

1A, 3MHz Micropower Synchronous Boost Converter

FEATURES

- **Synchronous Rectification: Up to 97% Efficiency**
- **1A Switch Current Rating**
- **Fixed Frequency Operation Up to 3MHz**
- **Wide Input Range: 0.5V to 5.5V (Operating)**
- **Very Low Quiescent Current: 38 μ A (Burst Mode[®] Operation)**
- 2.6V to 5.5V Adjustable Output Voltage
- 0.85V (Typ) Start-Up Voltage
- No External Schottky Diode Required ($V_{OUT} < 4.3V$)
- Synchronizable Switching Frequency
- Burst Mode Enable Control
- Antiringing Control Reduces Switching Noise
- PGOOD Output
- OPTI-LOOP[®] Compensation
- Very Low Shutdown Current: $< 1\mu A$
- Small 10-Pin MSOP Package

APPLICATIONS


- Pagers
- Handheld Instruments
- Cordless Phones
- Wireless Handsets
- GPS Receivers
- Battery Backup
- CCFL Backlights

DESCRIPTION

The LTC®3401 is a high efficiency, fixed frequency, step-up DC/DC converter that operates from an input voltage below 1V. The device includes a 0.16Ω N-channel MOSFET switch and a 0.18Ω P-channel synchronous rectifier. Switching frequencies up to 3MHz are programmed with an external timing resistor and the oscillator can be synchronized to an external clock. An external Schottky diode is optional but will slightly improve efficiency.

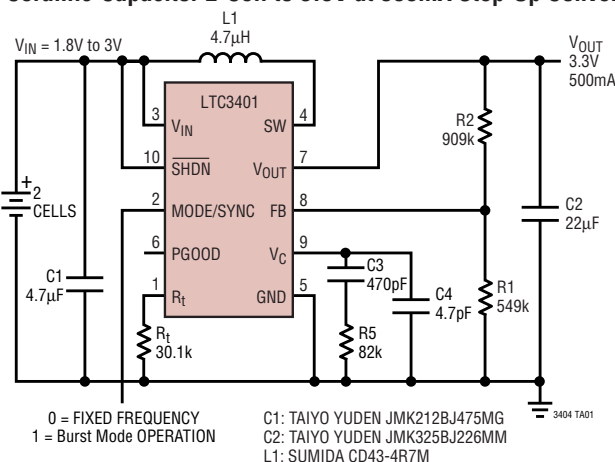
Quiescent current is only 38μA in Burst Mode operation, maximizing battery life in portable applications. Burst Mode operation is user controlled and can be enabled by driving the MODE/SYNC pin high. If the MODE/SYNC pin has either a clock or is driven low, then fixed frequency switching is enabled.

Other features include 1 μ A shutdown, antiringing control, open-drain power good output, thermal shutdown and current limit. The LTC3401 is available in the 10-lead thermally enhanced MSOP package. Higher current applications should use the 2A rated LTC3402 synchronous boost converter. Applications that require $V_{OUT} < 2.6V$ should use the LTC3423.

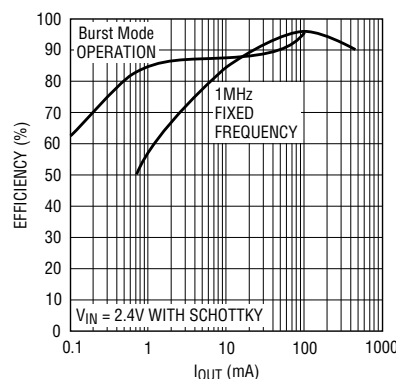
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Burst Mode and OPTI-LOOP are registered trademarks of Linear Technology Corporation.

TYPICAL APPLICATION

All-Ceramic-Capacitor 2-Cell to 3.3V at 500mA Step-Up Converter



Efficiency

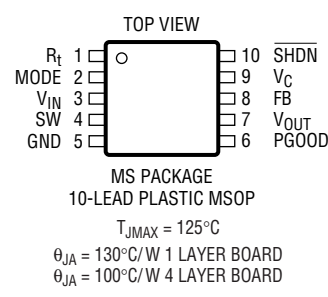


ABSOLUTE MAXIMUM RATINGS

(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, \overline{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

PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER
	LTC3401EMS
	MS PART MARKING
	LTPG

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 $T_A = 25^\circ\text{C}$.

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

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Start-Up Voltage	$I_{LOAD} < 1\text{mA}$		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— \overline{SHDN}	$\overline{SHDN} = 0V$, 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	●	1	1.6		A
NMOS Burst Current Limit			0.66		A
Maximum Duty Cycle	$R_t = 15k$ ●	80	85		%
Minimum Duty Cycle	●			0	%
Frequency Accuracy	$R_t = 15k$ ●	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	$\Delta I = -5\mu\text{A}$ to $5\mu\text{A}$, $V_C = V_{FB}$		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	$V_{SHDN} = V_{IN} = V_{OUT}$	1			V
SHDN Input Low				0.4	V
SHDN Input Current	$V_{SHDN} = 5.5\text{V}$		0.01	1	μA
Thermal Shutdown			170		$^\circ\text{C}$

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

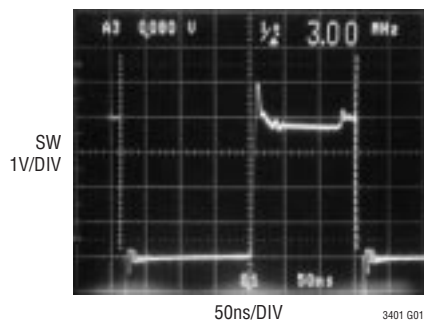
Note 2: The LTC3401 is guaranteed to meet performance specifications from 0°C to 70°C . Specifications over the -40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.

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

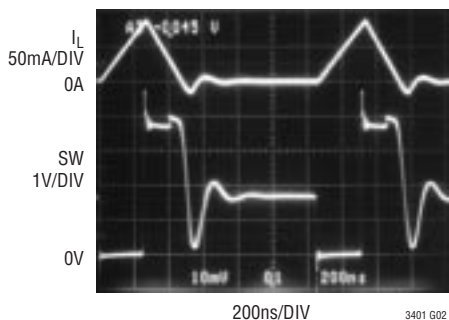
Note 4: Once the output is started, the IC is not dependant upon the V_{IN} supply.

TYPICAL PERFORMANCE CHARACTERISTICS

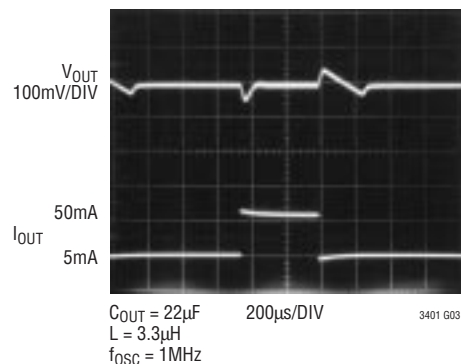
Switching Waveform on SW Pin



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

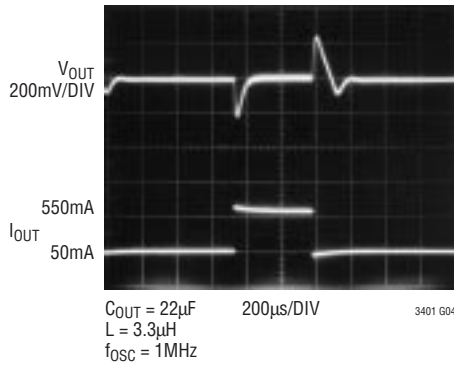


Transient Response 5mA to 50mA

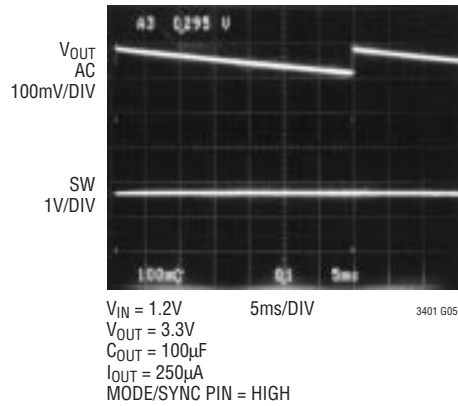


TYPICAL PERFORMANCE CHARACTERISTICS

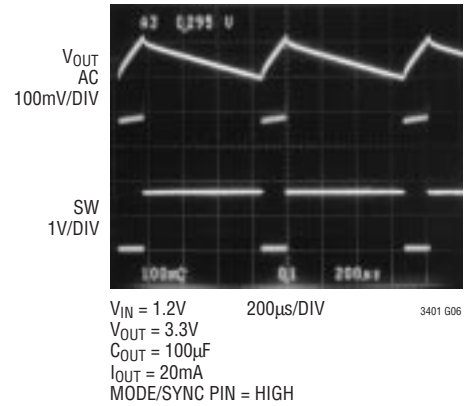
Transient Response 50mA to 500mA



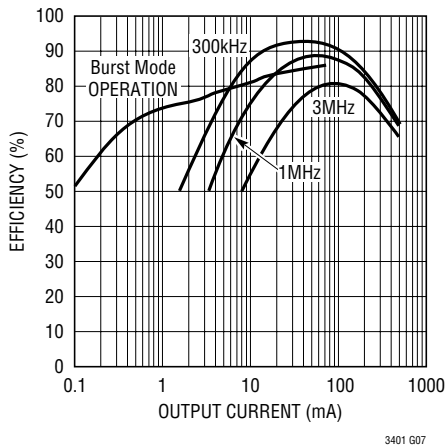
Burst Mode Operation



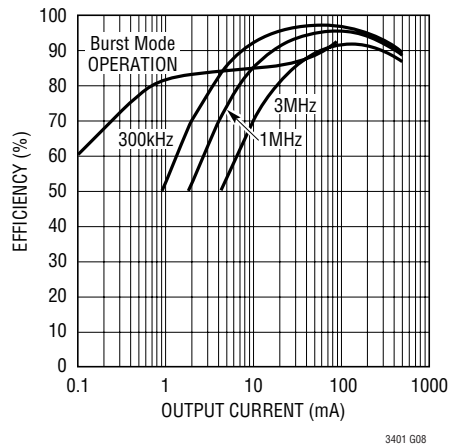
Burst Mode Operation



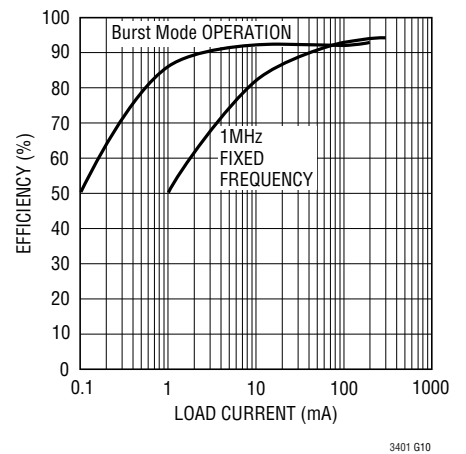
Converter Efficiency 1.2V to 3.3V



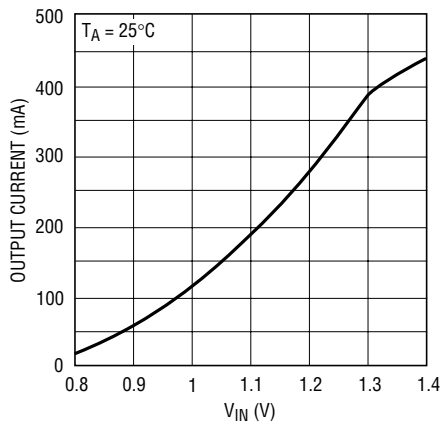
Converter Efficiency 2.4V to 3.3V



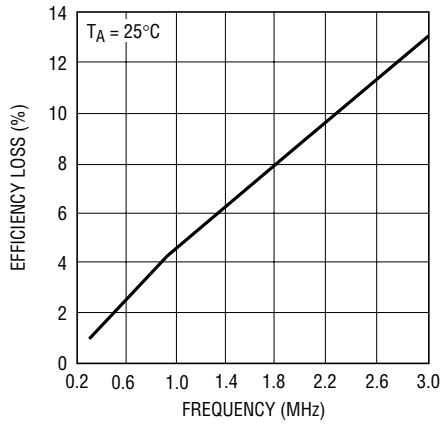
Converter Efficiency 3.6V to 5V



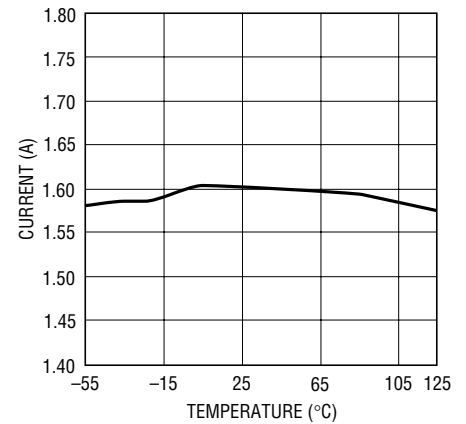
Start-Up Voltage
vs I_{OUT}



Efficiency Loss Without Schottky
vs Frequency

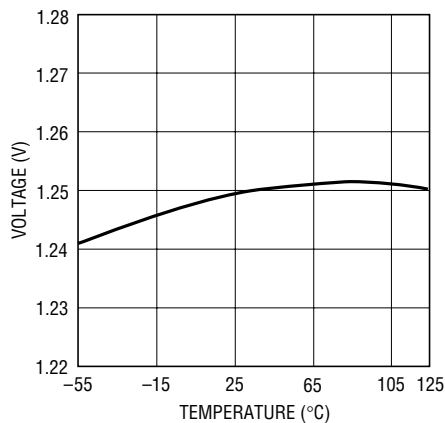


Current Limit



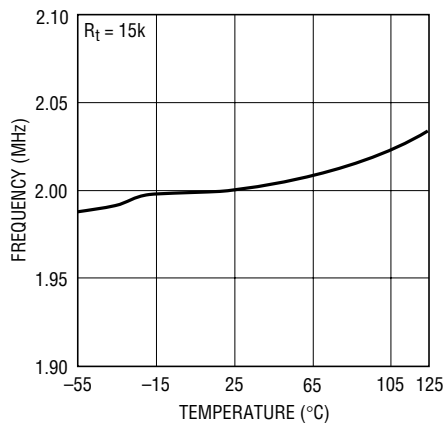
TYPICAL PERFORMANCE CHARACTERISTICS

EA FB Voltage

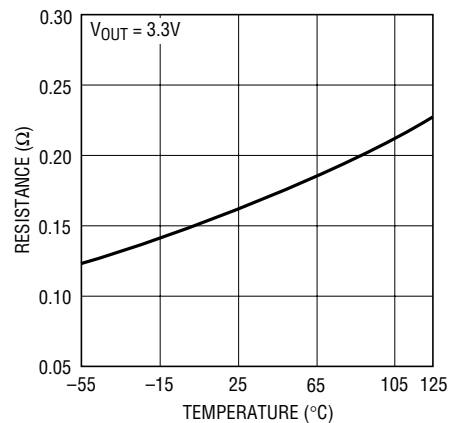


3401 G13

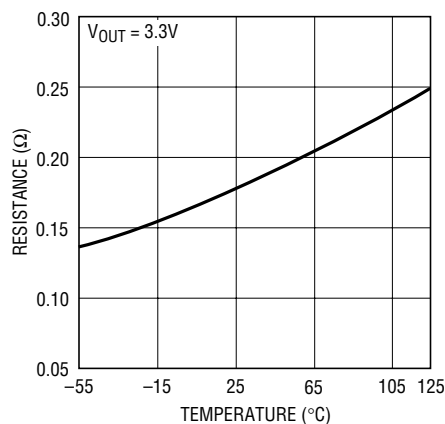
Oscillator Frequency Accuracy



3401 G14

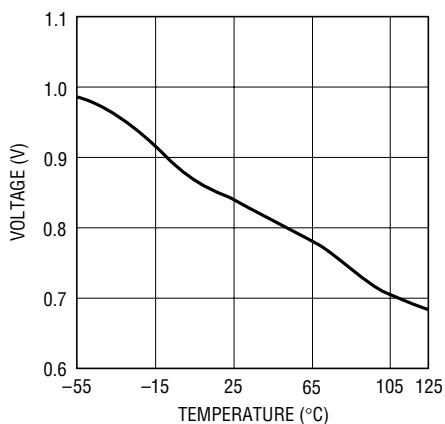
NMOS $R_{DS(ON)}$ 

3401 G22

PMOS $R_{DS(ON)}$ 

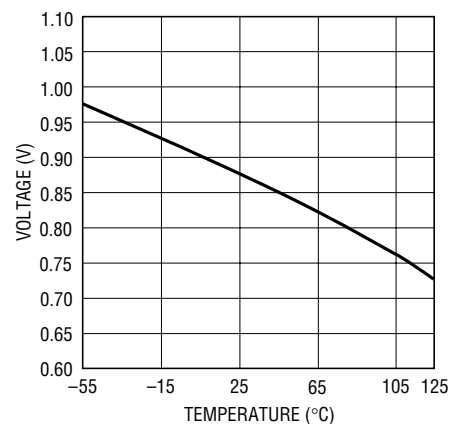
3401 G16

Start-Up Voltage



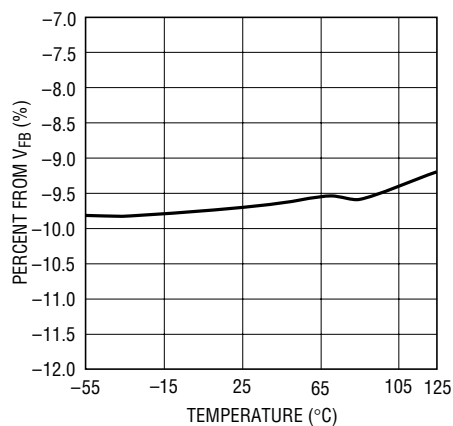
3401 G17

Shutdown Threshold



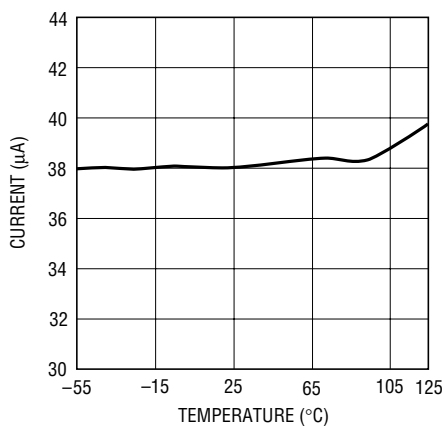
3401 G18

PGOOD Threshold

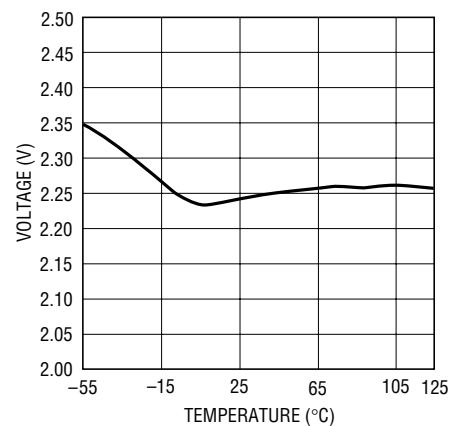


3401 G19

Burst Mode Operation Current



3401 G20

 V_{OUT} Turn-Off Voltage

3401 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 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.

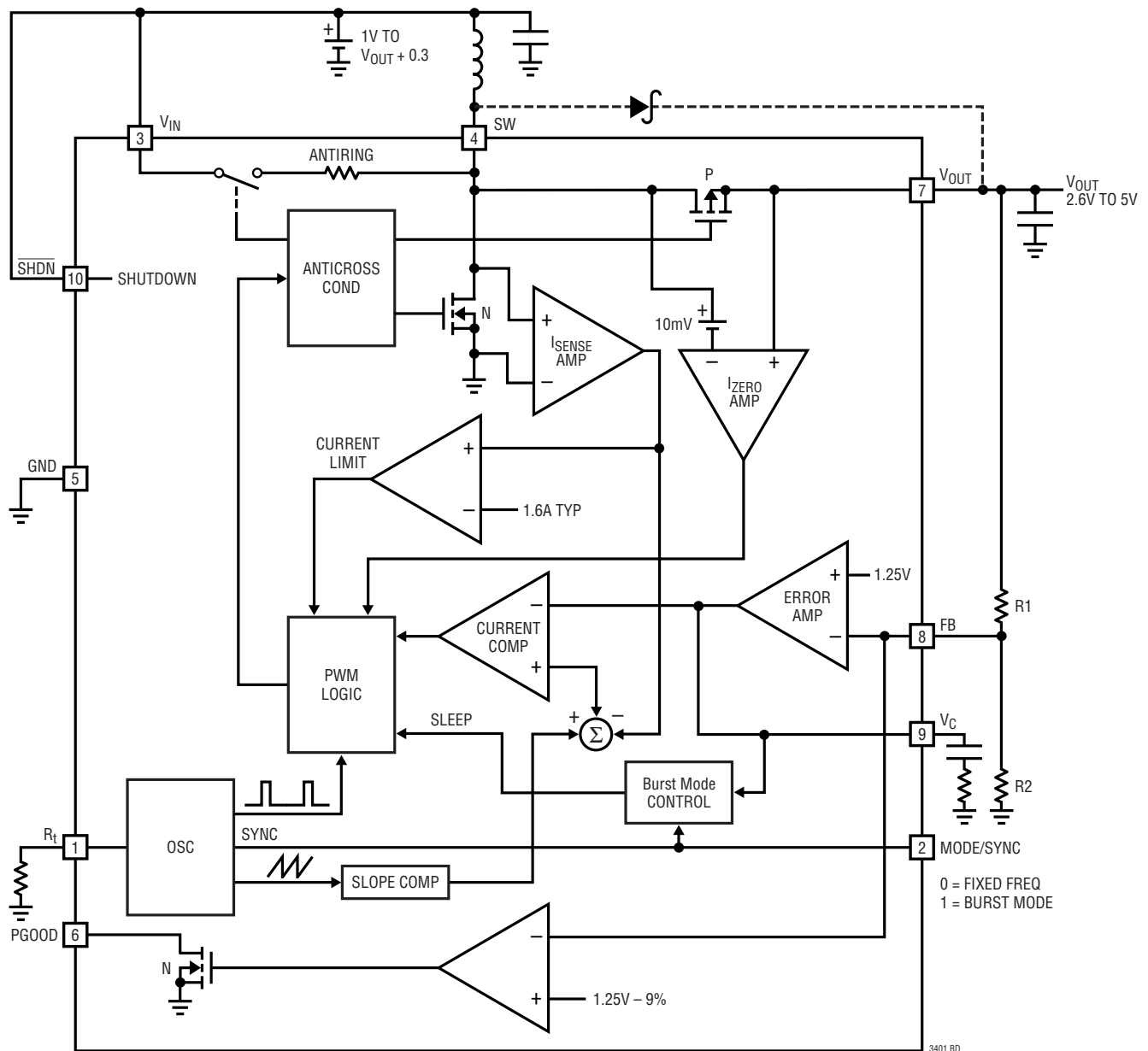
V_{OUT} (Pin 7): Output of the Synchronous Rectifier and Bootstrapped Power Source for the IC. A ceramic capacitor of at least 1μF is required and should be located as close to the V_{OUT} and GND pins as possible (Pins 7 and 5).

FB (Pin 8): Feedback Pin. Connect resistor divider tap here. The output voltage can be adjusted from 2.6V to 5.5V. 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 then refer to section "Output Disconnect Circuits".

BLOCK DIAGRAM



APPLICATIONS INFORMATION

DETAILED DESCRIPTION

The LTC3401 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 Schottky diode improves 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 LTC3401 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, the IC powers itself from V_{OUT} instead of V_{IN} . At this point, the internal circuitry has no dependency on the V_{IN} 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:

$$f = 3 \cdot 10^{10} / R_t$$

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 1/3 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:

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

APPLICATIONS INFORMATION

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

COMPONENT SELECTION

Inductor Selection

The high frequency operation of the LTC3401 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.

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

Table 1. Inductor Vendor Information

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	(847) 956-0702	www.japanlink.com
Japan:	81-3-3607-5111	81-3-3607-5144	sumida

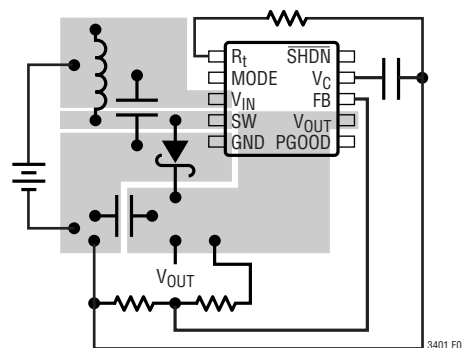


Figure 1. Recommended Component Placement. Traces Carrying High Current Are Direct. Trace Area FB and V_C Pins Are Kept Low. Lead Length to Battery Should Be Kept Short

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:

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

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:

$$V_{\text{R}_{\text{CESR}}} = I_P \cdot R_{\text{ESR}} V$$

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, Sanyo POSCAP, or Taiyo-Yuden ceramic capacitors are recommended. For through-hole applications Sanyo OS-CON capacitors offer low ESR in a small package size. See Table 2 for a list of component suppliers.

Table 2. Capacitor Vendor Information

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

APPLICATIONS INFORMATION

In some layouts it may be required to place a 1 μ F low ESR capacitor as close to the V_{OUT} and GND pins as possible.

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, demand on the input capacitor is much less and in most applications a 3.3 μ F is sufficient.

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 MBRM120T3, 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.

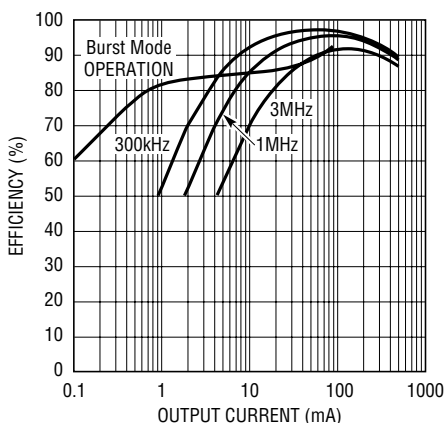


Figure 2. Converter Efficiency 2.4V to 3.3V

In this case, converter frequencies up to 3MHz may be employed.

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

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 LTC3401 converter at the V_C pin with respect to the inductor current is typically 130mA/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.

$V_{IN} = 0.9V \text{ TO } 1.5V$

LTC3401

3 V_{IN} SW 4

10 \overline{SHDN} V_{OUT} 7

2 MODE/SYNC FB 8

6 PGOOD V_C 9

1 R_t GND 5

ZETEX FM717

R_{B^*}

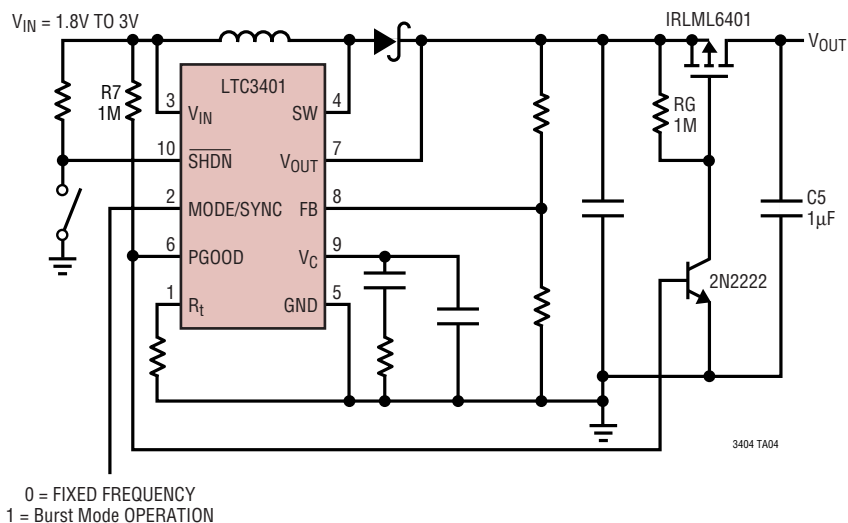
$C5$ $1\mu F$

V_{OUT}

3404 TA03

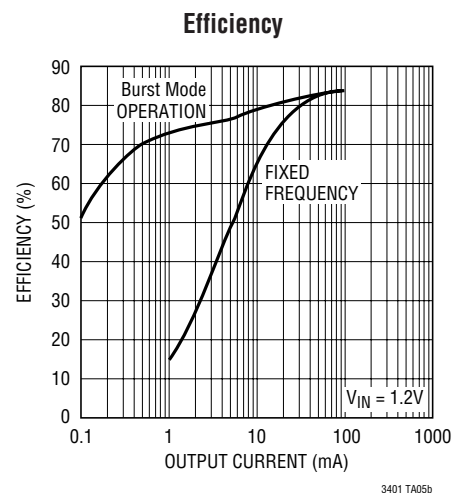
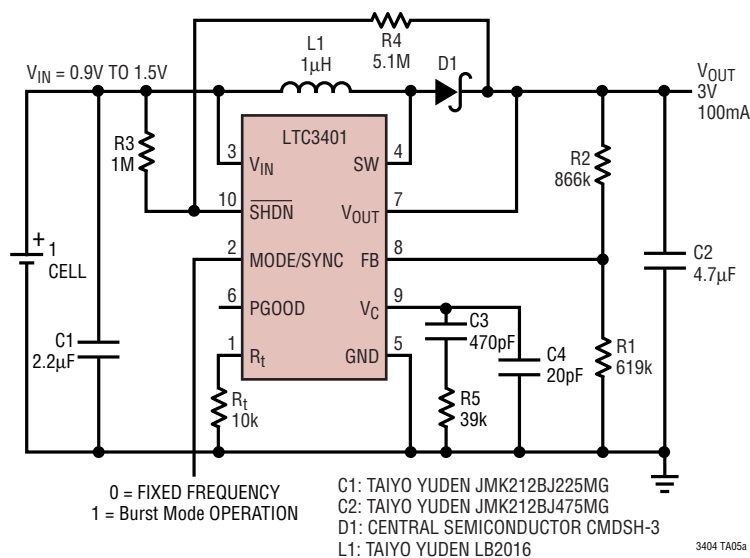
* SET R_B TO FORCE BETA OF ≤ 100 ; $R_B = \frac{(V_{OUT} - V_{INMIN} - 0.7V) \cdot 100}{I_{OUTMAX}}$

Dual Cell Output Disconnect Allowing Full Load Start-Up

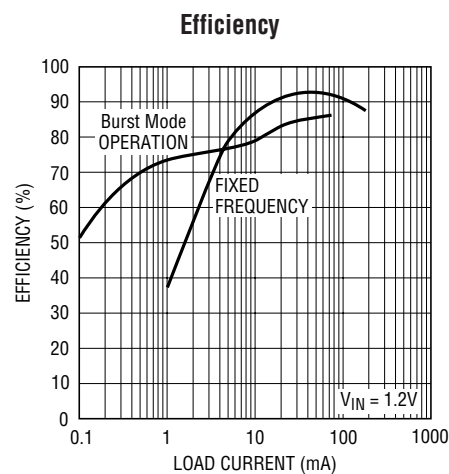
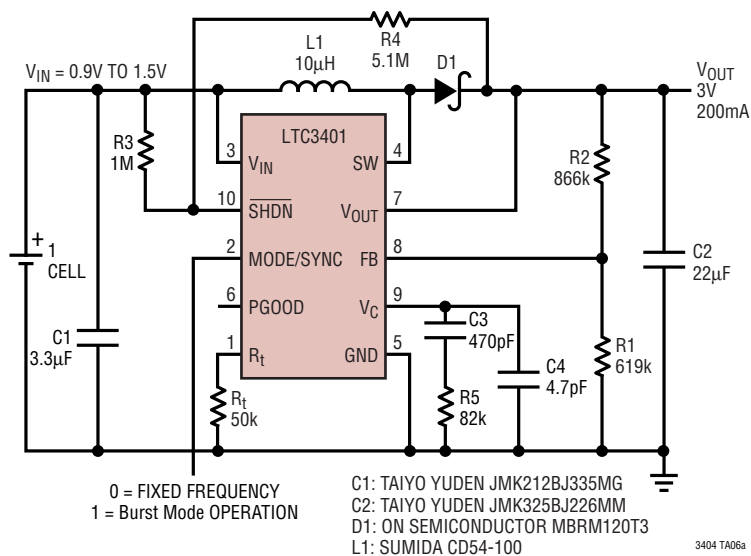


TYPICAL APPLICATIONS

Single Cell to 3V at 50mA, 1.2mm High, 3MHz Step-Up Converter



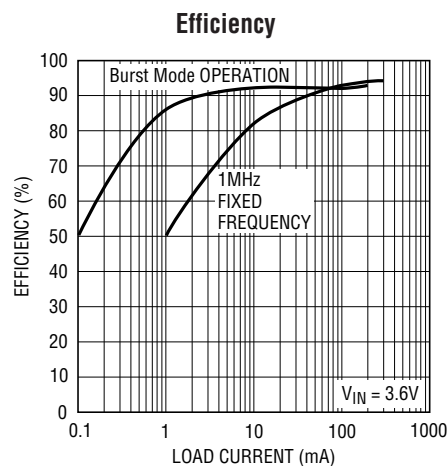
Single Cell to 3V at 200mA, 600kHz Step-Up Converter



[illegible]

0 = FIXED FREQUENCY
1 = Burst Mode OPERATION

*LOCATE COMPONENTS AS CLOSE TO
IC AS POSSIBLE
C1: TAIYO YUDEN JMK212BJ475MG
C2: TAIYO YUDEN JMK325BJ226MM
D1: ON SEMICONDUCTOR MBRM120T3
L1: SUMIDA CDC5023-100



3401 TA07H

[illegible]

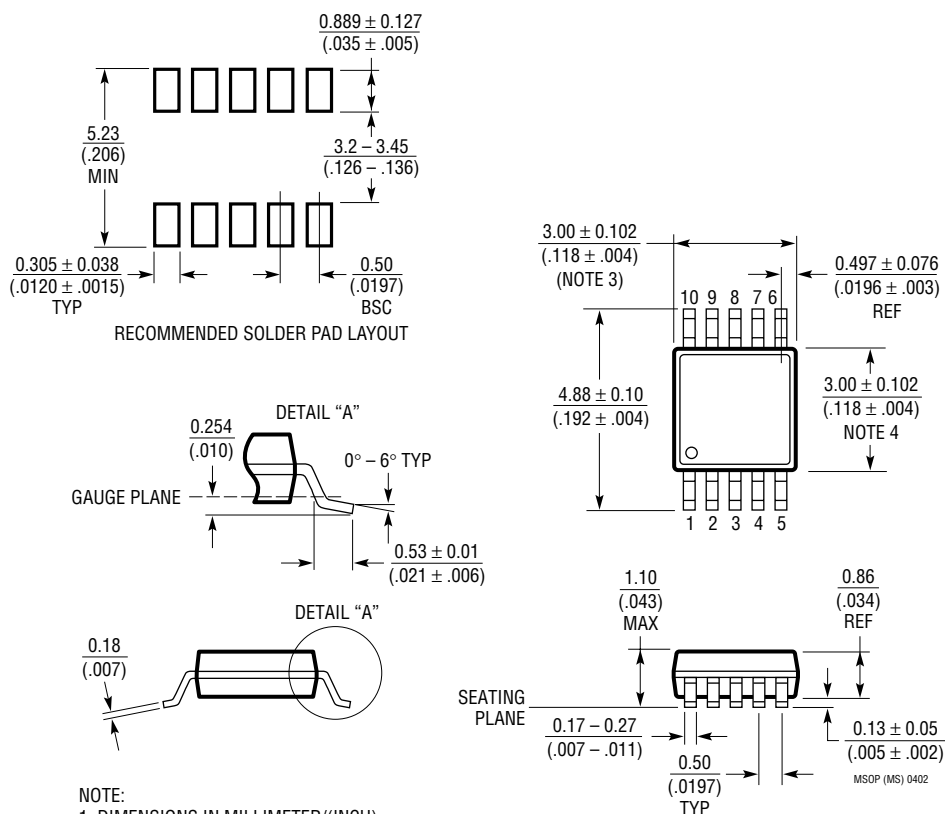
C1: TAIYO YUDEN JMK212BJ106MG
C2: PANASONIC ECH-U
D1: ZETEX ZHCS-1000
D2 TO D4: 1N4148

L1: SUMIDA CD-54-330MC
Q1, Q2: ZETEX FMMT-617
T1: SUMIDA C1Q122

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

