19-2875; Rev 1; 12/03

EVALUATION KIT AVAILABLE

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs



## General Description

The MAX1553/MAX1554 drive white LEDs in series with a constant current to provide efficient display backlighting in cellular phones, PDAs, and other hand-held devices. The step-up converter includes an internal 40V, low $R_{DSON}$, N-channel MOSFET switch for high efficiency and maximum battery life. The MAX1553 has a current limit of 480mA for driving two to six white LEDs, while the MAX1554 has a current limit of 970mA for driving up to 10 white LEDs.

A single analog/PWM Dual Mode™ input provides two simple means of brightness adjustment. A separate enable input provides on/off control. Soft-start minimizes inrush current during startup.

The MAX1553/MAX1554 are available in space-saving 8-pin TDFN 3mm x 3mm packages.

## Features

- **Constant-Current Regulation for Even LED Illumination**
- **Internal 40V MOSFET Switch Capable of Driving 10 LEDs**
- **Small, Low-Profile External Components**
- **2.7V to 5.5V Input Range**
- **Up to 88% Efficiency Driving 6 LEDs**
- **Up to 82% Efficiency Driving 9 LEDs (20mA, $V_{CC}$ = 3.6V)**
- **Analog or PWM Control of LED Intensity**
- **Optimized for Low Input Ripple**
- **Soft-Start to Minimize Inrush Current**
- **3mm x 3mm 8-Pin TDFN Package**

## Applications

Cellular Phones

PDA, Palmtop, and Wireless Handhelds

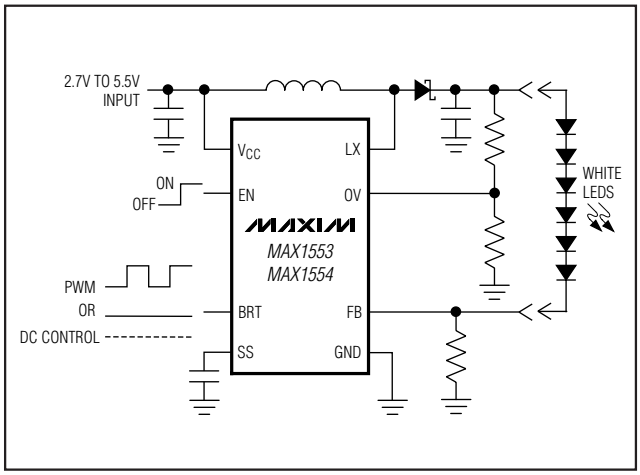
Color Display Backlight

*Dual Mode is a trademark of Maxim Integrated Products, Inc.*

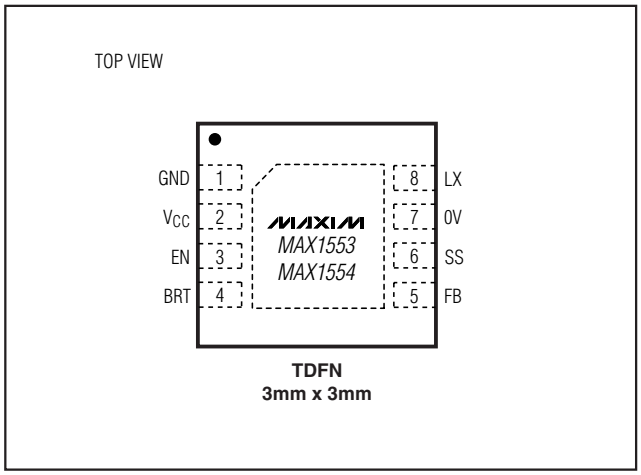
## Ordering Information

| PART | TEMP RANGE | PIN-PACKAGE | TOP MARK |
|---|---|---|---|
| **MAX1553**ETA | -40°C to +85°C | 8 TDFN 3mm x 3mm | AGX |
| **MAX1554**ETA | -40°C to +85°C | 8 TDFN 3mm x 3mm | AGY |

## Typical Operating Circuit




## Pin Configuration






For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

## ABSOLUTE MAXIMUM RATINGS

$V_{CC}$, FB, OV to GND .....-0.3V to +6.0V
LX to GND .....-0.3V to +45V
EN, BRT, SS to GND.....-0.3V to ($V_{CC}$ + 0.3V)
$I_{LX}$ .....$0.9A_{RMS}$
Continuous Power Dissipation ($T_A$ = +70°C)
8-Pin 3mm x 3mm TDFN
(derate 24.4mW/°C above +70°C).....1951mW
Operating Temperature Range .....-40°C to +85°C
Junction Temperature.....+150°C
Storage Temperature Range .....-65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C

*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## ELECTRICAL CHARACTERISTICS

($V_{CC}$ = 3.3V, $V_{OV}$ = 0V, $C_{OUT}$ = 1µF, $R_{SENSE}$ = 10Ω, **$T_A$ = 0°C to +85°C**, unless otherwise noted. Typical values are at $T_A$ = +25°C.)

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Supply Voltage | MAX1553 | | 2.7 | | 5.5 | V |
| | MAX1554 | | 3.15 | | 5.50 | |
| Undervoltage Lockout Threshold | $V_{CC}$ rising or falling, 35mV hysteresis typical | | 2.35 | 2.5 | 2.65 | V |
| Quiescent Current | Not switching | | | 0.33 | 0.65 | mA |
| | Switching | | | 0.44 | 0.9 | |
| Shutdown Supply Current | $V_{EN}$ = 0V | $T_A$ = +25°C | | 0.1 | 1 | µA |
| | | $T_A$ = +85°C | | 1 | | |
| OV Threshold | Rising edge | | 1.18 | 1.25 | 1.33 | V |
| OV Input Bias Current | $V_{OV}$ = 1V | $T_A$ = +25°C | | 1 | 200 | nA |
| | | $T_A$ = +85°C | | 10 | | |
| BRT Input Resistance | 0 < $V_{BRT}$ < 1.5V, EN = $V_{CC}$ | | 200 | 400 | 600 | kΩ |
| **TIMING CONTROL** | | | | | | |
| Maximum On-Time | $V_{CC}$ = 3.3V | | 2.0 | 3.4 | 4.8 | µs |
| On-Time Constant (K) | $t_{ON}$ = K / $V_{CC}$ | | | 6.3 | | µs-V |
| Minimum Off-Time | | | 150 | 250 | 350 | ns |
| **ERROR AMPLIFIER** | | | | | | |
| FB Threshold | $V_{BRT}$ = 1.25V | | 192 | 203 | 212 | mV |
| | $V_{BRT}$ = 3.3V | | | 280 | | |
| FB Input Bias Current | $V_{FB}$ = 1.0V | $T_A$ = +25°C | | 15 | 200 | nA |
| | | $T_A$ = +85°C | | 100 | | |
| **N-CHANNEL SWITCH** | | | | | | |
| LX On-Resistance | | | | 0.8 | 1.4 | Ω |

## ELECTRICAL CHARACTERISTICS (continued)

($V_{CC}$ = 3.3V, $V_{OV}$ = 0V, $C_{OUT}$ = 1µF, $R_{SENSE}$ = 10Ω, **$T_A$ = 0°C to +85°C**, unless otherwise noted. Typical values are at $T_A$ = +25°C.)

| PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| LX Current Limit | MAX1553 | | 300 | 480 | 600 | mA |
| | MAX1554, $V_{CC}$ = 4.2V | | 600 | 970 | 1200 | |
| LX Leakage Current | $V_{LX}$ = 38V, $V_{EN}$ = 0V | $T_A$ = +25°C | | 0.1 | 5 | µA |
| | | $T_A$ = +85°C | | 1 | | |
| **SHUTDOWN CONTROL** | | | | | | |
| EN Logic-Level High | | | 1.8 | | | V |
| EN Logic-Level Low | | | | | 0.4 | V |
| EN Input Current | $V_{EN}$ = 0V or 5.5V | $T_A$ = +25°C | | 0.01 | 1 | µA |
| | | $T_A$ = +85°C | | 0.1 | | |

## ELECTRICAL CHARACTERISTICS

($V_{CC}$ = 3.3V, $V_{OV}$ = 0V, $C_{OUT}$ = 1µF, $R_{SENSE}$ = 10Ω, **$T_A$ = -40°C to +85°C**, unless otherwise noted.) (Note 1)

| PARAMETER | CONDITIONS | MIN | MAX | UNITS |
|---|---|---|---|---|
| Supply Voltage | MAX1553 | 2.7 | 5.5 | V |
| | MAX1554 | 3.15 | 5.50 | |
| Undervoltage Lockout Threshold | $V_{CC}$ rising or falling, 35mV hysteresis typical | 2.35 | 2.65 | V |
| Quiescent Current | Not switching | | 0.65 | mA |
| | Switching | | 0.9 | |
| OV Threshold | Rising edge | 1.18 | 1.33 | V |
| BRT Input Resistance | 0 < $V_{BRT}$ < 1.5V, EN = $V_{CC}$ | 200 | 600 | kΩ |
| **TIMING CONTROL** | | | | |
| Maximum On-Time | $V_{CC}$ = 3.3V | 2.0 | 4.8 | µs |
| Minimum Off-Time | | 150 | 350 | ns |
| **ERROR AMPLIFIER** | | | | |
| FB Threshold | $V_{BRT}$ = 1.25V | 192 | 217 | mV |
| **N-CHANNEL SWITCH** | | | | |
| LX On-Resistance | | | 1.4 | Ω |
| LX Current Limit | MAX1553 | 300 | 600 | mA |
| | MAX1554, $V_{CC}$ = 4.2V | 600 | 1200 | |
| **SHUTDOWN CONTROL** | | | | |
| EN Logic-Level High | | 1.8 | | V |
| EN Logic-Level Low | | | 0.4 | V |

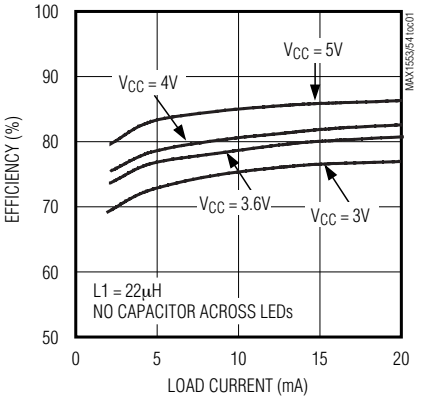
**Note 1:** Specifications to -40°C are guaranteed by design, not production tested.

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

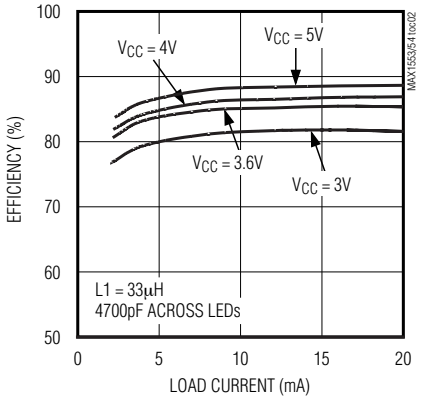
## Typical Operating Characteristics

(MAX1553 driving six white LEDs, $V_{CC}$ = $V_{EN}$ = 3.6V, Circuit of Figure 1, $T_A$ = +25°C, unless otherwise noted.)

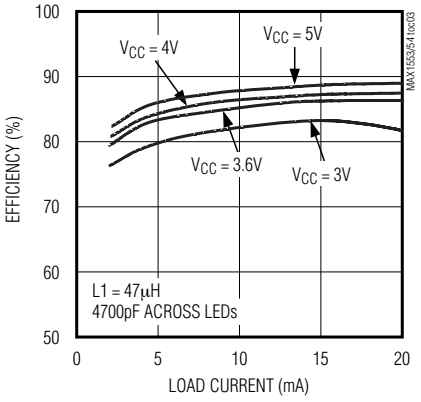
**EFFICIENCY vs. LOAD CURRENT DRIVING 6 WHITE LEDS**



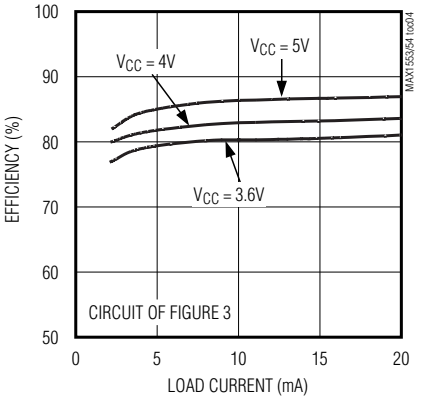

**EFFICIENCY vs. LOAD CURRENT DRIVING 6 WHITE LEDS**



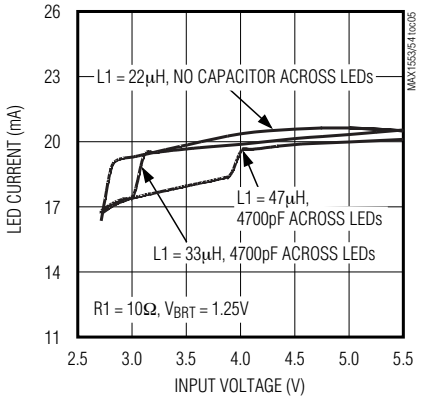

**EFFICIENCY vs. LOAD CURRENT DRIVING 6 WHITE LEDS**



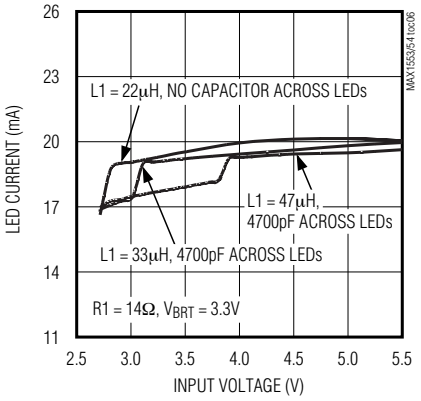

**EFFICIENCY vs. LOAD CURRENT WITH MAX1554 DRIVING 9 WHITE LEDS**



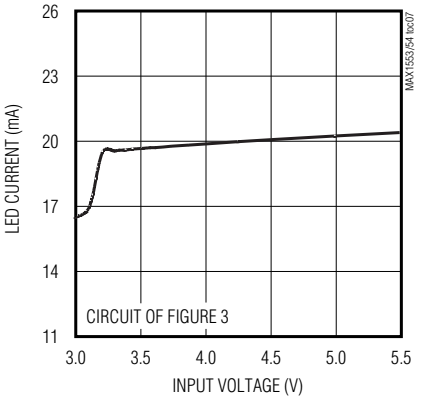

**LED CURRENT vs. INPUT VOLTAGE**



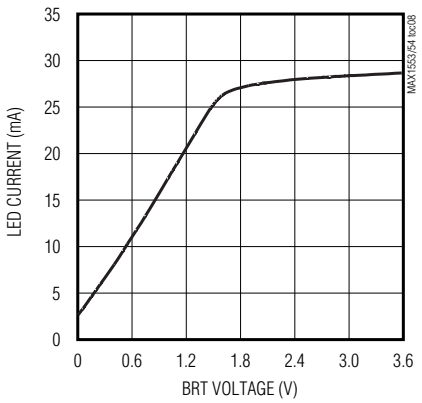

**LED CURRENT vs. INPUT VOLTAGE**



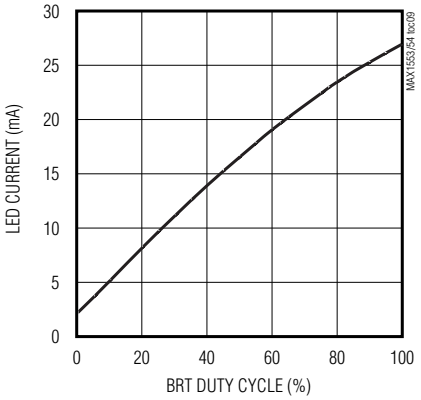

**LED CURRENT vs. INPUT VOLTAGE WITH MAX1554 DRIVING 9 LEDS**




**LED CURRENT vs. BRT VOLTAGE**



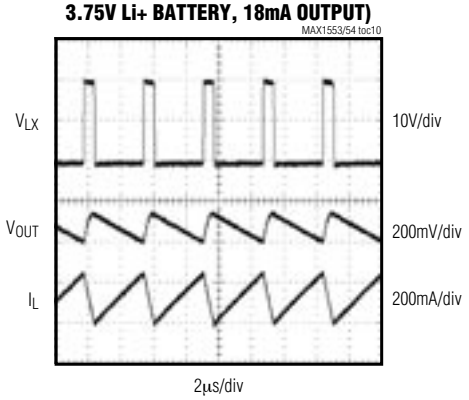

**LED CURRENT vs. BRT DUTY CYCLE**



## Typical Operating Characteristics (continued)

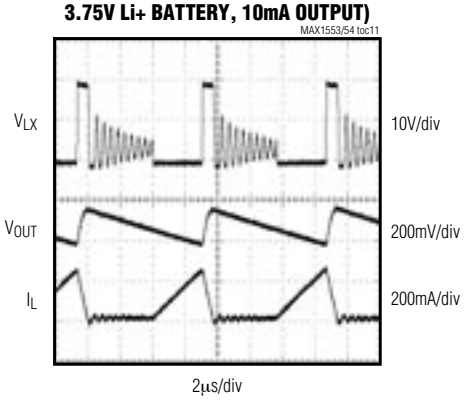
(MAX1553 driving six white LEDs, $V_{CC}$ = $V_{EN}$ = 3.6V, Circuit of Figure 1, $T_A$ = +25°C, unless otherwise noted.)

**SWITCHING WAVEFORMS (CONTINUOUS OPERATION, 3.75V Li+ BATTERY, 18mA OUTPUT)**



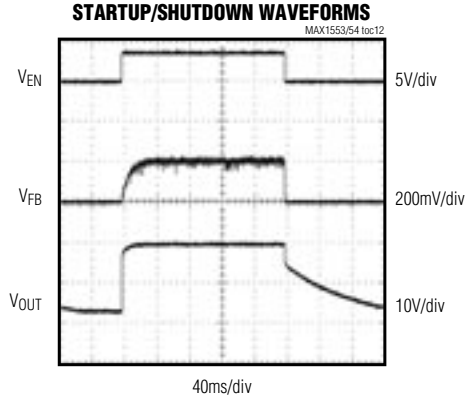

L1 = 47µH, 4700pF CAPACITOR ACROSS LEDs

**SWITCHING WAVEFORMS (DISCONTINUOUS OPERATION, 3.75V Li+ BATTERY, 10mA OUTPUT)**



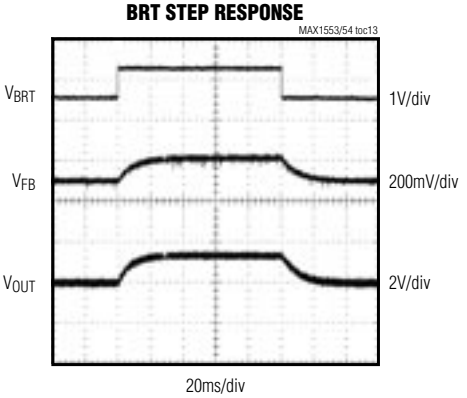

L1 = 47µH, 4700pF CAPACITOR ACROSS LEDs

**STARTUP/SHUTDOWN WAVEFORMS**




L1 = 22µH

**BRT STEP RESPONSE**




L1 = 22µH,
$V_{BRT}$ = 0.5V TO 1.25V TO 0.5V

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

## Pin Description

| PIN | NAME | FUNCTION |
|---|---|---|
| 1 | GND | Ground |
| 2 | $V_{CC}$ | Voltage-Supply Input. 2.7V to 5.5V. The IC is powered from $V_{CC}$. |
| 3 | EN | Enable Input. Drive high or connect to $V_{CC}$ to enable the IC. Drive EN low for shutdown. |
| 4 | BRT | Brightness-Control Input. Either an analog or PWM control signal can be used. The LED current can be controlled over a 10 to 1 range. The PWM signal must be between 100Hz and 10kHz, and must have an amplitude greater than 1.72V. |
| 5 | FB | Feedback Input. Connect to the cathode of the LED string and connect a resistor from FB to GND to set the LED current. |
| 6 | SS | Soft-Start Timing-Control Input. Connect a capacitor from SS to GND to control soft-start timing. See the *Soft-Start* section for information on selecting the soft-start capacitor. SS is pulled to ground with an internal 200Ω switch when EN is low. |
| 7 | OV | Overvoltage Sense. Connect to a resistor-divider from the anode of the LED string to set the overvoltage threshold. See Figures 1, 2, and 3. |
| 8 | LX | Inductor Connection. Connect to the inductor and diode. LX is high impedance when EN is low. |
| — | EP | Exposed Pad. Connect to GND. |

## Detailed Description

### Control Scheme

The MAX1553/MAX1554 utilize a minimum off-time, current-limited control scheme. If the voltage at FB drops below the regulation threshold, the internal low-side MOSFET turns on and the inductor current ramps up to the current limit. Once the current-limit comparator trips, the low-side MOSFET turns off for the minimum off-time (250ns). After 250ns, if the voltage at FB is above the regulation threshold, the low-side MOSFET stays off. If the voltage at FB is below the regulation point, the low-side MOSFET turns back on and the cycle repeats. By using a regulation control scheme that is not fixed frequency and that can skip pulses, the MAX1553/MAX1554 operate with very high efficiency.

### Soft-Start

Soft-start is provided on the MAX1553/MAX1554 to minimize inrush current. The soft-start time is set with an external capacitor, C3 (Figures 1, 2, and 3). Use the following equation to solve for C3:

$$C3 = \frac{t_{SS}}{2 \times 10^5}$$

where $t_{SS}$ is the soft-start time. A value of 0.1µF provides a soft-start time of 20ms.

### Shutdown

The MAX1553/MAX1554 feature a low-current shutdown feature. When EN is low, the IC turns off, reducing its supply current to approximately 0.1µA. For normal operation, drive EN high or connect to $V_{CC}$.

### Overvoltage Protection

The MAX1553/MAX1554 have an adjustable overvoltage-protection circuit. When the voltage at OV reaches the overvoltage threshold (1.25V typ), the protection circuitry prevents the internal MOSFET from switching, allowing the output voltage to decay.

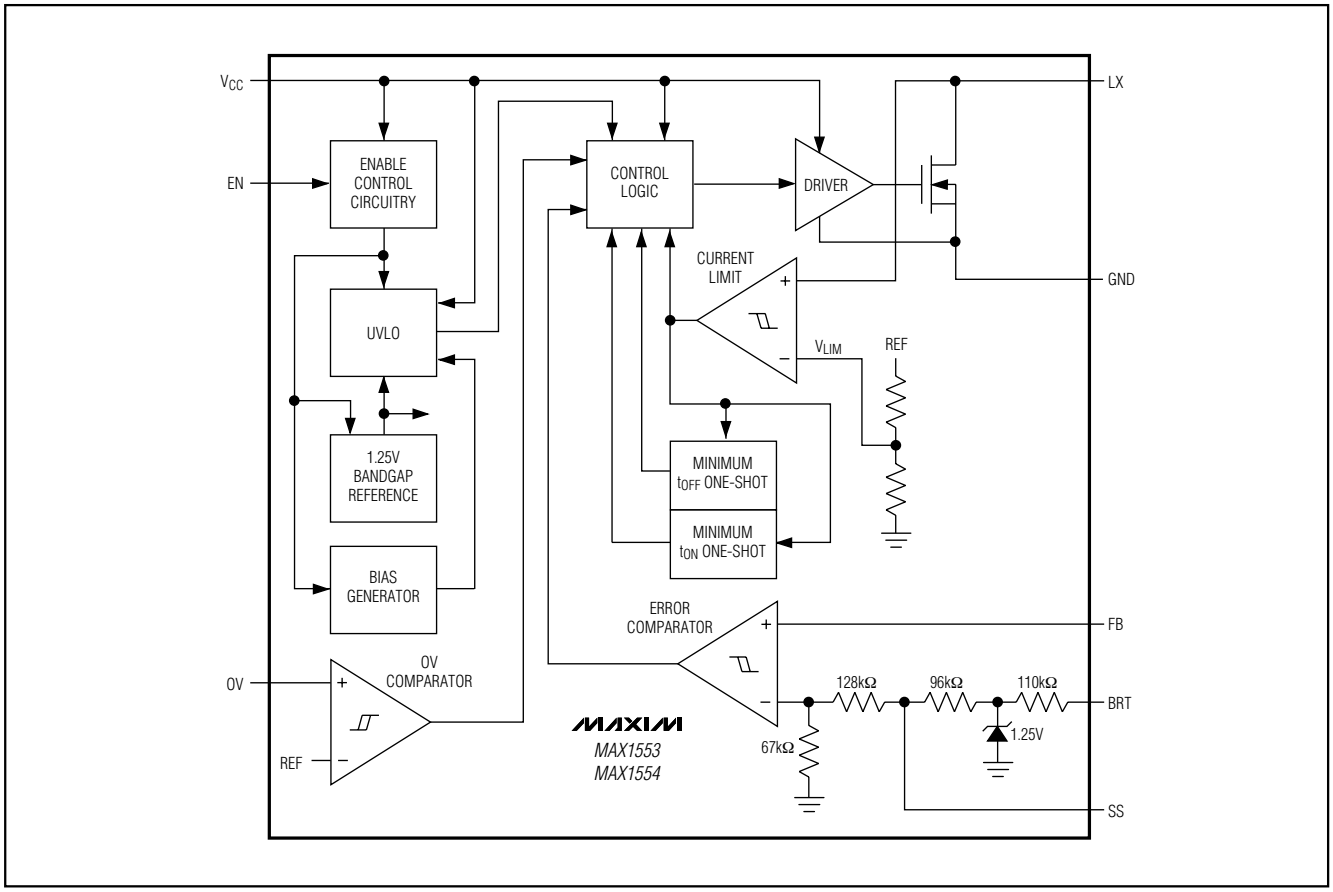
The peak output voltage in an overvoltage-protection event is set with a resistor-divider from the output connected to OV (R2 and R3 in Figures 1, 2, and 3). Select a value for R3 (10kΩ is recommended), then solve for R2 using the following equation:

$$R2 = R3 \times \left( \frac{V_{OUT(PEAK)}}{V_{OV}} - 1 \right)$$

where $V_{OV}$ is the overvoltage threshold (1.25V typ), and $V_{OUT(PEAK)}$ is the desired peak output voltage.

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

## Functional Diagram



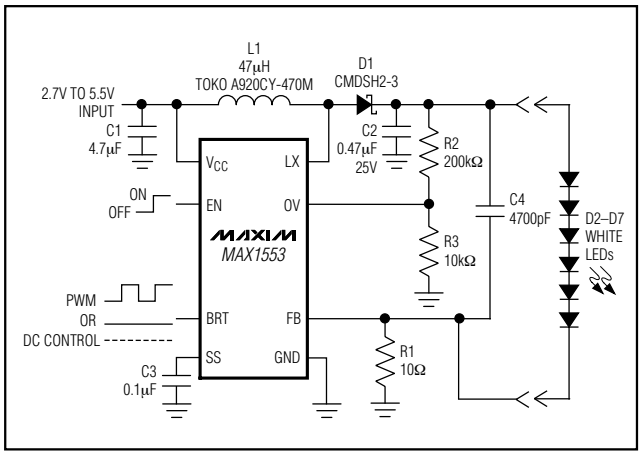




Figure 1. Circuit with the MAX1553 Driving Six White LEDs

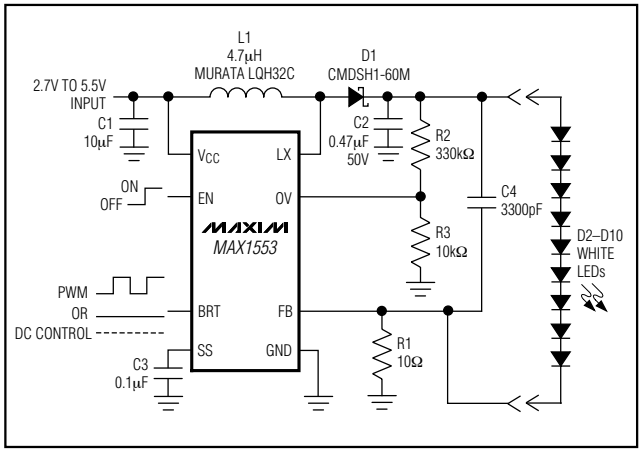



Figure 2. Circuit with the MAX1553 Driving Nine White LEDs at Up to 15mA

# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

### Adjusting the LED Current

Adjusting the output current changes the brightness of the LEDs. The LED current is set by the voltage at BRT ($V_{BRT}$) and the sense resistor (R1) at FB. The $V_{BRT}$ range for adjusting output current is 0 to 1.25V. Over this range, the LED current is found from the following equation:

$$I_{LED} = \frac{V_{BRT} + 0.17}{6.67 \times R1}$$

BRT can be overdriven; however, applying a $V_{BRT}$ greater than 1.72V does not increase the output current above the level at 1.72V. See the LED Current vs. BRT Voltage graph in the *Typical Operating Characteristics* section. To set the maximum LED current, calculate R1 when $V_{BRT}$ is at its maximum, as follows:

$$R1 = \frac{V_{BRT(MAX)} + 0.17}{6.67 \times I_{LED(MAX)}}$$

where $V_{BRT(MAX)}$ is 1.72V if BRT is connected to any value greater than 1.72V, such as $V_{CC}$. Otherwise, $V_{BRT(MAX)}$ is the maximum applied BRT control voltage. Power dissipation in R1 is typically less than 5mW; therefore, power dissipation in a standard chip resistor is not a concern.

### PWM Dimming Control

The BRT input is also used as a digital input allowing LED brightness control with a logic-level PWM signal applied directly to BRT. The frequency range is from 100Hz to 10kHz, and the duty cycle range is 0 to 100%. A 0% duty cycle corresponds to the minimum current, and a 100% duty cycle corresponds to full current. See the LED Current vs. BRT Duty Cycle graph in the *Typical Operating Characteristics* section. The BRT resistor and SS capacitor form a lowpass filter, so PWM dimming results in DC current to the LEDs without the need for additional RC filters.

### Capacitor Selection

A 0.47µF ceramic output capacitor (C2) is recommended for most applications. For circuits driving six or fewer LEDs, use a 4.7µF ceramic input capacitor (C1). For circuits driving more than six LEDs, use a 10µF input capacitor (C1). For best stability over a wide temperature range, use capacitors with an X5R, X7R, or better dielectric.

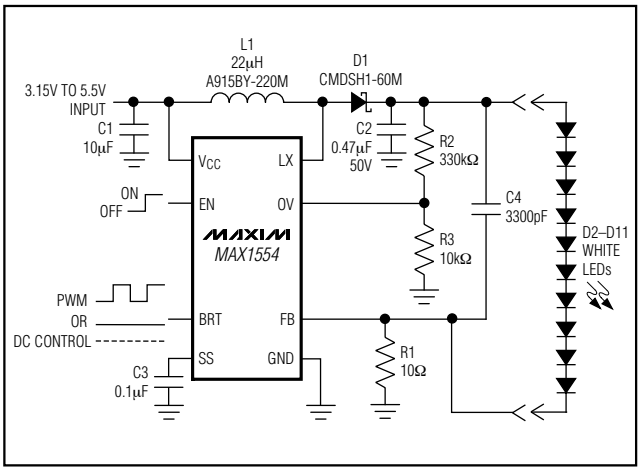



*Figure 3. Circuit with the MAX1554 Driving 10 White LEDs*

### Inductor Selection

The MAX1553 has a 480mA inductor current limit and can drive up to six LEDs at 20mA or nine LEDs at 15mA. Inductor values from 4.7µH to 47µH work satisfactorily. Larger values provide the best efficiency while small inductor values allow the smallest inductor size. A good choice for best efficiency is the TOKO D62 or D62L series at 47µH. For smallest size, the Murata LQH32C at 4.7µH works well.

The MAX1554 has a 970mA inductor current limit and can drive up to 10 LEDs at 20mA. Inductor values from 4.7µH to 22µH work satisfactorily. A good choice for high efficiency and small size when driving 9 or 10 LEDs is the TOKO D62 series at 22µH.

When large inductor values are used to optimize efficiency, the MAX1553/MAX1554 operate with continuous inductor current. With large inductor values (typically greater than 10µH), stability, input, and output ripple are improved by connecting a capacitor in parallel with the LEDs (C4 in Figures 1, 2, and 3).

To prevent saturation, use an inductor with a current rating that matches the device's LX current limit. However, if size is particularly important, it is sometimes acceptable to operate the inductor 10% into saturation. For best efficiency, the inductor's DC resistance should also be as low as possible.

### Diode Selection

The MAX1553/MAX1554s' high switching frequency demands a high-speed rectification diode (D1) for optimum efficiency. A Schottky diode is recommended due to its fast recovery time and low forward-voltage drop.

## Table 1. Component Suppliers

| SUPPLIER | PHONE | WEBSITE |
|---|---|---|
| Central Semiconductor | 631-435-1110 | www.centralsemi.com |
| Kamaya | 260-489-1533 | www.kamaya.com |
| Murata | 814-237-1431 | www.murata.com |
| Nichia | 248-352-6575 | www.nichia.com |
| Panasonic | 714-373-7939 | www.panasonic.com |
| Sumida | 847-956-0666 | www.sumida.com |
| Taiyo Yuden | 408-573-4150 | www.t-yuden.com |
| TDK | 847-803-6100 | www.component.tdk.com |
| TOKO | 847-297-0070 | www.toko.com |

Ensure the diode's average and peak current ratings exceed the average output current and peak inductor current. In addition, the diode's reverse breakdown voltage must exceed $V_{OUT}$.

## Applications Information

### Low Input-Voltage Applications

The MAX1553/MAX1554 have minimum input voltages of 2.7V (MAX1553) and 3.15V (MAX1554). However, lower battery voltages can still be boosted for LED drive as long as $V_{CC}$ remains within the operating range. Since most systems have a 3.3V system supply active when the display is active and backlit, that logic supply can be used to supply $V_{CC}$, while the battery power connects directly to the boost inductor. No battery current is drawn when EN is low (Figure 4).

### PC Board Layout

Due to fast-switching waveforms and high-current paths, careful PC board layout is required. An evaluation kit (MAX1553EVKIT) is available as an example of a proper layout.

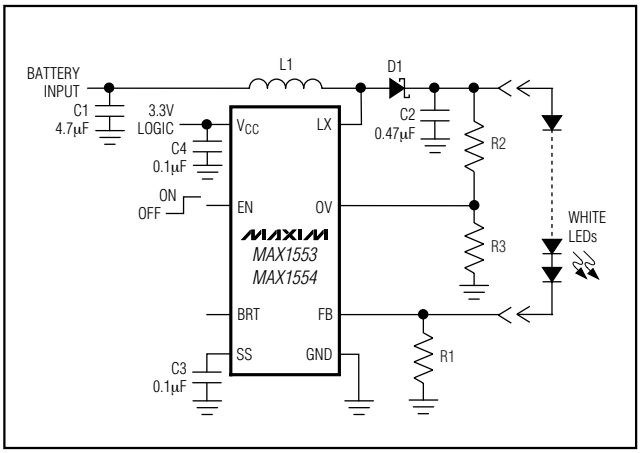



*Figure 4. The MAX1553/MAX1554 can drive LEDs from battery voltages that are lower than the device operating voltage range by powering $V_{CC}$ from a logic supply and connecting the boost inductor to the battery.*

When laying out a board, minimize trace lengths between the IC and the inductor, diode, input capacitor, output capacitor, and R1. Keep traces short, direct, and wide. Keep noisy traces, such as the LX node trace, away from FB. Place the $V_{CC}$ bypass capacitor (C1) as close to the IC as possible. The ground connections of C1 and C2 should be as close together as possible. Star connect the grounds for R1, R3, C3, and the BRT voltage supply as close to the IC as possible. The traces from $V_{CC}$ to C1, from C2 to the LEDs, and from the LEDs to R1 can be longer if required.

## Chip Information

TRANSISTOR COUNT: 740

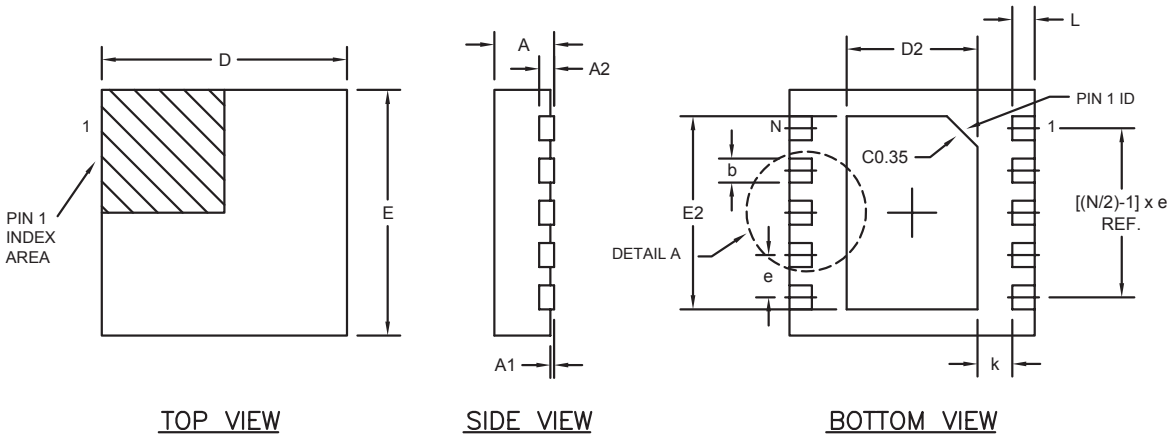
PROCESS: BiCMOS

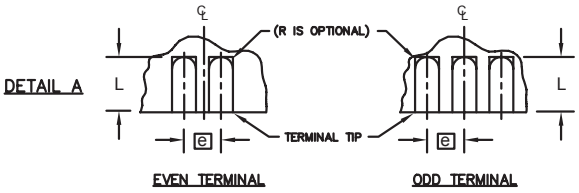
# High-Efficiency, 40V Step-Up Converters for 2 to 10 White LEDs

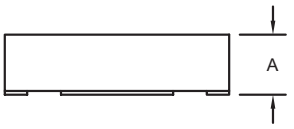
## Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.

6, 8, &10L, DFN THIN.EPS




NUMBER OF LEADS SHOWN ARE FOR REFERENCE ONLY

DALLAS SEMICONDUCTOR MAXIM

PROPRIETARY INFORMATION

TITLE:
PACKAGE OUTLINE, 6, 8 & 10L,
TDFN, EXPOSED PAD, 3x3x0.80 mm

| APPROVAL | DOCUMENT CONTROL NO. | REV. | |
|---|---|---|---|
| | 21-0137 | D | 1/2 |

## Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.

| COMMON DIMENSIONS | | |
|---|---|---|
| SYMBOL | MIN. | MAX. |
| A | 0.70 | 0.80 |
| D | 2.90 | 3.10 |
| E | 2.90 | 3.10 |
| A1 | 0.00 | 0.05 |
| L | 0.20 | 0.40 |
| k | 0.25 MIN. | |
| A2 | 0.20 REF. | |

| PACKAGE VARIATIONS | | | | | | | |
|---|---|---|---|---|---|---|---|
| PKG. CODE | N | D2 | E2 | e | JEDEC SPEC | b | [(N/2)-1] x e |
| T633-1 | 6 | 1.50±0.10 | 2.30±0.10 | 0.95 BSC | MO229 / WEEA | 0.40±0.05 | 1.90 REF |
| T833-1 | 8 | 1.50±0.10 | 2.30±0.10 | 0.65 BSC | MO229 / WEEC | 0.30±0.05 | 1.95 REF |
| T1033-1 | 10 | 1.50±0.10 | 2.30±0.10 | 0.50 BSC | MO229 / WEED-3 | 0.25±0.05 | 2.00 REF |

NOTES:
1. ALL DIMENSIONS ARE IN mm. ANGLES IN DEGREES.
2. COPLANARITY SHALL NOT EXCEED 0.08 mm.
3. WARPAGE SHALL NOT EXCEED 0.10 mm.
4. PACKAGE LENGTH/PACKAGE WIDTH ARE CONSIDERED AS SPECIAL CHARACTERISTIC(S).
5. DRAWING CONFORMS TO JEDEC MO229, EXCEPT DIMENSIONS "D2" AND "E2".
6. "N" IS THE TOTAL NUMBER OF LEADS.

DALLAS SEMICONDUCTOR MAXIM

PROPRIETARY INFORMATION

TITLE: PACKAGE OUTLINE, 6, 8 & 10L, TDFN, EXPOSED PAD, 3x3x0.80 mm

| APPROVAL | DOCUMENT CONTROL NO. | REV. | |
|---|---|---|---|
| | 21-0137 | D | 2/2 |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