

## MAX1553/MAX1554

## 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  $R_{DS(ON)}$ , 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.

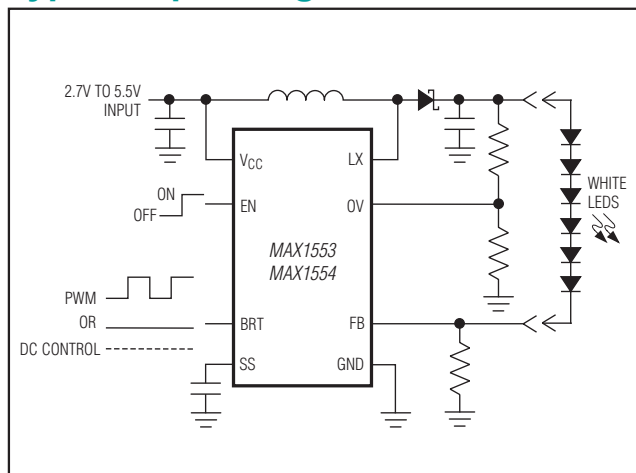
The MAX1553/MAX1554 are available in space-saving 8-pin TDFN 3mm x 3mm packages.

### Applications

Cellular Phones  
PDA, Palmtop, and Wireless Handhelds  
Color Display Backlight

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

### Typical Operating Circuit



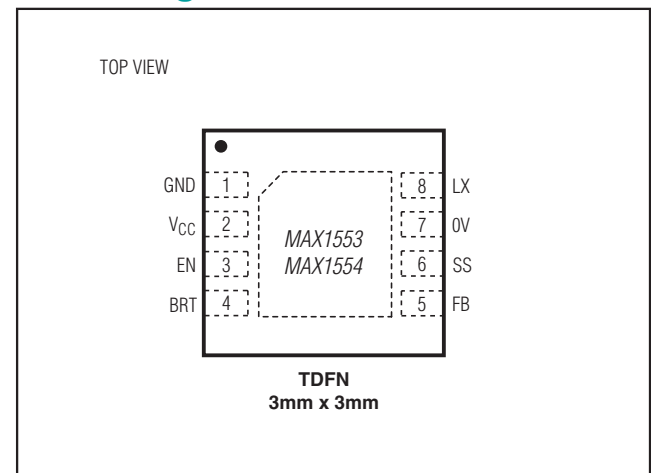
### Benefits and Features

- Highly Integrated and Flexible Solution for Wide Range of Backlighting Applications
  - Constant-Current Regulation for Even LED Illumination
  - Internal 40V MOSFET Switch Capable of Driving 10 LEDs
  - 2.7V to 5.5V Input Voltage Range
  - Analog or PWM Control of LED Intensity
  - Optimized for Low Input Ripple
- Soft-Start Minimizes Inrush Current
- High Efficiency Improves Battery Life
  - Up to 88% Efficiency Driving 6 LEDs
  - Up to 82% Efficiency Driving 9 LEDs (20mA,  $V_{CC} = 3.6V$ )
- Tiny 8-Pin, 3mm x 3mm TDFN Package Saves Space
  - Small, Low-Profile External Components

### Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX1553ETA	-40°C to +85°C	8 TDFN 3mm x 3mm	AGX
MAX1554ETA	-40°C to +85°C	8 TDFN 3mm x 3mm	AGY

### Pin Configuration



## Absolute Maximum Ratings

V <sub>CC</sub> , 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 <sub>CC</sub> + 0.3V)
I <sub>LX</sub> .....	0.9A <sub>RMS</sub>
Continuous Power Dissipation (T <sub>A</sub> = +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<sub>CC</sub> = 3.3V, V<sub>OV</sub> = 0V, C<sub>OUT</sub> = 1μF, R<sub>SENSE</sub> = 10Ω, T<sub>A</sub> = 0°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = +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 <sub>CC</sub> 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 <sub>EN</sub> = 0V	T <sub>A</sub> = +25°C	0.1	1	μA
		T <sub>A</sub> = +85°C		1	
OV Threshold	Rising edge	1.18	1.25	1.33	V
OV Input Bias Current	V <sub>OV</sub> = 1V	T <sub>A</sub> = +25°C		1	nA
		T <sub>A</sub> = +85°C		10	
BRT Input Resistance	0 < V <sub>BRT</sub> < 1.5V, EN = V <sub>CC</sub>	200	400	600	kΩ
<b>TIMING CONTROL</b>					
Maximum On-Time	V <sub>CC</sub> = 3.3V	2.0	3.4	4.8	μs
On-Time Constant (K)	t <sub>ON</sub> = K / V <sub>CC</sub>		6.3		μs-V
Minimum Off-Time		150	250	350	ns
<b>ERROR AMPLIFIER</b>					
FB Threshold	V <sub>BRT</sub> = 1.25V	192	203	212	mV
	V <sub>BRT</sub> = 3.3V		280		
FB Input Bias Current	V <sub>FB</sub> = 1.0V	T <sub>A</sub> = +25°C		15	nA
		T <sub>A</sub> = +85°C		100	
<b>N-CHANNEL SWITCH</b>					
LX On-Resistance			0.8	1.4	Ω

**Electrical Characteristics (continued)**(V<sub>CC</sub> = 3.3V, V<sub>OV</sub> = 0V, C<sub>OUT</sub> = 1μF, R<sub>SENSE</sub> = 10Ω, T<sub>A</sub> = 0°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	
LX Current Limit	MAX1553	300	480	600	mA	
	MAX1554, V <sub>CC</sub> = 4.2V	600	970	1200		
LX Leakage Current	V <sub>LX</sub> = 38V, V <sub>EN</sub> = 0V	T <sub>A</sub> = +25°C		0.1	5	μA
		T <sub>A</sub> = +85°C		1		
<b>SHUTDOWN CONTROL</b>						
EN Logic-Level High		1.8			V	
EN Logic-Level Low		0.4			V	
EN Input Current	V <sub>EN</sub> = 0V or 5.5V	T <sub>A</sub> = +25°C		0.01	1	μA
		T <sub>A</sub> = +85°C		0.1		

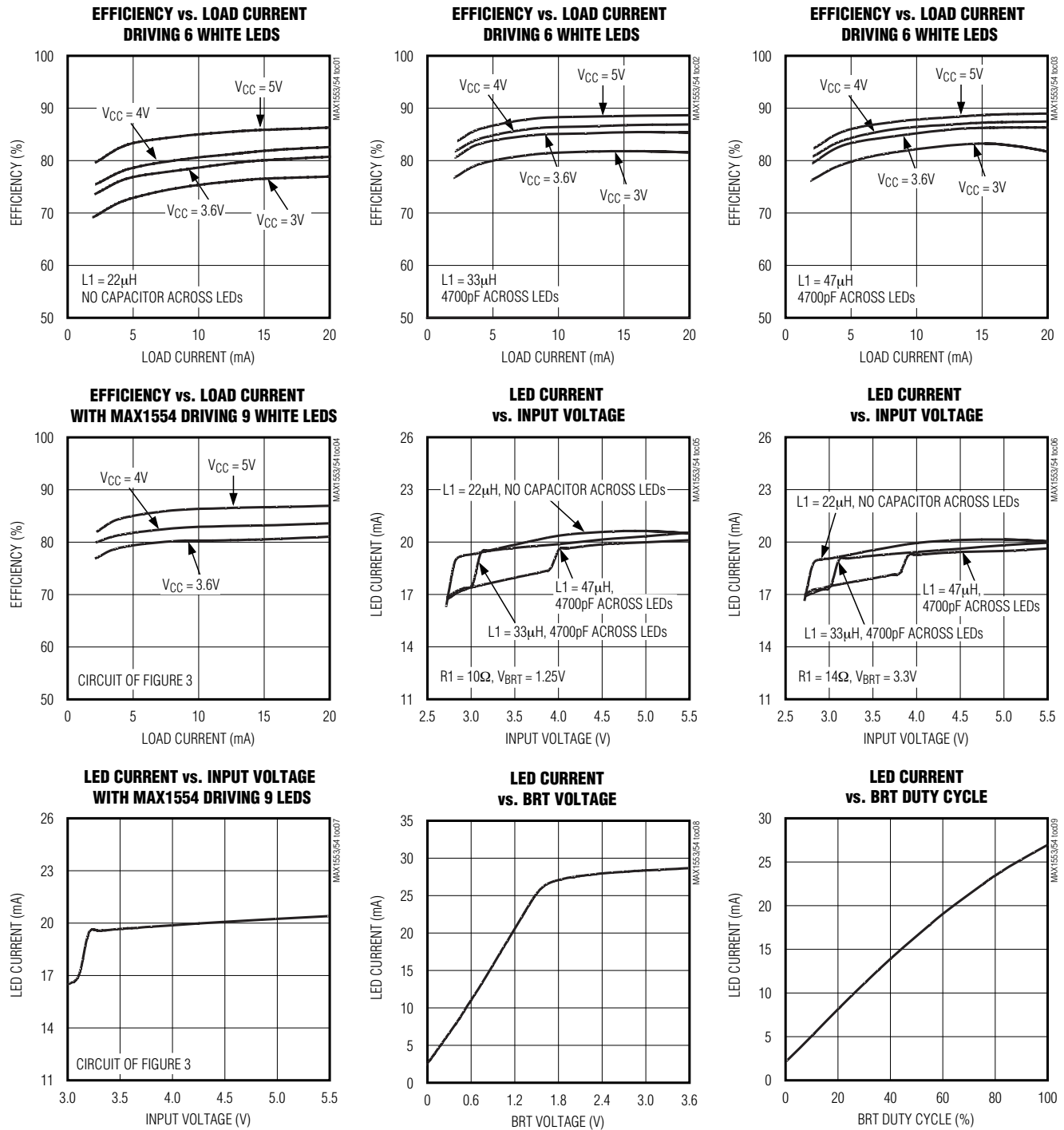
**Electrical Characteristics**(V<sub>CC</sub> = 3.3V, V<sub>OV</sub> = 0V, C<sub>OUT</sub> = 1μF, R<sub>SENSE</sub> = 10Ω, T<sub>A</sub> = -40°C to +85°C, unless otherwise noted.) (Note 1)

PARAMETER	CONDITIONS	MIN	MAX	UNITS	
Supply Voltage	MAX1553	2.7	5.5	V	
	MAX1554	3.15	5.50		
Undervoltage Lockout Threshold	V <sub>CC</sub> 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 <sub>BRT</sub> < 1.5V, EN = V <sub>CC</sub>	200	600	kΩ	
<b>TIMING CONTROL</b>					
Maximum On-Time	V <sub>CC</sub> = 3.3V	2.0	4.8	μs	
Minimum Off-Time		150	350	ns	
<b>ERROR AMPLIFIER</b>					
FB Threshold	V <sub>BRT</sub> = 1.25V	192	217	mV	
<b>N-CHANNEL SWITCH</b>					
LX On-Resistance		1.4		Ω	
LX Current Limit	MAX1553	300	600	mA	
	MAX1554, V <sub>CC</sub> = 4.2V	600	1200		
<b>SHUTDOWN CONTROL</b>					
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.

Typical Operating Characteristics

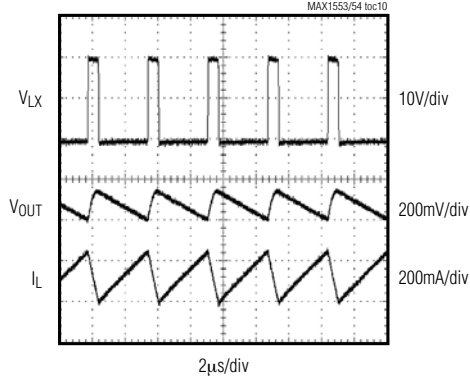
(MAX1553 driving six white LEDs,  $V_{CC} = V_{EN} = 3.6V$ , Circuit of Figure 1,  $T_A = +25^\circ C$ , unless otherwise noted.)



Typical Operating Characteristics (continued)

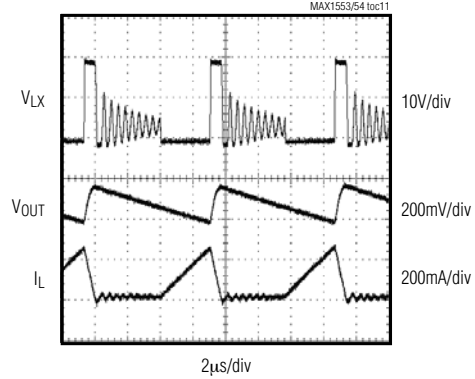
(MAX1553 driving six white LEDs,  $V_{CC} = V_{EN} = 3.6V$ , Circuit of Figure 1,  $T_A = +25^\circ C$ , unless otherwise noted.)

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



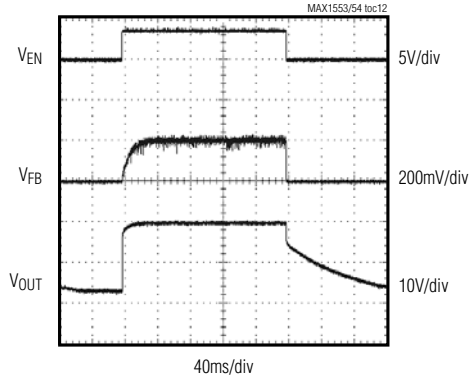
L1 = 47µH, 4700pF CAPACITOR ACROSS LEDs

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



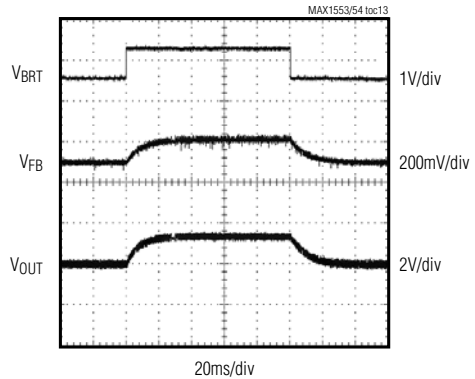
L1 = 47µH, 4700pF CAPACITOR ACROSS LEDs

**STARTUP/SHUTDOWN WAVEFORMS**



L1 = 22µH

**BRT STEP RESPONSE**



L1 = 22µH,  
VBRT = 0.5V TO 1.25V TO 0.5V

## Pin Description

PIN	NAME	FUNCTION
1	GND	Ground
2	V <sub>CC</sub>	Voltage-Supply Input. 2.7V to 5.5V. The IC is powered from V <sub>CC</sub> .
3	EN	Enable Input. Drive high or connect to V <sub>CC</sub> 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 <i>Soft-Start</i> 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<sub>CC</sub>.

### 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.

Functional Diagram

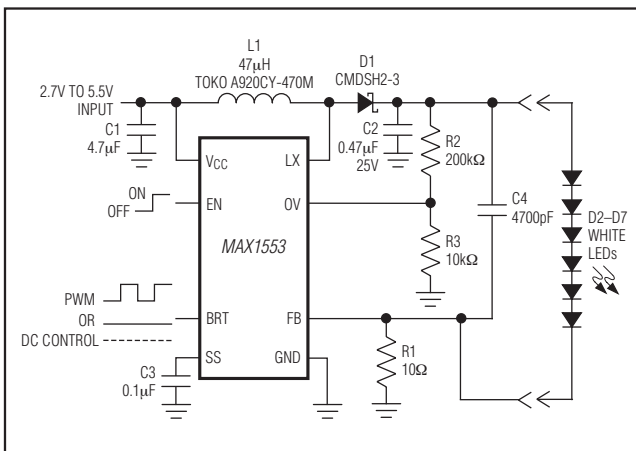
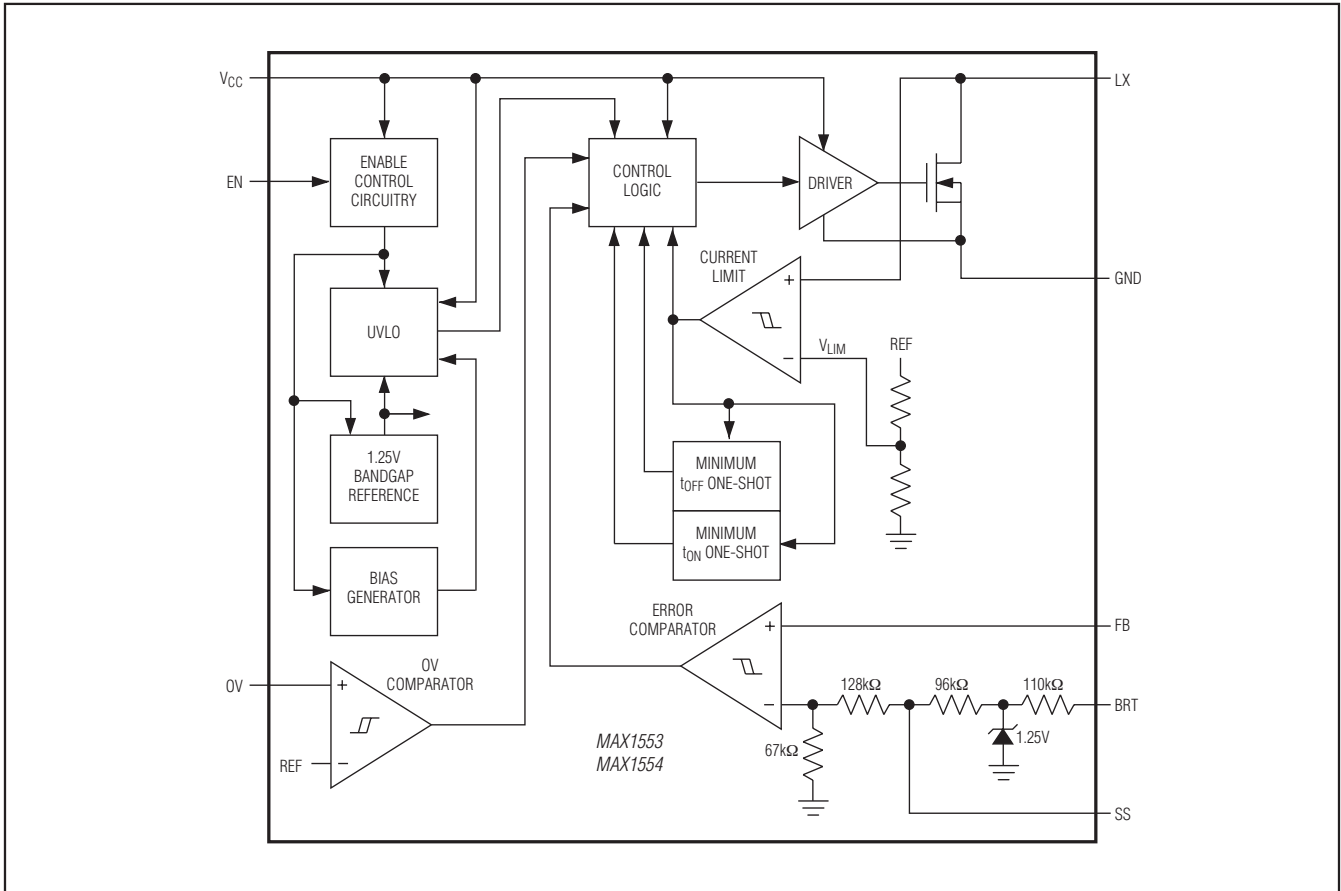


Figure 1. Circuit with the MAX1553 Driving Six White LEDs

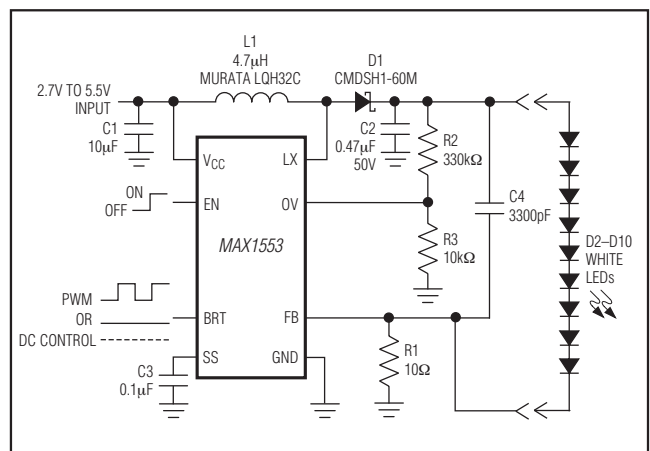


Figure 2. Circuit with the MAX1553 Driving Nine White LEDs at Up to 15mA

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

### Inductor Selection

The MAX1553 has a 480mA inductor current limit and can drive up to six LEDs at 20mA or nine LEDs at

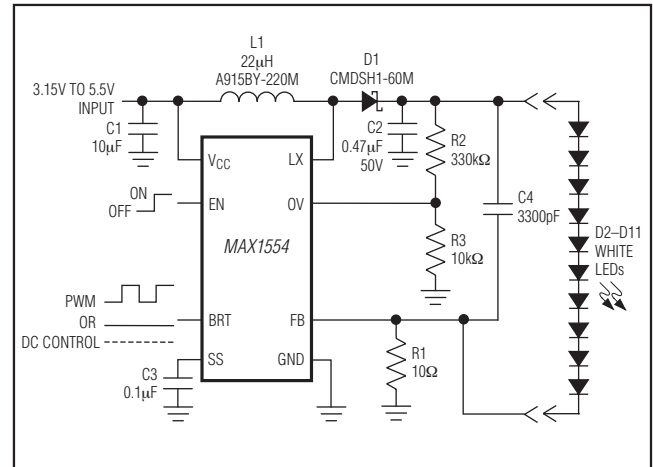


Figure 3. Circuit with the MAX1554 Driving 10 White LEDs

15mA. Inductor values from 4.7 $\mu$ H to 47 $\mu$ H 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 47 $\mu$ H. For smallest size, the Murata LQH32C at 4.7 $\mu$ H works well.

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

When large inductor values are used to optimize efficiency, the MAX1553/MAX1554 operate with continuous inductor current. With large inductor values (typically greater than 10 $\mu$ H), 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. 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  $V_{OUT}$ .



**Table 1. Component Suppliers**

SUPPLIER	PHONE	WEBSITE
Central Semiconductor	631-435-1110	www.centrasemi.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

## 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<sub>CC</sub> 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<sub>CC</sub>, 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.

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<sub>CC</sub> 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<sub>CC</sub> to C1, from C2 to the LEDs, and from the LEDs to R1 can be longer if required.

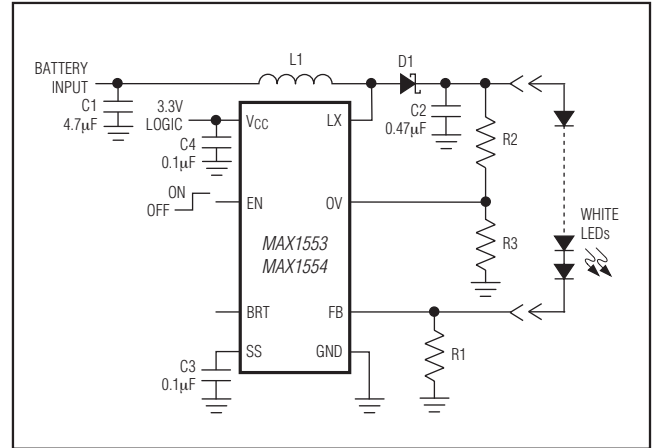


Figure 4. The MAX1553/MAX1554 can drive LEDs from battery voltages that are lower than the device operating voltage range by powering V<sub>CC</sub> from a logic supply and connecting the boost inductor to the battery.

## Chip Information

TRANSISTOR COUNT: 740

PROCESS: BiCMOS

## Package Information

For the latest package outline information and land patterns (footprints), go to [www.maximintegrated.com/packages](http://www.maximintegrated.com/packages). Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
TDFN-EP	T833-2	<a href="#">21-0137</a>	<a href="#">90-0059</a>

## Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
2	5/15	Revised <i>Benefits and Features</i> section	1

For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim Integrated's website at [www.maximintegrated.com](http://www.maximintegrated.com).

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