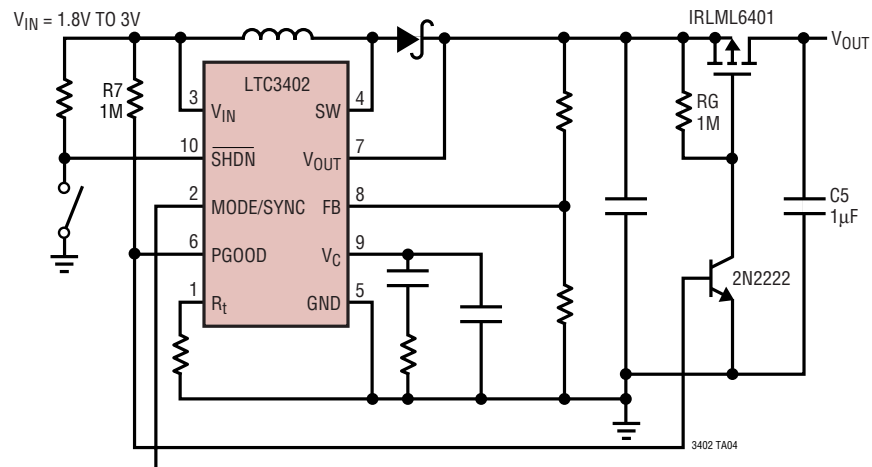
OUTPUT DISCONNECT CIRCUITS

Single Cell Output Disconnect



0 = FIXED FREQUENCY
1 = Burst Mode OPERATION

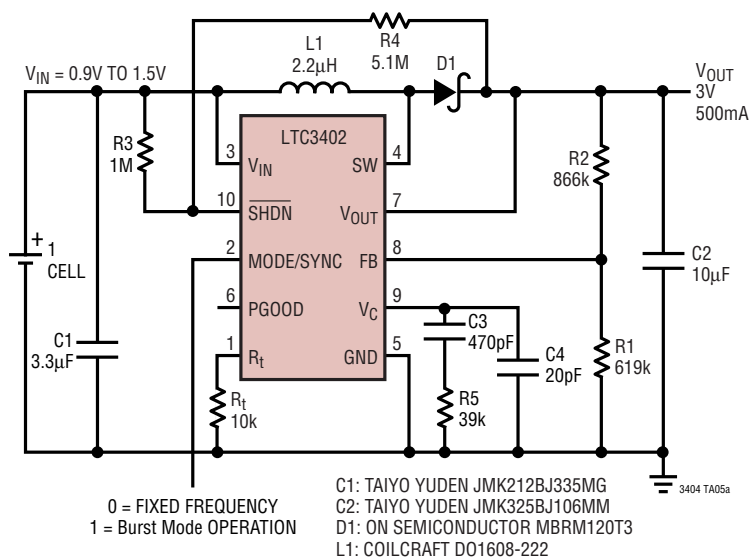
Dual Cell Output Disconnect Allowing Full Load Start-Up



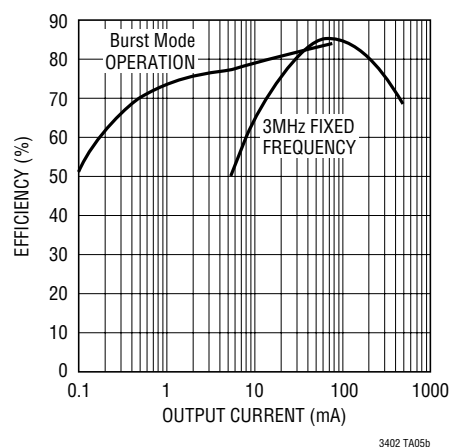
0 = FIXED FREQUENCY
1 = Burst Mode OPERATION

TYPICAL APPLICATIONS

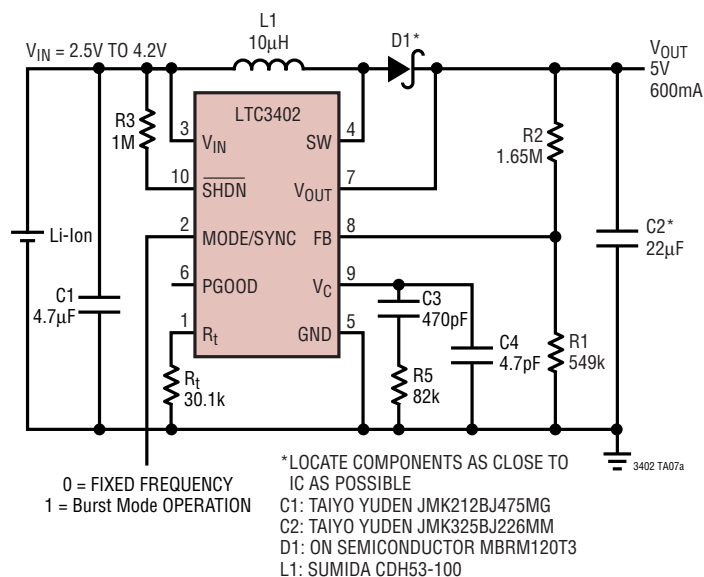
Single Cell to 3V at 500mA, All Ceramic Capacitor, 3MHz Step-Up Converter



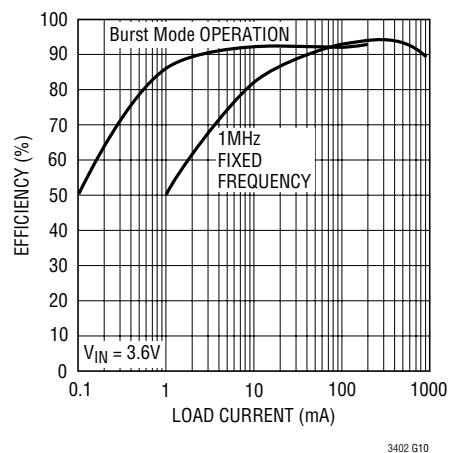
Efficiency



Li-Ion to 5V at 300mA, 1MHz Step-Up Converter



Efficiency

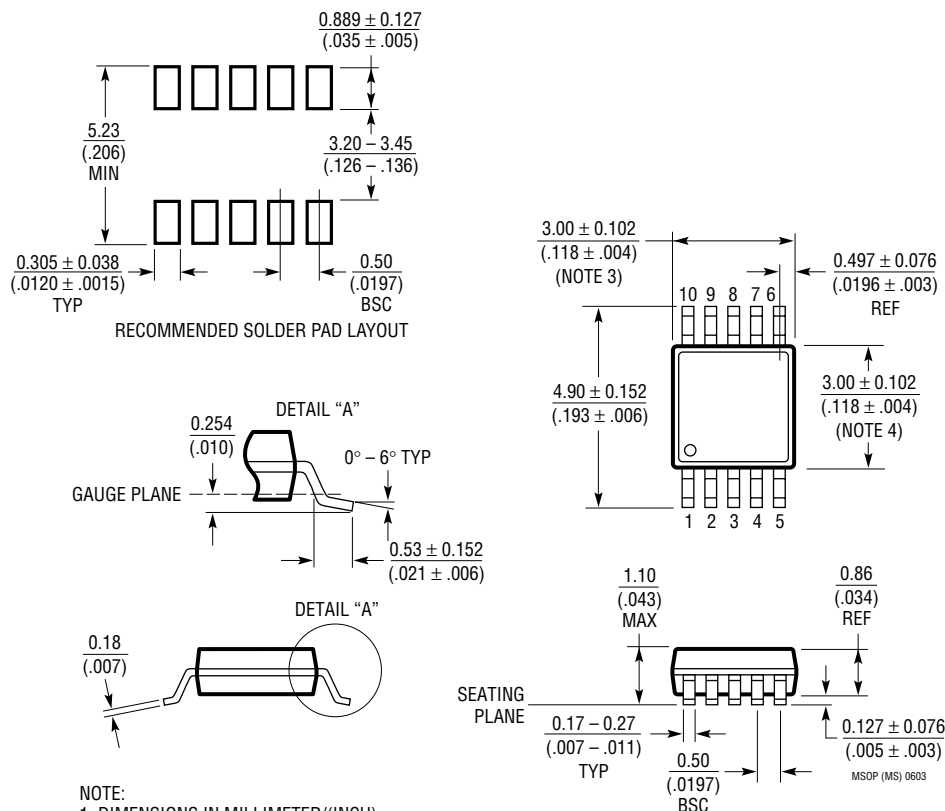


The schematic diagram illustrates a 3402 TA06 LED driver circuit. The input is a Li-Ion battery providing $V_{IN} = 2.5V$ TO $4.2V$. The circuit includes an LTC3402 IC, which is configured with various components: R_1 (300 Ω), R_2 (10k), R_3 (1k), R_4 (20k), R_5 (1M), and R_T (150k). Capacitors C_1 (10 μF), C_2 (0.22 μF), C_3 (27pF), C_4 (0.1 μF), and C_5 (1 μF) are used for filtering and timing. Inductors L_1 (33 μH) and T_1 (transformer) are part of the power conversion stage. The output stage consists of a MOSFET (Q1), a diode (D1), and a transformer (T1) connected to a CCFL load. A DIMMING INPUT (0V TO 2.5V) is connected to the circuit via a resistor (R4) and a diode (D4). The circuit is labeled 3402 TA06.

CCFL BACKLIGHT APPLICATION CIRCUITS
CONTAINED IN THIS DATA SHEET ARE
COVERED BY U.S. PATENT NUMBER 5408162
AND OTHER PATENTS PENDING

PACKAGE DESCRIPTION

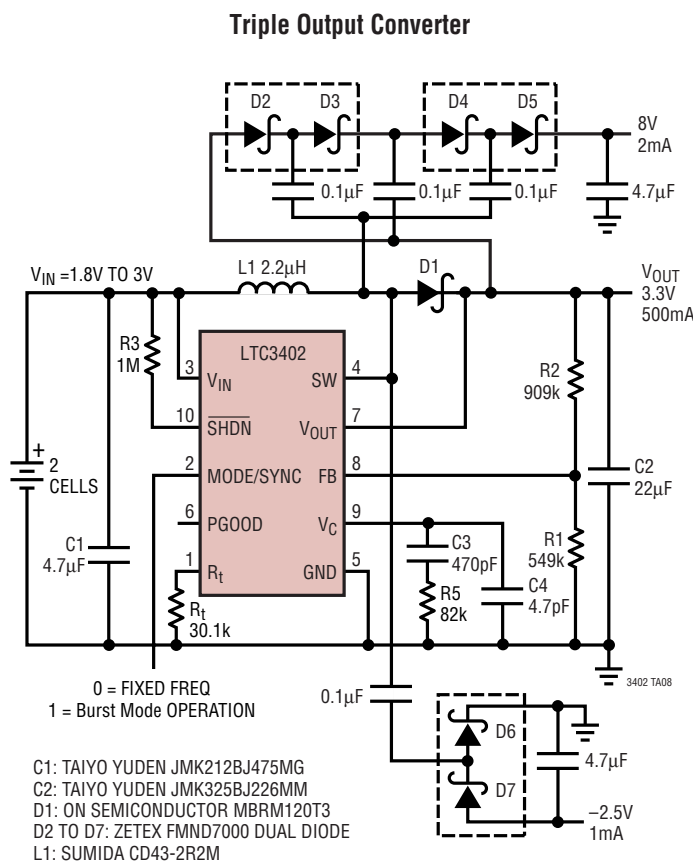
MS Package
10-Lead Plastic MSOP
 (Reference LTC DWG # 05-08-1661)



NOTE:

1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

TYPICAL APPLICATION



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT [®] 1306	Sync, Fixed Frequency, Step-Up DC/DC Converter	Internal 2A Switches; V_{IN} As Low As 1.8V
LT1308A/LT1308B	High Current, Micropower, Single Cell 600kHz DC/DC Converter	5V at 1A with Single Li-Ion Cell, V_{OUT} to 34V
LT1613	1.4MHz, Single Cell DC/DC Converter in SOT-23	V_{IN} As Low As 1.1V, 3V at 30mA from Single Cell
LT1615	Micropower Step-Up DC/DC Converter in SOT-23	$I_Q = 20\mu A$, $1\mu A$ Shutdown Current, V_{IN} As Low As 1V
LT1619	High Efficiency Boost DC/DC Controller	1A Gate Drive, 1.1V to 20V Input, Separate V_{CC} for Gate Drive
LTC1872	SOT-23 Boost DC/DC Controller	550kHz, 2.5V to 9.8V Input
LT1930/LT1930A	1.2MHz/2.2MHz DC/DC Converters in SOT-23	$V_{IN} = 2.6V$ to 16V, 5V at 450mA from 3.3V Input
LT1949	600kHz, 1A Switch PWM DC/DC Converter	1A, 0.5Ω , 30V Internal Switch, V_{IN} As Low As 1.5V, Low-Battery Detect Active in Shutdown
LTC3400	Single Cell, High Current (600mA), Micropower, Synchronous 1.2MHz Step-Up DC/DC Converter	$V_{IN} = 0.85V$ to 5.5V, Up to 92% Efficiency Synchronizable Oscillator from 100kHz to 1.2MHz, ThinSOT Package
LTC3401	Single Cell, High Current (1A), Micropower, Synchronous 3MHz Step-Up DC/DC Converter	$V_{IN} = 0.5V$ to 5V, Up to 97% Efficiency Synchronizable Oscillator from 100kHz to 3MHz, 10-Lead MSOP Package
LTC3424	Single Cell, High Current (2A), Micropower, Synchronous 3MHz Step-Up DC/DC Converter	$V_{OUT} = 1.5V$, Up to 97% Efficiency Synchronizable Oscillator from 100kHz to 3MHz, 10-Lead MSOP Package