

## Regulated 50mA Buck-Boost Switched Capacitor DC/DC Converter

### General Description

The LM3355 is a CMOS switched capacitor DC/DC converter that produces a regulated output voltage by automatically stepping up (boost) or stepping down (buck) the input voltage. It accepts an input voltage between 2.5V and 5.5V. The LM3355 is available with a standard output voltage of 4.1V (ideal for white LED applications). If other output voltage options between 1.8V and 4.1V are desired for other applications, please contact your National Semiconductor representative.

The LM3355's proprietary buck-boost architecture enables up to 50 mA of load current at an average efficiency greater than 75%. Typical operating current is only 375  $\mu$ A and the typical shutdown current is only 2.3  $\mu$ A.

The LM3355 is available in a 10-pin MSOP package. This package has a maximum height of only 1.1 mm.

The high efficiency of the LM3355, low operating and shutdown currents, small package size, and the small size of the overall solution make this device ideal for battery powered, portable, and hand-held applications.

See the LM3352 for up to 200mA of output current.

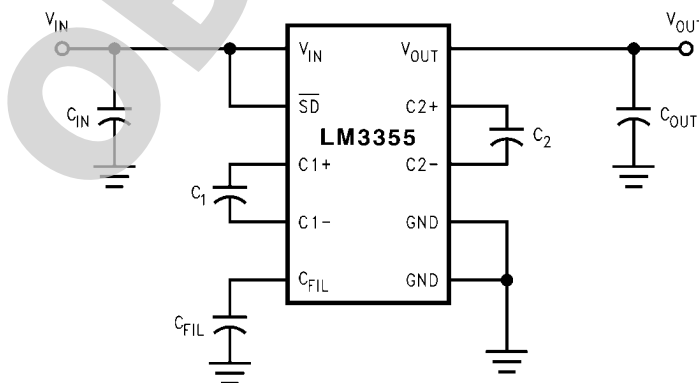
### Features

- Regulated  $V_{OUT}$  with  $\pm 3\%$  accuracy
- Standard output voltage of 4.1V
- Custom output voltages available from 1.8V to 4.1V in 100 mV increments
- 2.5V to 5.5V input voltage
- Up to 50 mA output current
- >75% average efficiency
- Uses few, low-cost external components
- Very small solution size
- 375  $\mu$ A typical operating current
- 2.3  $\mu$ A typical shutdown current
- 1 MHz switching frequency (typical)
- Architecture and control methods provide high load current and good efficiency
- MSOP-10 package
- Over-temperature protection

### Applications

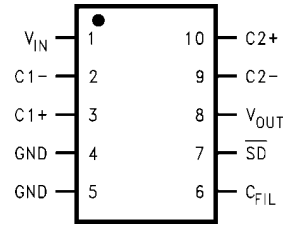
- White LED display backlights
- 1-cell Lilon battery-operated equipment including PDAs, hand-held PCs, cellular phones
- Flat panel displays
- Hand-held instruments
- NiCd, NiMH, or alkaline battery powered systems

### Typical Operating Circuit



20021901

## Connection Diagram



20021902

**Top View**  
**MSOP-10 Pin Package**  
 See NS Package Number MUB10A

## Ordering Information

| Order Number  | Package Type | NSC Package Drawing | Supplied As               |
|---------------|--------------|---------------------|---------------------------|
| LM3355MMX-4.1 | MSOP-10      | MUB10A              | 3.5k Units, Tape and Reel |
| LM3355MM-4.1  | MSOP-10      | MUB10A              | 1k Units, Tape and Reel   |

## Pin Descriptions

| Pin Number | Name            | Function  |
|------------|-----------------|---|
| 1          | $V_{IN}$        | Input Supply Voltage                                    |
| 2          | C1-             | Negative Terminal for C1                                |
| 3          | C1+             | Positive Terminal for C1                                |
| 4          | GND             | Ground  |
| 5          | GND             | Ground  |
| 6          | $C_{FIL}$       | Filter Capacitor, a 1 $\mu$ F capacitor is recommended. |
| 7          | $\overline{SD}$ | Shutdown, active low                                    |
| 8          | $V_{OUT}$       | Regulated Output Voltage                                |
| 9          | C2-             | Negative Terminal for C2                                |
| 10         | C2+             | Positive Terminal for C2                                |

## Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

|  |                    |
|--|--------------------|
| All Pins                                       | -0.5V to 5.6V      |
| Power Dissipation ( $T_A = 25^\circ\text{C}$ ) | Internally Limited |
| (Note 2)                                       |                    |
| $T_{JMAX}$ (Note 2)                            | 150°C              |
| $\theta_{JA}$ (Note 2)                         | 250°C/W            |
| Storage Temperature                            | -65°C to +150°C    |
| Lead Temperature (Soldering, 5 sec.)           | 260°C              |
| ESD Rating (Note 3)                            |                    |
| Human Body Model                               | 1.5 kV             |
| Machine Model                                  | 100V               |

## Operating Ratings

|   |                 |
|---|-----------------|
| Input Voltage ( $V_{IN}$ )              | 2.5V to 5.5V    |
| Output Voltage ( $V_{OUT}$ )            | 1.8V to 4.1V    |
| Ambient Temperature ( $T_A$ ) (Note 2)  | -40°C to +85°C  |
| Junction Temperature ( $T_J$ ) (Note 2) | -40°C to +125°C |

## Electrical Characteristics

Limits in standard typeface are for  $T_A = 25^\circ\text{C}$ , and limits in **boldface** type apply over the full operating temperature range of  $-40^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$ . Unless otherwise specified:  $C_1 = C_2 = 0.33 \mu\text{F}$ ;  $C_{IN} = 10 \mu\text{F}$ ;  $C_{OUT} = 10 \mu\text{F}$ ;  $C_{FIL} = 1 \mu\text{F}$ ;  $V_{IN} = 3.5\text{V}$ .

| Parameter                                 | Conditions  | Min (Note 5)                   | Typ (Note 4) | Max (Note 5)                   | Units             |
|---|---|--------------------------------|--------------|--------------------------------|-------------------|
| <b>LM3355-4.1</b>                         |   |                                |              |                                |                   |
| Output Voltage ( $V_{OUT}$ )              | $V_{IN} = 3.5\text{V}$ ; $I_{LOAD} = 50 \text{ mA}$                                 | 4.038                          | 4.1          | 4.162                          | V                 |
|   | $2.6\text{V} < V_{IN} < 5.5\text{V}$ ;<br>$1 \text{ mA} < I_{LOAD} < 50 \text{ mA}$ | 3.977/ <b>3.936</b>            | 4.1          | 4.223/ <b>4.264</b>            |                   |
|   | $2.5\text{V} < V_{IN} < 5.5\text{V}$ ;<br>$1 \text{ mA} < I_{LOAD} < 40 \text{ mA}$ | 3.977/ <b>3.936</b>            | 4.1          | 4.223/ <b>4.264</b>            |                   |
| Efficiency                                | $I_{LOAD} = 10 \text{ mA}$  |                                | 80           |                                | %                 |
|   | $I_{LOAD} = 50 \text{ mA}$  |                                | 75           |                                |                   |
| Output Voltage Ripple (Peak-to-Peak)      | $I_{LOAD} = 50 \text{ mA}$<br>$C_{OUT} = 10 \mu\text{F}$<br>ceramic                 |                                | 75           |                                | mV <sub>P-P</sub> |
| <b>LM3355-ALL OUTPUT VOLTAGE VERSIONS</b> |   |                                |              |                                |                   |
| Operating Quiescent Current               | Measured at Pin $V_{IN}$ ;<br>$I_{LOAD} = 0\text{A}$ (Note 6)                       |                                | 375          | <b>475</b>                     | $\mu\text{A}$     |
| Shutdown Quiescent Current                | SD Pin at 0V (Note 7)   |                                | 2.3          | <b>5</b>                       | $\mu\text{A}$     |
| Switching Frequency                       |   | <b>0.60</b>                    | 1            | <b>1.40</b>                    | MHz               |
| SD Input Threshold Low                    | $2.5\text{V} < V_{IN} < 5.5\text{V}$  |                                |              | <b>0.2 <math>V_{IN}</math></b> | V                 |
| SD Input Threshold High                   | $2.5\text{V} < V_{IN} < 5.5\text{V}$  | <b>0.8 <math>V_{IN}</math></b> |              |                                | V                 |
| SD Input Current                          | Measured at SD Pin;<br>SD Pin = $V_{IN} = 5.5\text{V}$                              |                                | 0.3          |                                | $\mu\text{A}$     |

**Note 1:** "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings are conditions for which the device is intended to be functional, but device parameter specifications may not be guaranteed. For guaranteed specifications and test conditions, see "Electrical Characteristics".

**Note 2:** As long as  $T_A \leq +85^\circ\text{C}$ , all electrical characteristics hold true and the junction temperature should remain below  $+125^\circ\text{C}$ .

**Note 3:** The Human Body Model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin. The Machine Model is a 200 pF capacitor discharged directly into each pin.

**Note 4:** Typical numbers are at  $25^\circ\text{C}$  and represent the most likely norm.

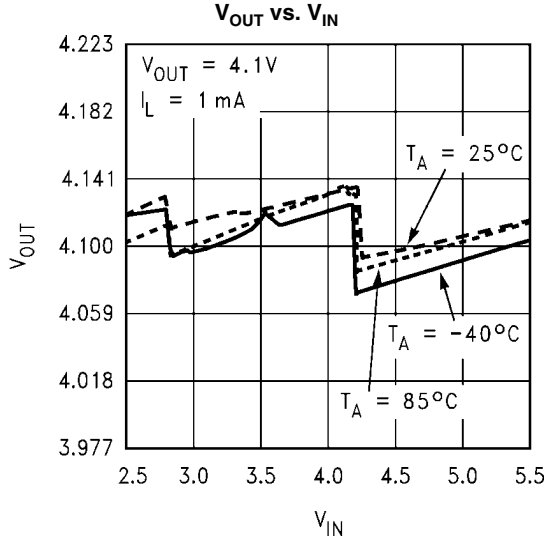
**Note 5:** All limits guaranteed at room temperature (standard typeface) and at temperature extremes (bold typeface). All room temperature limits are 100% tested or guaranteed through statistical analysis. All limits at temperature extremes are guaranteed by correlation using standard Statistical Quality Control methods (SQC). All limits are used to calculate Average Outgoing Quality Level (AOQL).

**Note 6:** The  $V_{OUT}$  pin is forced to 200 mV above the typical  $V_{OUT}$ . This is to insure that the internal switches are off.

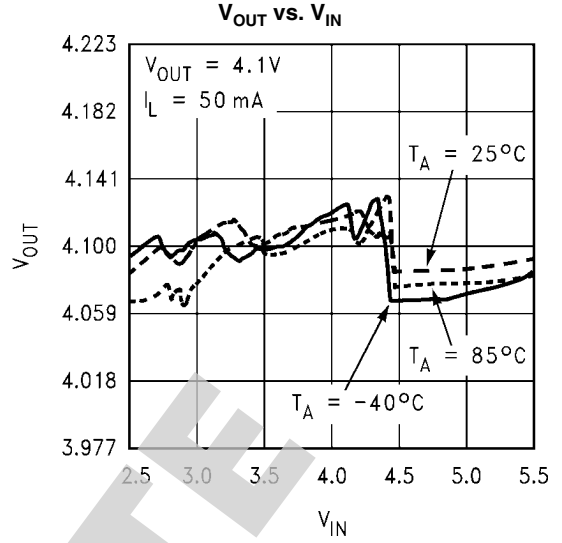
**Note 7:** The output capacitor  $C_{OUT}$  is fully discharged before measurement.

# Typical Performance Characteristics

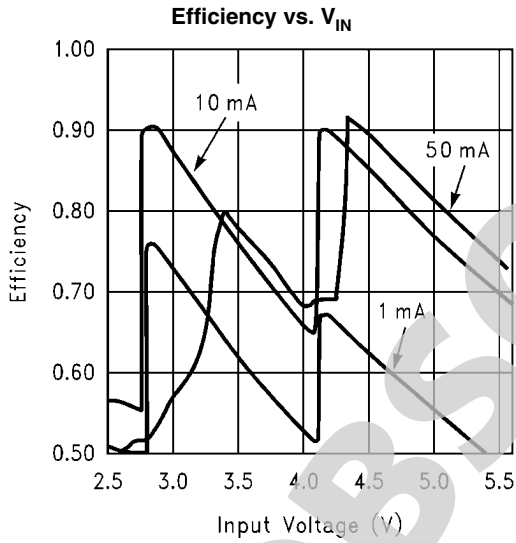
Unless otherwise specified  $T_A = 25^\circ\text{C}$ .



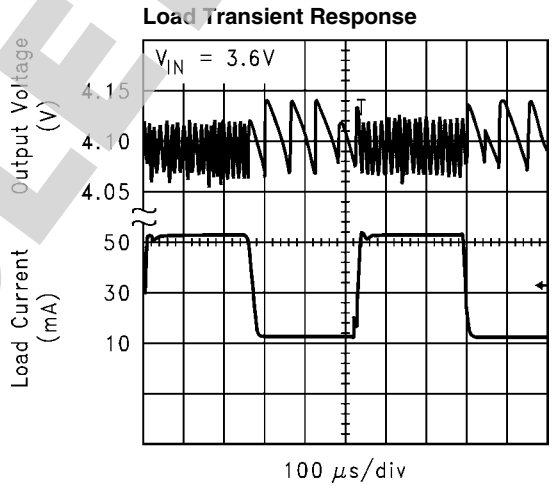
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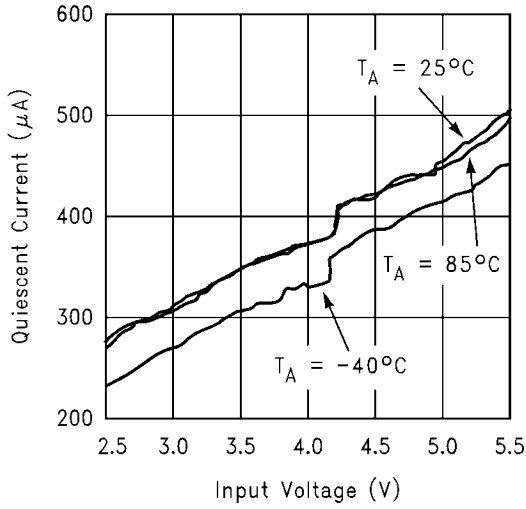


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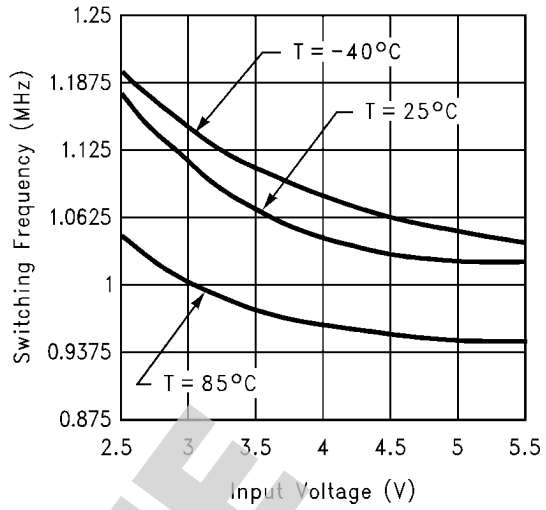
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**Operating Quiescent Current vs.  $V_{IN}$**



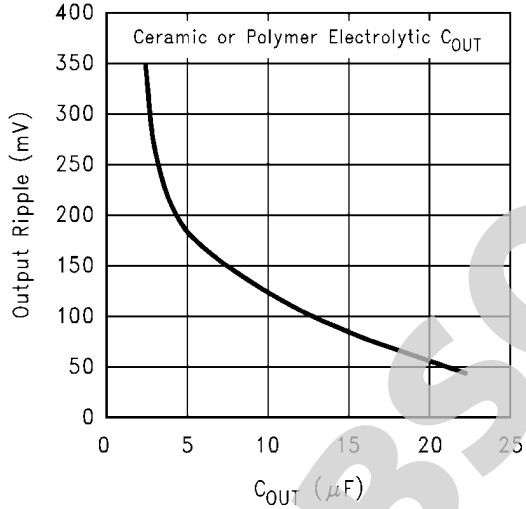
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**Switching Frequency vs.  $V_{IN}$**



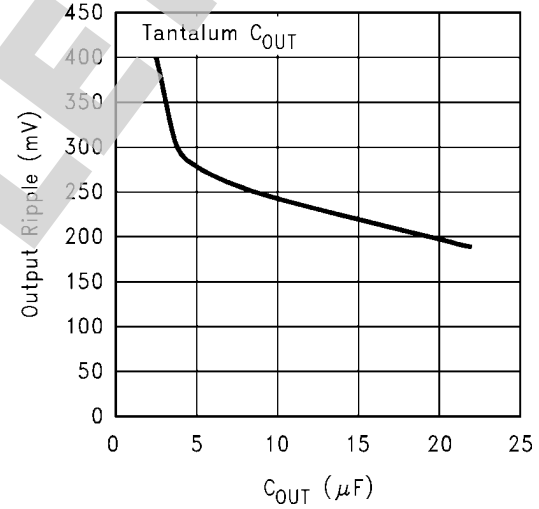
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**Maximum  $V_{OUT}$  Ripple vs.  $C_{OUT}$**



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**Maximum  $V_{OUT}$  Ripple vs.  $C_{OUT}$**



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## Applications Information

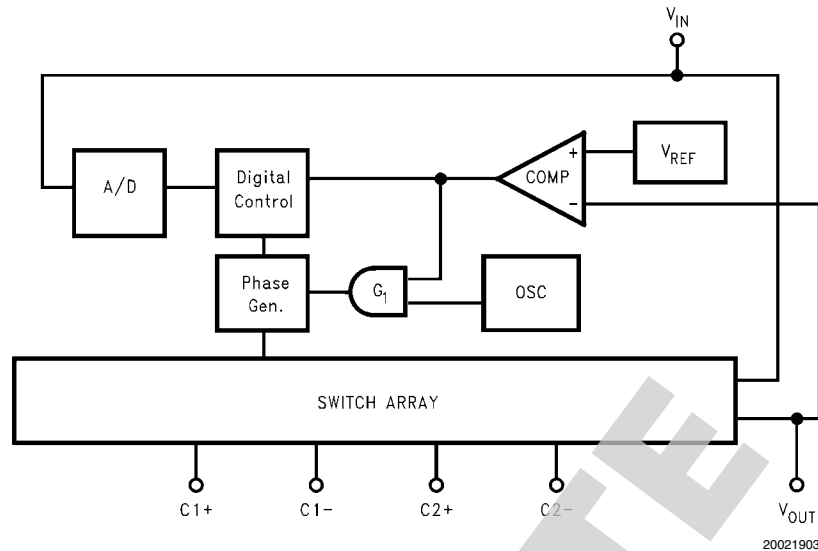


FIGURE 1. Block Diagram

### Operating Principle

The LM3355 is designed to provide a step-up/step-down voltage regulation in battery powered systems. It combines switched capacitor circuitry, reference, comparator, and shut-down logic in a single 10-pin MSOP package. The LM3355 can provide a regulated voltage between 1.8V and 4.1V from an input voltage between 2.5V and 5.5V. It can supply a load current up to 50 mA.

As shown in Figure 1, the LM3355 employs two feedback loops to provide regulation in the most efficient manner possible. The first loop is from  $V_{OUT}$  through the comparator COMP, the AND gate  $G_1$ , the phase generator, and the switch array. The comparator's output is high when  $V_{OUT}$  is less than the reference  $V_{REF}$ . Regulation is provided by gating the clock to the switch array. In this manner, charge is transferred to the output only when needed. The second loop controls the gain configuration of the switch array. This loop consists of the comparator, the digital control block, the phase generator, and the switch array. The digital control block computes the most efficient gain from a set of five gains based on inputs from the A/D and the comparator. The gain signal is sent to the phase generator which then sends the appropriate timing and configuration signals to the switch array. This dual loop provides regulation over a wide range of loads efficiently.

Since efficiency is automatically optimized, the curves for  $V_{OUT}$  vs.  $V_{IN}$  and Efficiency vs.  $V_{IN}$  in the Typical Performance Characteristics section exhibit small variations. The reason is that as input voltage or output load changes, the digital control loops are making decisions on how to optimize efficiency. As the switch array is reconfigured, small variations in output voltage and efficiency result. In all cases where these small variations are observed, the part is operating correctly; minimizing output voltage changes and optimizing efficiency.

### Charge Pump Capacitor Selection

A 0.33  $\mu\text{F}$  ceramic capacitor is suggested for C1 and C2. To ensure proper operation over temperature variations, an X7R dielectric material is recommended.

### Filter Capacitor Selection

#### a) CAPACITOR TECHNOLOGIES

The three major technologies of capacitors that can be used as filter capacitors for LM3355 are: i) tantalum, ii) ceramic and iii) polymer electrolytic technologies.

#### i) Tantalum

Tantalum capacitors are widely used in switching regulators. Tantalum capacitors have the highest CV rating of any technology; as a result, high values of capacitance can be obtained in relatively small package sizes. It is also possible to obtain high value tantalum capacitors in very low profile (<1.2 mm) packages. This makes the tantalums attractive for low-profile, small size applications. Tantalums also possess very good temperature stability; i.e., the change in the capacitance value, and impedance over temperature is relatively small. However, the tantalum capacitors have relatively high ESR values which can lead to higher voltage ripple and their frequency stability (variation over frequency) is not very good, especially at high frequencies (>1 MHz).

#### ii) Ceramic

Ceramic capacitors have the lowest ESR of the three technologies and their frequency stability is exceptionally good. These characteristics make the ceramics an attractive choice for low ripple, high frequency applications. However, the temperature stability of the ceramics is bad, except for the X7R and X5R dielectric types. High capacitance values (>1  $\mu\text{F}$ ) are achievable from companies such as Taiyo-yuden which are suitable for use with regulators. Ceramics are taller and larger than the tantalums of the same capacitance value.

#### iii) Polymer Electrolytic

Polymer electrolytic is a third suitable technology. Polymer capacitors provide some of the best features of both the ceramic and the tantalum technologies. They provide very low ESR values while still achieving high capacitance values. However, their ESR is still higher than the ceramics, and their capacitance value is lower than the tantalums of the same

size. Polymers offer good frequency stability (comparable to ceramics) and good temperature stability (comparable to tantalums). The Aluminum Polymer Electrolytics offered by Cornell-Dubilier and Panasonic, and the POSCAPs offered by Sanyo fall under this category.

Table 1 compares the features of the three capacitor technologies.

**TABLE 1. Comparison of Capacitor Technologies**

|   | Ceramic   | Tantalum        | Polymer Electrolytic |
|---|---|-----------------|----------------------|
| <b>ESR</b>  | Lowest  | High            | Low                  |
| <b>Relative Height</b>  | Low for Small Values (<10 $\mu\text{F}$ ); Taller for Higher Values | Lowest          | Low                  |
| <b>Relative Footprint</b>   | Large   | Small           | Largest              |
| <b>Temperature Stability</b>  | X7R/X5R-Acceptable  | Good            | Good                 |
| <b>Frequency Stability</b>  | Good  | Acceptable      | Good                 |
| <b><math>V_{\text{OUT}}</math> Ripple Magnitude @ &lt;50 mA</b>             | Low   | High            | Low                  |
| <b><math>V_{\text{OUT}}</math> Ripple Magnitude @ &gt;100 mA</b>            | Low   | Slightly Higher | Low                  |
| <b><math>dv/dt</math> of <math>V_{\text{OUT}}</math> Ripple @ All Loads</b> | Lowest  | High            | Low                  |

## b) CAPACITOR SELECTION

### i) Output Capacitor ( $C_{\text{OUT}}$ )

The output capacitor  $C_{\text{OUT}}$  directly affects the magnitude of the output ripple voltage so  $C_{\text{OUT}}$  should be carefully selected. The graphs titled  $V_{\text{OUT}}$  Ripple vs.  $C_{\text{OUT}}$  in the Typical Performance Characteristics section show how the ripple voltage magnitude is affected by the  $C_{\text{OUT}}$  value and the capacitor technology. These graphs are taken at the gain at which worst case ripple is observed. In general, the higher the value of  $C_{\text{OUT}}$ , the lower the output ripple magnitude. At lighter loads, the low ESR ceramics offer a much lower  $V_{\text{OUT}}$  ripple than the higher ESR tantalums of the same value. At higher loads, the ceramics offer a slightly lower  $V_{\text{OUT}}$  ripple magnitude than the tantalums of the same value. However, the  $dv/dt$  of the  $V_{\text{OUT}}$  ripple with the ceramics and polymer electrolytics is much lower than the tantalums under all load conditions. The tantalums are suggested for very low profile, small size applications. The ceramics and polymer electrolytics are a good choice for low ripple, low noise applications where size is less of a concern.

### ii) Input Capacitor ( $C_{\text{IN}}$ )

The input capacitor  $C_{\text{IN}}$  directly affects the magnitude of the input ripple voltage, and to a lesser degree the  $V_{\text{OUT}}$  ripple. A

higher value  $C_{\text{IN}}$  will give a lower  $V_{\text{IN}}$  ripple. To optimize low input and output ripple as well as size a 10  $\mu\text{F}$  polymer electrolytic or ceramic, or 15  $\mu\text{F}$  tantalum capacitor is recommended. This will ensure low input ripple at 50 mA load current. If lower currents will be used or higher input ripple can be tolerated then a smaller capacitor may be used to reduce the overall size of the circuit. The lower ESR ceramics and polymer electrolytics achieve a lower  $V_{\text{IN}}$  ripple than the higher ESR tantalums of the same value. Tantalums make a good choice for small size, very low profile applications. The ceramics and polymer electrolytics are a good choice for low ripple, low noise applications where size is less of a concern. The 10  $\mu\text{F}$  polymer electrolytics are physically much larger than the 15  $\mu\text{F}$  tantalums and 10  $\mu\text{F}$  ceramics.

### iii) $C_{\text{FIL}}$

A 1  $\mu\text{F}$ , X7R ceramic capacitor should be connected to pin  $C_{\text{FIL}}$ . This capacitor provides the filtering needed for the internal supply rail of the LM3355.

Of the different capacitor technologies, a sample of vendors that have been verified as suitable for use with the LM3355 are shown in Table 2.

**TABLE 2. Capacitor Vendor Information**

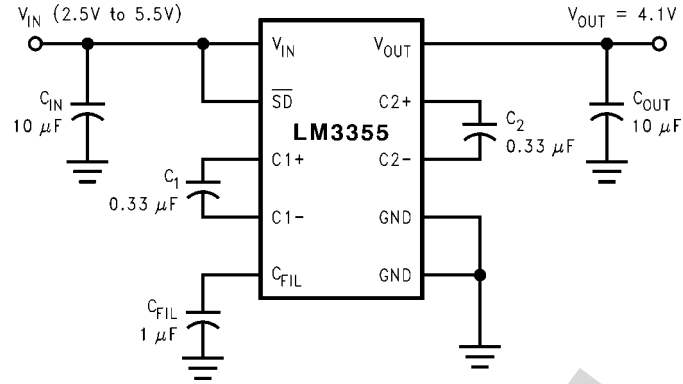
|                             | Manufacturer            | Tel            | Fax            | Website                  |
|-----------------------------|-------------------------|----------------|----------------|--------------------------|
| <b>Ceramic</b>              | Taiyo-yuden             | (408) 573-4150 | (408) 573-4159 | www.t-yuden.com          |
| <b>Tantalum</b>             | AVX                     | (803) 448-9411 | (803) 448-1943 | www.avxcorp.com          |
|                             | Sprague/Vishay          | (207) 324-4140 | (207) 324-7223 | www.vishay.com           |
|                             | Nichicon                | (847) 843-7500 | (847) 843-2798 | www.nichicon.com         |
| <b>Polymer Electrolytic</b> | Cornell-Dubilier (ESRD) | (508) 996-8561 | (508) 996-3830 | www.cornell-dubilier.com |
|                             | Sanyo (POSCAP)          | (619) 661-6322 | (619) 661-1055 | www.sanyovideo.com       |

## Thermal Protection

During output short circuit conditions, the LM3355 will draw high currents causing a rise in the junction temperature. On-

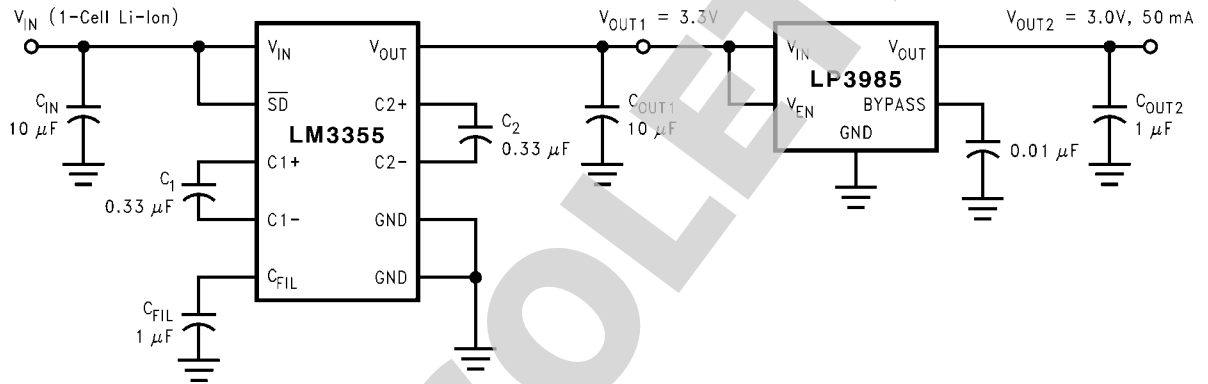
chip thermal protection circuitry disables the charge pump action once the junction temperature exceeds the thermal trip point, and re-enables the charge pump when the junction temperature falls back to a safe operating point.

## Typical Application Circuits



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FIGURE 2. Basic Buck/Boost Regulator



20021915

FIGURE 3. Low Output Noise and Ripple Buck/Boost Regulator

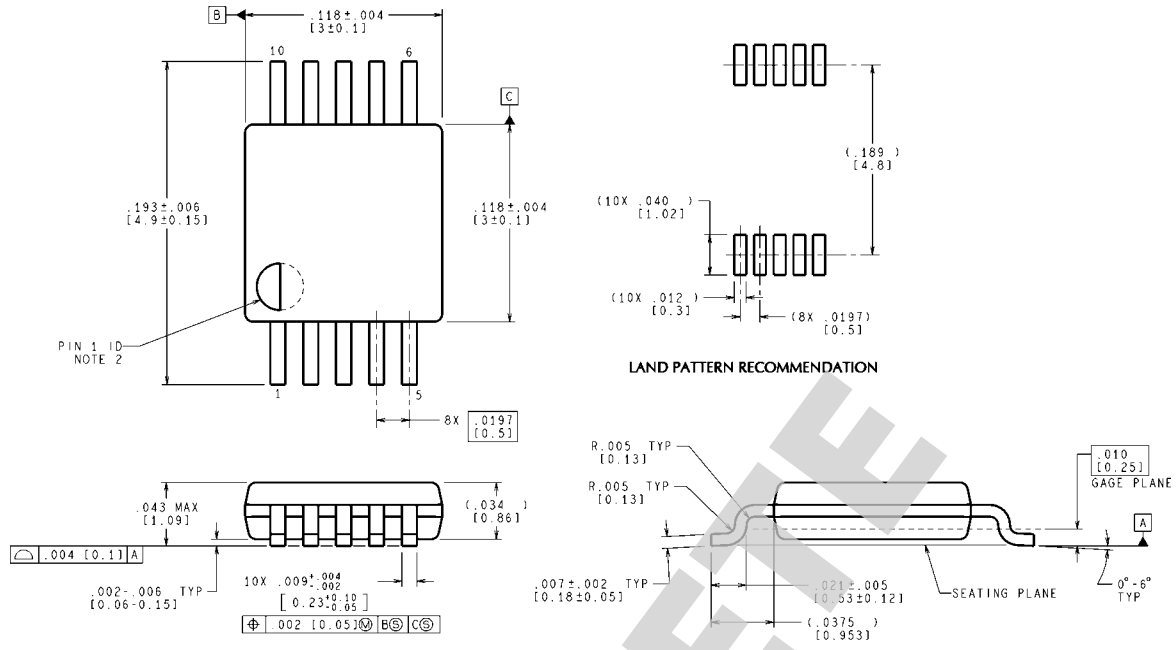
### Layout Considerations

Due to the 1 MHz typical switching frequency of the LM3355, careful board layout is a must. It is important to place the ca-

pacitors as close to the IC as possible and to keep the traces between the capacitors and the IC short and direct. Use of a ground plane is recommended.



**Physical Dimensions** inches (millimeters) unless otherwise noted



CONTROLLING DIMENSION IS INCH  
 VALUES IN [ ] ARE MILLIMETERS  
 DIMENSIONS IN ( ) FOR REFERENCE ONLY

MUB10A (Rev B)

**MSOP-10 Pin Package (MM)**  
**For Ordering, Refer to Ordering Information Table**  
**NS Package Number MUB10A**

OBSOLETE

## Notes

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| Audio                          | <a href="http://www.national.com/audio">www.national.com/audio</a>           | App Notes                    | <a href="http://www.national.com/appnotes">www.national.com/appnotes</a>           |
| Clock and Timing               | <a href="http://www.national.com/timing">www.national.com/timing</a>         | Reference Designs            | <a href="http://www.national.com/refdesigns">www.national.com/refdesigns</a>       |
| Data Converters                | <a href="http://www.national.com/adc">www.national.com/adc</a>               | Samples                      | <a href="http://www.national.com/samples">www.national.com/samples</a>             |
| Interface                      | <a href="http://www.national.com/interface">www.national.com/interface</a>   | Eval Boards                  | <a href="http://www.national.com/evalboards">www.national.com/evalboards</a>       |
| LVDS                           | <a href="http://www.national.com/lvds">www.national.com/lvds</a>             | Packaging                    | <a href="http://www.national.com/packaging">www.national.com/packaging</a>         |
| Power Management               | <a href="http://www.national.com/power">www.national.com/power</a>           | Green Compliance             | <a href="http://www.national.com/quality/green">www.national.com/quality/green</a> |
| Switching Regulators           | <a href="http://www.national.com/switchers">www.national.com/switchers</a>   | Distributors                 | <a href="http://www.national.com/contacts">www.national.com/contacts</a>           |
| LDOs                           | <a href="http://www.national.com/ldo">www.national.com/ldo</a>               | Quality and Reliability      | <a href="http://www.national.com/quality">www.national.com/quality</a>             |
| LED Lighting                   | <a href="http://www.national.com/led">www.national.com/led</a>               | Feedback/Support             | <a href="http://www.national.com/feedback">www.national.com/feedback</a>           |
| Voltage References             | <a href="http://www.national.com/vref">www.national.com/vref</a>             | Design Made Easy             | <a href="http://www.national.com/easy">www.national.com/easy</a>                   |
| PowerWise® Solutions           | <a href="http://www.national.com/powerwise">www.national.com/powerwise</a>   | Applications & Markets       | <a href="http://www.national.com/solutions">www.national.com/solutions</a>         |
| Serial Digital Interface (SDI) | <a href="http://www.national.com/sdi">www.national.com/sdi</a>               | Mil/Aero                     | <a href="http://www.national.com/milaero">www.national.com/milaero</a>             |
| Temperature Sensors            | <a href="http://www.national.com/tempensors">www.national.com/tempensors</a> | SolarMagic™                  | <a href="http://www.national.com/solarmagic">www.national.com/solarmagic</a>       |
| PLL/VCO                        | <a href="http://www.national.com/wireless">www.national.com/wireless</a>     | PowerWise® Design University | <a href="http://www.national.com/training">www.national.com/training</a>           |

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Life support devices or systems are devices which (a) are intended for surgical implant into the body, or (b) support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in a significant injury to the user. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system or to affect its safety or effectiveness.

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