National Semiconductor

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LM3351
Switched Capacitor Voltage Converter

General Description

The LM3351 is a CMOS charge-pump voltage converter which efficiently provides a 3.3V to 5V step-up, or 5V to 3.3V step-down. The LM3351 is pin for pin compatible with the LM3350 but consumes 66% less quiescent current. The LM3351 uses four small, low cost capacitors to provide the voltage conversion. It eliminates the cost, size and radiated EMI related to inductor based circuits, or the power loss of a linear regulator. Operating power conversion efficiency greater than 90% provides ideal performance for battery powered portable systems.

The architecture provides a fixed voltage conversion ratio of 3/2 or 2/3. Thus it can be used for other DC-DC conversions as well.

Features

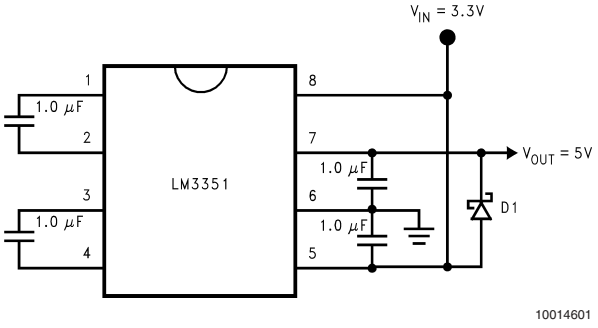
- Conversion of 3.3V to 5V, or 5V to 3.3V
- 200 kHz switch frequency allows use of very small, inexpensive capacitors.
- 4.2Ω typical step-up output impedance
- 1.8Ω typical step-down output impedance
- 95% typical power conversion efficiency at 50 mA
- 250 nA typical shutdown current
- No inductor required
- Low quiescent current extends battary life
- Small Mini SO-8 package

Applications

- Any mixed 5V and 3.3V system
- Laptop computers and PDAs
- Handheld instrumentation
- PCMCIA cards

Basic Operating Circuits

Step-Up Converter



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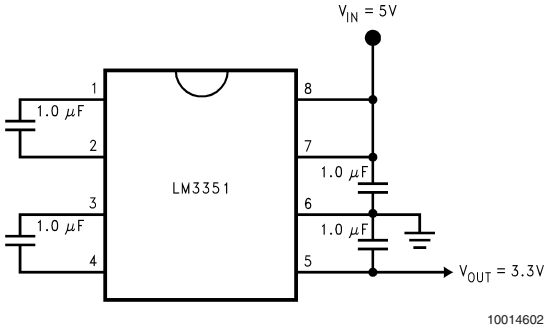
Step-Down Converter



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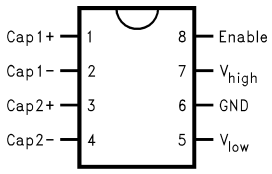
Connection Diagram

Mini SO8 Package



Top View

Ordering Information

Order Number	Package Type	NSC Package Drawing	Package Marking	Supplied As
LM3351MMX	Mini SO-8	MUA08A	S05A	3500 Units on Tape and Reel
LM3351MM	Mini SO-8	MUA08A	S05A	1000 Units on Tape and Reel

Pin Description

Pin	Name	Function
1	Cap1+	Positive terminal for the first charge pump capacitor.
2	Cap1−	Negative terminal for the first charge pump capacitor.
3	Cap2+	Positive terminal for the second charge pump capacitor.
4	Cap2−	Negative terminal for the second charge pump capacitor.
5	V_{low}	In Step-Up mode, this will be the input terminal. In Step-Down mode, this will be the output terminal.
6	Gnd	Ground
7	V_{high}	In Step-Down mode, this will be the input terminal. In Step-Up mode, this will be the output terminal.
8	Enable	Active high CMOS logic level Enable Input. Connect to Voltage Input terminal to enable the IC. Connect to Ground (Pin 6) to disable.

Absolute Maximum Ratings (Note 1)

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

Maximum Input Voltage, Step-Down	5.5V
Maximum Input Voltage, Step-Up	3.65V
Power Dissipation (P_D) (T_A=25˚C, (Note 2))	500 mW
θ_{ja} (Note 2)	250˚C/W
Tj Max (Note 2)	150˚C
Storage Temperature	−65˚C to +150˚C
Lead Temperature (Soldering, 10 secs)	260˚C
ESD Susceptibility (Note 3)	2kV

Not short circuit protected.

Operating Conditions (Note 1)

Ambient Temperature Range	−40˚C to + 85˚C

Electrical Characteristics 3/2 Step-Up Voltage Converter

Specifications in standard type face are for T_j = 25˚C, and those with **boldface type** apply over **full operating temperature range**. Unless otherwise specified, V_{in} = 3.3V, V_{Enable} = 3.3V, I_{load} = 50 mA, C_1, C_2, C_{in} and C_{out} = 1 µF.

Symbol	Parameter	Conditions	**Typ** (Note 4)	**Limits** (Note 5)	Units
$V_{out_{NL}}$	Output Voltage at No Load	I_{load} = 0 A	5.0		V
$V_{out_{FL}}$	Output Voltage at 50 mA	I_{load} = 50 mA	4.7		V
V_{in}	Input Supply Voltage Range		3.3	**2.5** **3.65**	V V(Min) V(Max)
I_{Q1}	Quiescent Current	Shutdown Mode, V_{Enable} = 0V, I_{load}=0 A; Current into pin V_{low}	0.025	**3**	µA µA(Max)
I_{Q2}	Quiescent Current	Normal Mode, I_{load} = 0A; Current into pin V_{low}	1.1	**1.5**	mA mA(Max)
Z_{out}	Output Source Impedance	I_{load} = 50 mA	4.2	**6.25**	Ω Ω (Max)
f_{SW}	Switching Frequency	(Note 6)	200	**125** **275**	kHz kHz(Min) kHz(Max)
V_{Enable}	Enable Threshold Voltage		1.7	**1.0** **2.5**	V V(Min) V(Max)
I_{Enable}	Leakage Current	Current into ENABLE pin; ENABLE = 5V and all other pins at ground	0.025	**1**	µA µA(Max)
P_η	Power Efficiency		95		%

Electrical Characteristics 2/3 Step-Down Voltage Converter

Specifications in standard type face are for T_j = 25˚C, and those with **boldface type** apply over **full operating temperature range**. Unless otherwise specified, V_{high} = 5V, V_{Enable} = 5V, I_{load} = 50 mA, C_1, C_2, C_{in} and C_{out} = 1 µF.

Symbol	Parameter	Conditions	**Typ** (Note 4)	**Limits** (Note 5)	Units
$V_{out_{NL}}$	Output Voltage at No Load	I_{load} = 0 A	3.3		V
$V_{out_{FL}}$	Output Voltage at 50 mA	I_{load} =50 mA	3.2		V

Electrical Characteristics
2/3 Step-Down Voltage Converter (Continued)

Specifications in standard type face are for T_j = 25˚C, and those with **boldface type** apply over **full operating temperature range**. Unless otherwise specified, V_{high} = 5V, V_{Enable} = 5V, I_{load} = 50 mA, C_1, C_2, C_{in} and C_{out} = 1 µF.

Symbol	Parameter	Conditions	**Typ** (Note 4)	**Limits** (Note 5)	Units
V_{in}	Input Supply Voltage Range		5		V
				2.2	V(Min)
				5.5	V(Max)
I_{Q1}	Quiescent Current	Shutdown Mode, V_{Enable} = 0V, I_{load}=0 A; Current into pin V_{high}	0.25		µA
				3	µA(Max)
I_{Q2}	Quiescent Current	Normal Mode, I_{load} = 0A; Current into pin V_{high}	0.8		mA
				1.0	mA(Max)
Z_{out}	Output Source Impedance	I_{load} = 50 mA	1.8		Ω
				3	Ω (Max)
f_{SW}	Switching Frequency	(Note 6)	200		kHz
				125	kHz(Min)
				275	kHz(Max)
V_{Enable}	Enable Threshold Voltage		1.7		V
				1.0	V(Min)
				2.5	V(Max)
I_{Enable}	Leakage Current	Current into ENABLE pin; ENABLE = 5V and all other pins at ground	0.025		µA
				1	µA(Max)
P_η	Power Efficiency		95		%

Note 1: Absolute maximum ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2: For operation at elevated temperatures, LM3351 must be derated based on package thermal resistance of θ_{ja} and T_j max, $T_j = T_A + \theta_{ja} P_D$.

Note 3: The human body model is a 100 pF capacitor discharged through a 1.5 kW resistor into each pin.

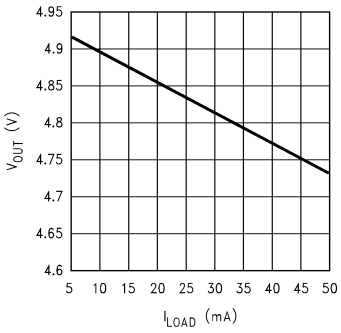
Note 4: Typical numbers are at 25˚C and represent the most likely parametric norm.

Note 5: Limits are 100% production tested at 25˚C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Averaging Outgoing Quality Level (AOQL).

Note 6: The internal oscillator runs at 1.6 MHz, the output switches operate at one eighth of the oscillator frequency, $f_{OSC} = 8 f_{SW}$.

Typical Performance Characteristics

V_{out} vs I_{load} (Step-Up)



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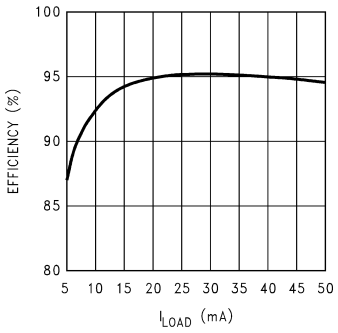
P_{η} vs I_{load} (Step-Up)



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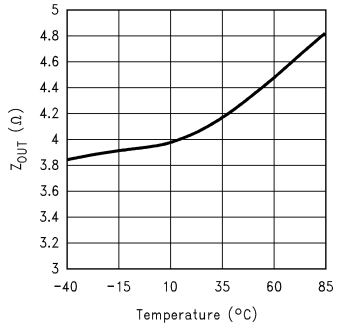
Output Source Impedance vs Temperature (Step-Up)



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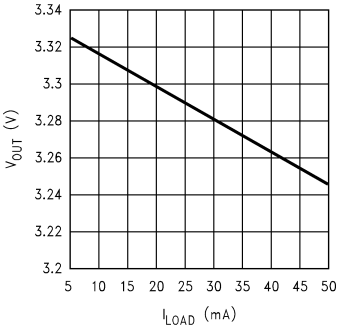
V_{out} vs I_{load} (Step-Down)



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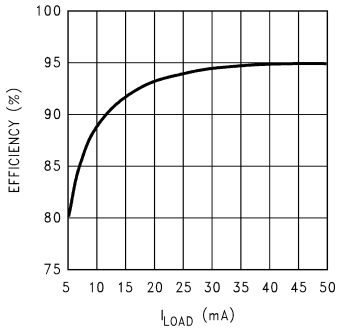
P_{η} vs I_{load} (Step-Down)



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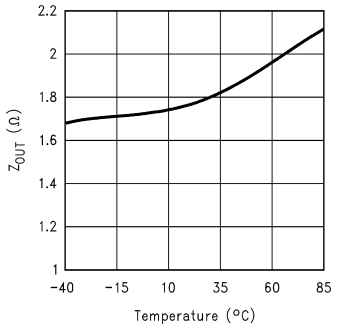
Output Source Impedance vs Temperature (Step-Down)



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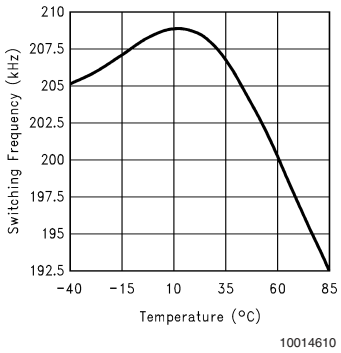
Typical Performance Characteristics (Continued)

Switching Frequency vs Temperature



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Detailed Operation

OPERATING PRINCIPLE

The LM3351 is a charge-pump voltage converter that provides a voltage conversion ratio of 3/2 in step-up mode and a conversion ratio of 2/3 in the step-down mode. Thus it can be used in the step-down mode to provide a 3.3V output from a regulated 5V input or in the step-up mode to provide a 5V output from a regulated 3.3V input. Other values of input voltages can be used as long as they are within the limits.

The LM3351 contains an array of CMOS switches which are operated in a certain sequence to provide the step-up or step-down of the input supply. An internal RC oscillator provides the timing signals.

Energy transfer and storage are provided by four inexpensive ceramic capacitors. The selection of these capacitors is explained in the Capacitor Selection section under Application Information.

STEP-UP APPLICATIONS NEED AN EXTRA DIODE

The LM3351 is biased from pin V_{high}. Thus for step-up applications, an external Schottky diode (D1) is needed to supply power to V_{high} during startup (See *Figure 1*). Note that during shutdown, this diode will provide a DC path from V_{in} to V_{out}. The load may therefore continue to draw current from the input voltage source. This Schottky diode is not required for step-down applications (See *Figure 2*).

SHUTDOWN MODE

When ENABLE is a logic low (ground), the LM3351 enters a low power shutdown mode. In this mode, all circuitry is disabled and therefore, all switching action stops. During shutdown, the current consumption drops to 250 nA (typical).

When ENABLE is a logic high, (i.e. 3.3V for step-up mode and 5.0V for step-down mode), the LM3351 returns to normal operation.

Application Information

CAPACITOR SELECTION

The LM3351 requires four capacitors: an input bypass capacitor (connected between V_{in} and ground), an output hold capacitor (connected between V_{out} and ground), and two sampling capacitors (C1 and C2 in *Figures 1, 2*). 1.0 µF (±20%) ceramic chip type capacitors are recommended for all four capacitors. The usable operating frequency should be greater than 5 MHz for all capacitors.

The output hold capacitor value determines the output ripple. Increasing the value of the hold capacitor decreases the ripple. The value of this capacitor (C_{out}) can be calculated (approximately) based on the output ripple (ΔV_{out}) requirements from:

$$C_{OUT} = \frac{I_{LOAD}}{\Delta V_{OUT}\, f_O}$$

where I_{load} is the load current and f_O is the oscillator frequency.

In order to ensure superior performance over the entire operating temperature range, capacitors made of X7R dielectric material are suggested. However, capacitors made of other dielectric materials that still meet the ±20% specification over the entire temperature range can also be used.

PRECAUTIONS

The LM3351 is not short circuit protected.

Typical Application Circuits

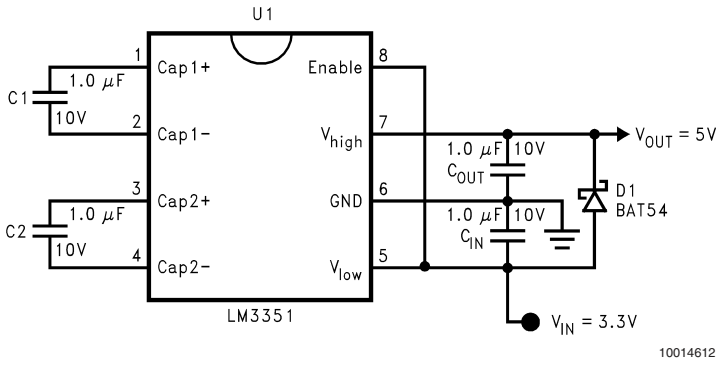


FIGURE 1. Step-Up Converter

Typical Application Circuits (Continued)

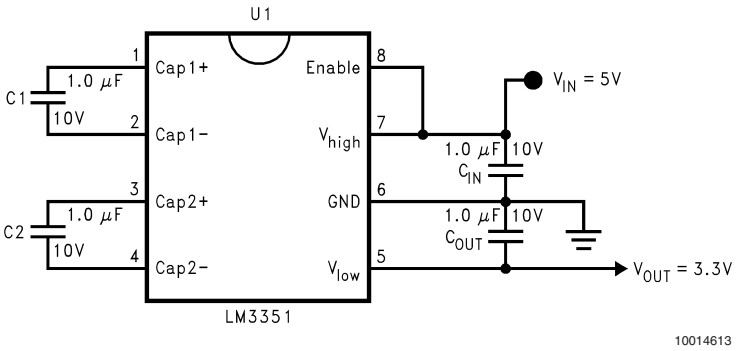


FIGURE 2. Step-Down Converter

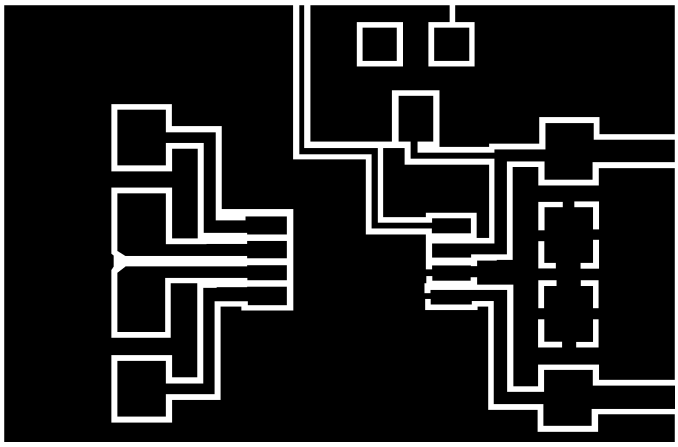
Layout Information

LAYOUT CONSIDERATIONS

The LM3351's high switching frequency (200 kHz) makes a good layout important. *Figure 3* illustrates a typical layout. It is important to keep the distance short between the four capacitors and the IC. Wide traces and grounding are also recommended. These steps will minimize trace inductance and high frequency ringing. Of the four capacitors, C_{IN} and C_{OUT} have the highest value of di/dt. It is therefore most important to keep them close to the IC. The ground lead that C_{IN} and C_{OUT} share should also be kept wide and short.

The location of the diode (D1) used in the step-up configuration is not critical. This diode is only used during the initial turn on of the IC. D1 is not needed in step-down applications.

Layout Information (Continued)



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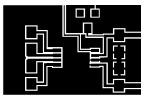
A. Copper side (5X)



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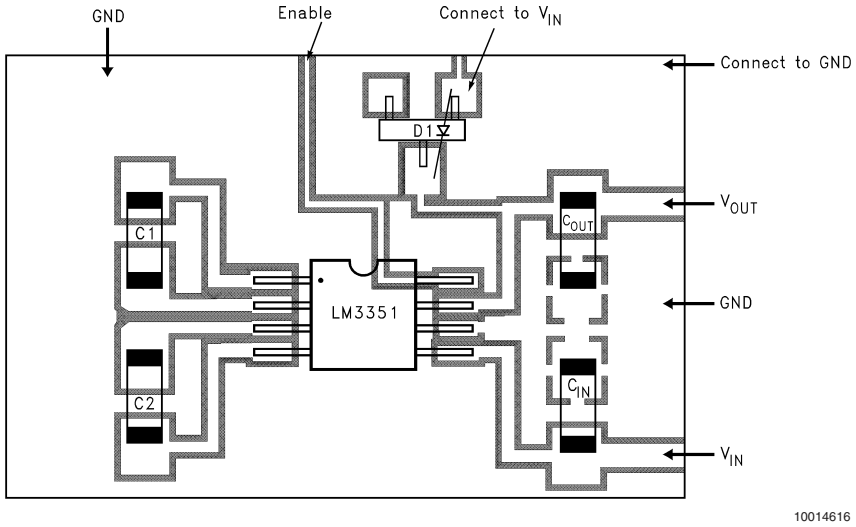
B. Actual Size of the Layout



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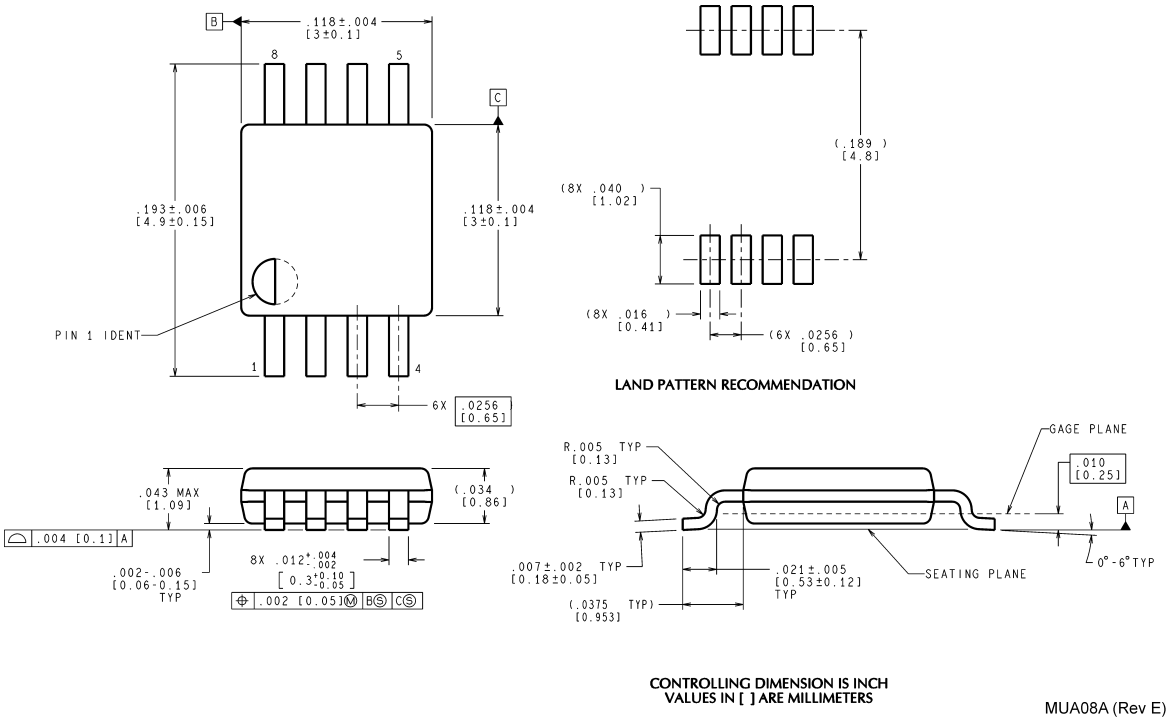
C. Copper side with Component Locations (5X)

FIGURE 3. Typical Layout

Physical Dimensions inches (millimeters) unless otherwise noted



MUA08A (Rev E)

8-Lead Mini SO (MM)
Order Number LM3351MMX or LM3351MM
NS Package Number MUA08A

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