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High Frequency LED Driver with Integrated Schottky and Simple Interconnect

POWER MANAGEMENT
Features

- V_{IN} Range — 2.9V to 22V
- V_{OUT} Range — Up to 25V
- I_{OUT} Range:
    - Up to 100mA (Boost)
    - Up to 200mA (Buck)
- Drives Up to 7 Series WLEDs (Boost)
- Drives Up to 5 Series WLEDs (Buck)
- Integrated Schottky Rectifier
- Single-Wire LED Connect
- Current Mode Control
    - Frequency — 2.0MHz
    - No External Compensation
- Direct PWM Dimming
    - 100:1 Range at 500Hz
- Open-LED Protection — 27V
- Low Shutdown Current < 1µA
- Package Options:
    - Low Profile MLPD-UT, 6-pin 2x2 x0.6(mm)
    - SOT23, 6-pin 2.9x2.8 x1.45(mm)
- Lead-free, Halogen-Free and WeEE/RoHS Compliant

Applications

- Keypad Illumination
- DSC and DSLR Display Backlight
- Cellular Handsets
- Automotive Lighting

Description

The SC4541 is a fully integrated, high voltage boost (step-up) and buck (step-down) LED driver. The input voltage range is 2.9V to 22V with output voltage up to 25V. The device is capable of driving up to 7 white LEDs. The high side sense enables a single-wire LED connection by taking advantage of the available system ground. This reduces connector cost and complexity.

The device includes a current mode PWM controller, 260mA power switch, and high performance Schottky rectifier. The LED driver eliminates external compensation components for minimum solution size.
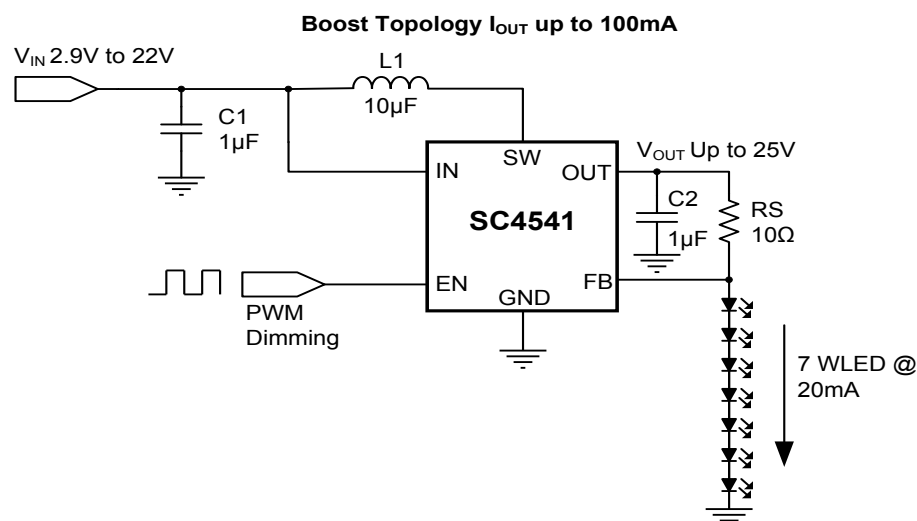
The wide input voltage range and low standby current are ideal for portable devices. The high input voltage allows direct connection to multi-cell battery packs which increases operating efficiency and extends battery life.
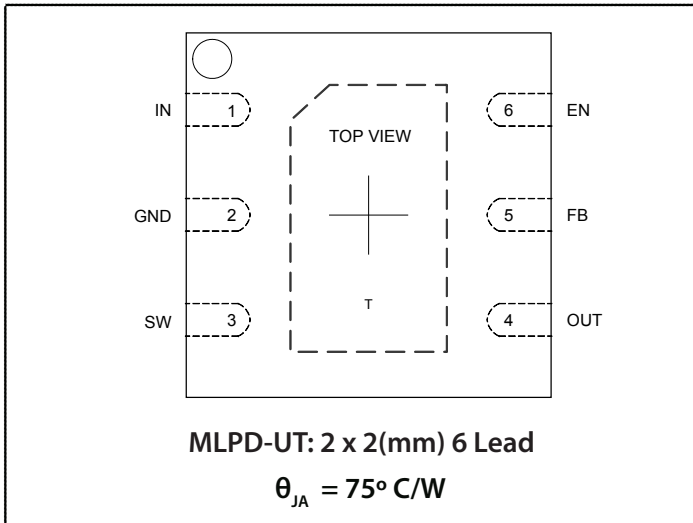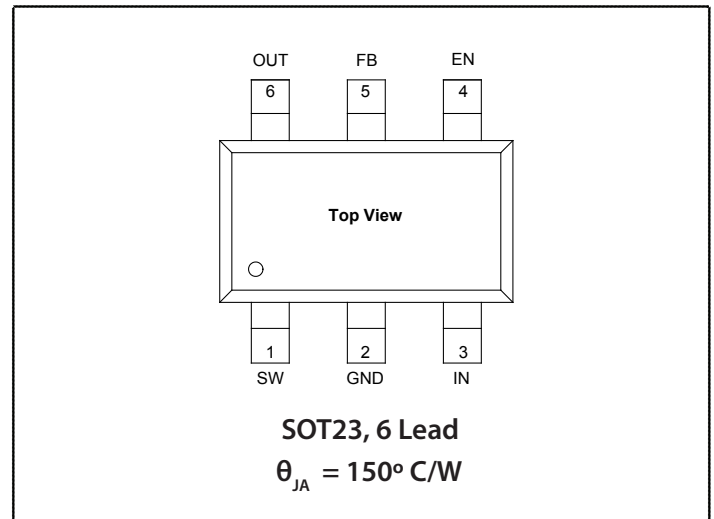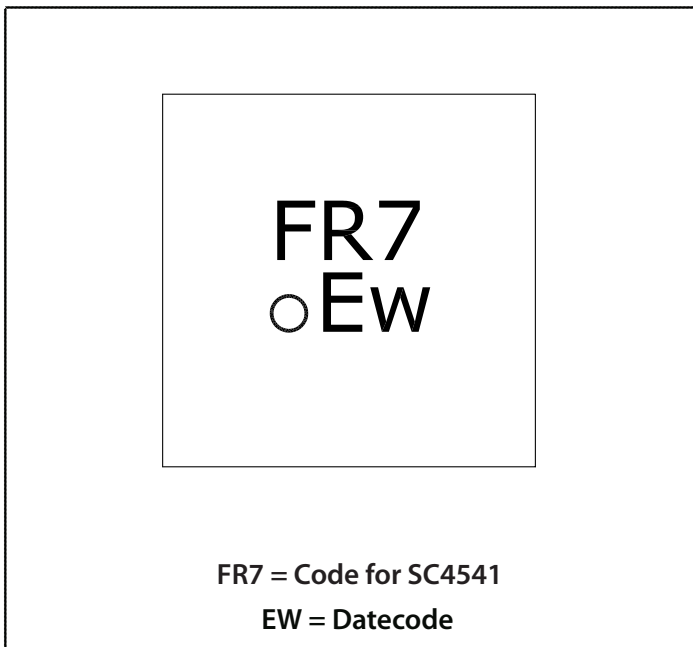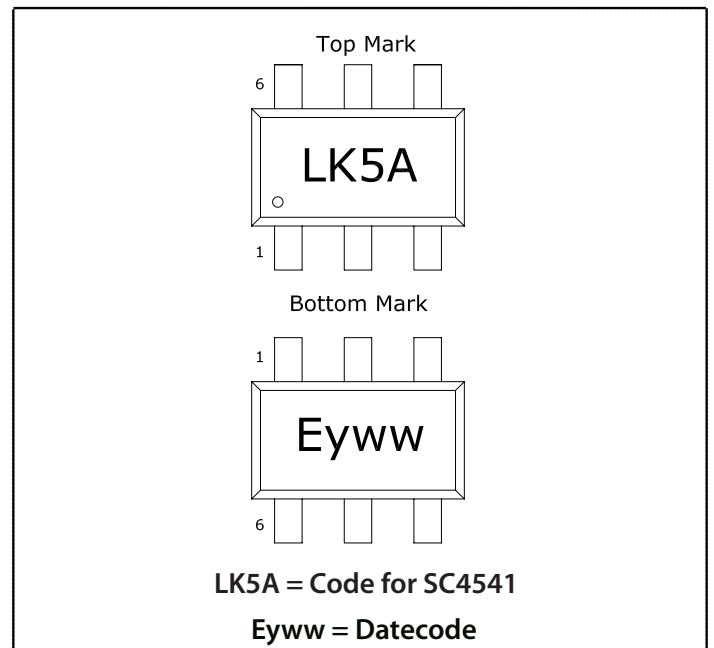
Output current is programmed with an external sense resistor up to 100mA (Boost) or 200mA (Buck). The device provides ±5% constant current accuracy across the entire operating temperature range.

A logic level PWM dimming signal may be applied directly to the enable (EN) pin - for direct PWM dimming with a wide dimming range. Output OVP (over voltage protection) protects the SC4541 from open circuit faults in the LED string or connector. External OVP programming resistors are not required.

The SC4541 is available in low profile MLPD-UT and SOT23,6-pin packages. The device is rated across the temperature range -40°C to +85°C.

Typical Application Circuit

Boost Topology I_{OUT} up to 100mA

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Pin Configuration, MLPD-UT6

IN 1
GND 2
SW 3
EN 6
FB 5
OUT 4

TOP VIEW

T

MLPD-UT: 2 x 2(mm) 6 Lead

$\theta_{JA} = 75^o$ C/W

Pin Configuration, SOT23-6

OUT 6
FB 5
EN 4

Top View

SW 1
GND 2
IN 3

SOT23, 6 Lead

$\theta_{JA} = 150^o$ C/W

Marking Information, MLPD-UT6

FR7
Ew

FR7 = Code for SC4541

EW = Datecode

Marking Information, SOT23-6

Top Mark

6

LK5A

1

Bottom Mark

1

Eyww

6

LK5A = Code for SC4541

Eyww = Datecode

Ordering Information

Device	Package
SC4541SKTRT[1,2]	SOT23-6
SC4541ULTRT[1,2]	2 x 2 x 0.6(mm) MLPD-UT6
SC4541EVB-1	Evaluation Board, SOT23-6
SC4541EVB-2	Evaluation Board, MLPD-UT6

Notes:
(1) Available in tape and reel only. A reel contains 3,000 devices.
(2) Available in lead-free package only. Device is WEEE/RoHS compliant
    and halogen-free.

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Absolute Maximum Ratings

Supply IN Voltage(V) . . . . -0.3 to 26

SW Voltage, OUT Voltage(V) . . . . -0.3 to 28

FB, Enable Voltage(V) . . . . -0.3 to VIN+0.3

ESD Protection Level[1](kV) 4

Recommended Operating Conditions

Supply IN Voltage (V) . . . . 2.9 to 22

Maximum Output Voltage (V) 25

Ambient Temperature Range (℃) . . . . -40 to +85

Thermal Information

Thermal Resistance, Junction to Ambient[2]

MLPD-UT6(℃/W) 75

SOT23-6(℃/W) 150

Maximum Junction Temperature (℃) . . . . +125

Storage Temperature Range (℃) . . . . -65 to +150

Peak IR Reflow Temperature (10s to 30s) (℃) . . . . +300

Exceeding the above specifications may result in permanent damage to the device or device malfunction. Operation outside of the parameters specified in the Electrical Characteristics section is not recommended.

NOTES:

(1)   Tested according to JEDEC standard JESD22-A114-B.

(2)   Calculated from package in still air, mounted to 3 x 4.5(in), 4 layer FR4 PCB with thermal vias under the exposed pad per JESD51 standards.

Electrical Characteristics

V_{IN} =5V, C_{IN}=1uF, C_{OUT}=1uF, L=10uH, T_A= -40℃ to 85℃, unless specified otherwise.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Input Voltage	V_{IN}		2.9		22	V
Supply Current	$I_{IN(Q)}$	V_{IN}=22V, V_{OUT}=18V, V_{FB}=17V, EN=3V		1.5	3	mA
Shutdown Supply Current	$I_{IN(SHDN)}$	EN=0V			1	μA
EN Logic High Voltage	$V_{EN(H)}$		2			V
EN Logic Low Voltage	$V_{EN(L)}$				0.4	V
EN Logic Bias Current	$I_{EN(L)}$, $I_{EN(H)}$				1	μA
Boost Converter Characteristics						
Switching Frequency	f_{SW}		1.6	2.0	2.4	MHz
Maximum Duty Cycle	D_{MAX}		84			%
Switch Current limit	I_{LIMIT}		260	350	450	mA
Switch Leakage Current	I_{SW}	V_{SW} = 18V		0.1	5	μA
Switch Saturation Voltage	V_{SAT}	I_{SW} = 0.2A		200		mV
OUT Over-Voltage Protection	$V_{OUT(OVP)}$	T_A=25℃	25.5		28.0	V
Schottky Forward Drop	$V_{F(D)}$	I_{OUT} = 100mA, T_A=25℃		0.7		V

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Electrical Characteristics (continued)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Boost Converter Characteristics (continued)						
Schottky Leakage Current	$I_{LEAK(D)}$	V_{OUT} = 20V			4	µA
Current Sink Characteristics						
LED Current Sense Voltage (V_{OUT}-V_{FB})	V_{SENSE}	V_{OUT}=18V, T_A=25°C	192	200	208	mV
		V_{OUT}=18V, T_A=-40°C to 85°C	188		212	mV
OUT Pin Bias Current	$I_{OUTB(BIAS)}$	V_{OUT}=18V		55		µA
FB Pin Bias Current	$I_{FB(BIAS)}$	V_{FB}=18V		12		µA
V_{OUT}, V_{FB} Common Mode Voltage	V_{CM}		2.9			V

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Typical Characteristics

EN Threshold

VIN = 10V

EN Threshold Voltage (V) vs Temperature (°C)
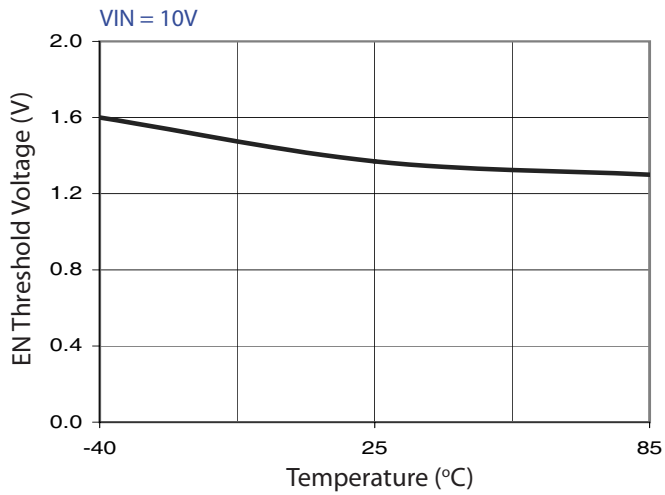
Switching Frequency

Switching Frequency (MHz)
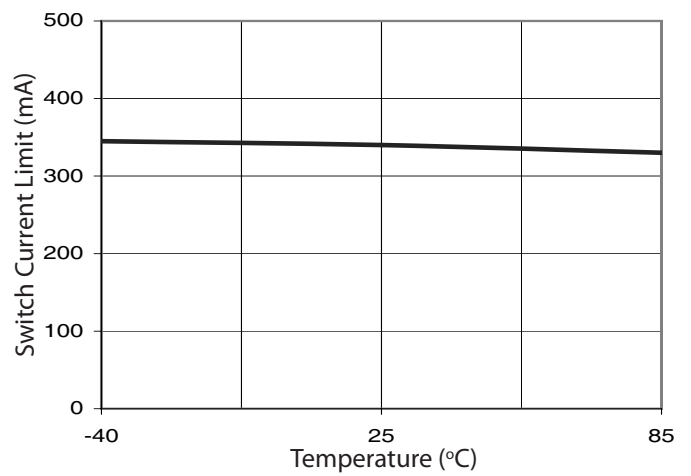
VIN = 5V
VIN = 12V
VIN = 22V

vs Temperature (°C)

Switch Current Limit

Switch Current Limit (mA) vs Temperature (°C)

Switch Leakage Current

V_{SW} = 10V

Switch Leakage Current (µA) vs Temperature (°C)

Output Over Voltage Protection

Over Voltage Protection (V) vs Temperature (°C)

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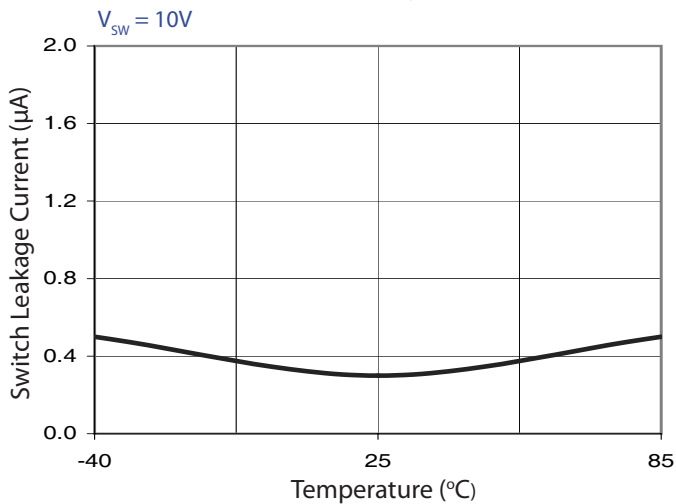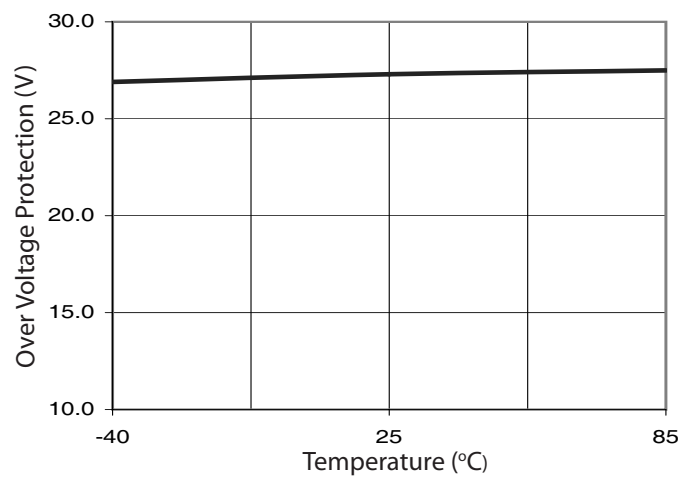
Typical Characteristics (continued)

Schottky Forward Drop
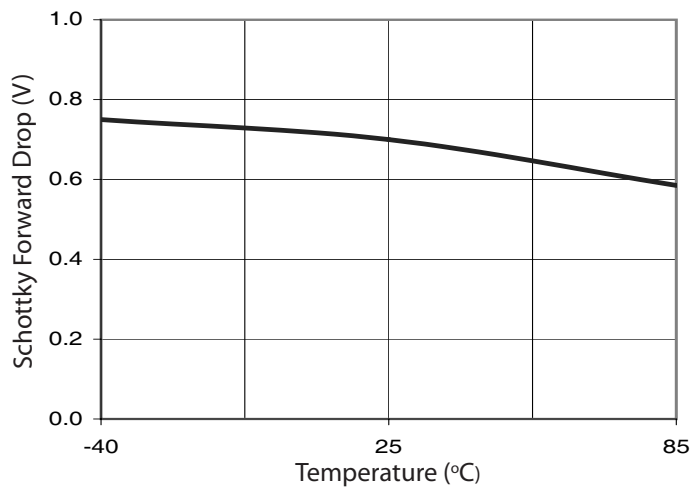
Schottky Leakage Current
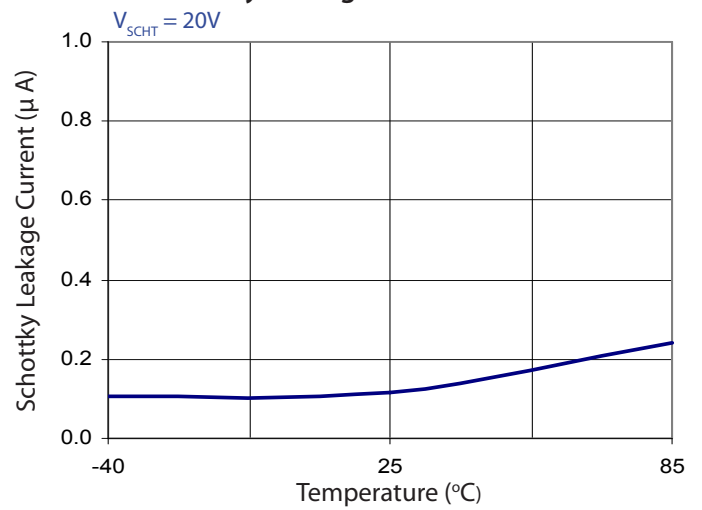
$V_{SCHT} = 20V$

LED Current Sense Voltage(FB)
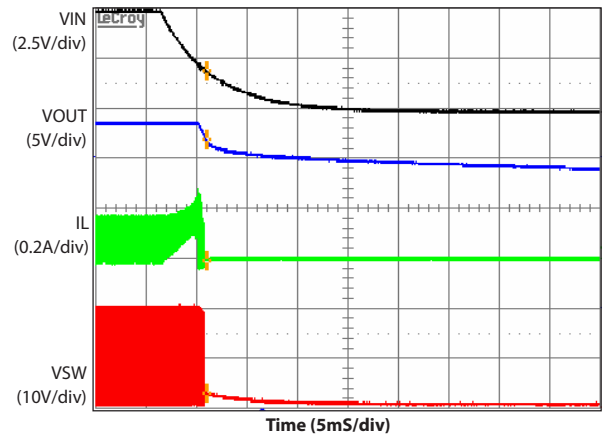
VIN = 5V
VIN = 12V
VIN = 22V
VOUT = 18V

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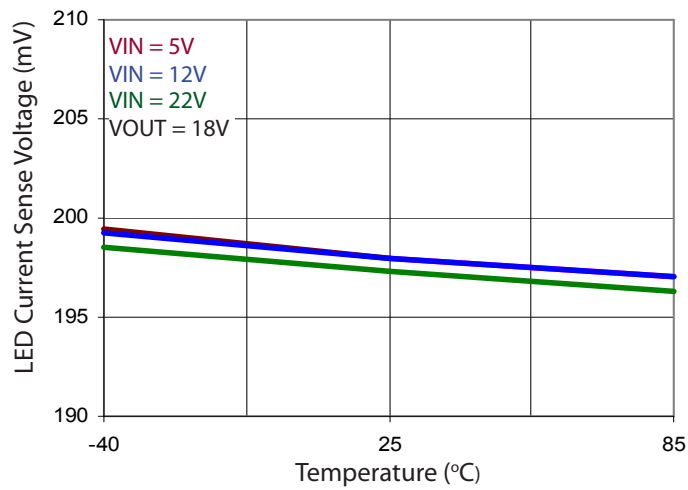
Typical Characteristics (continued)

Conditions: $5V_{IN}$, 20mA, 6 LEDs in series, $C_{IN}/C_{OUT}=1\mu F$, $L=10\mu H$
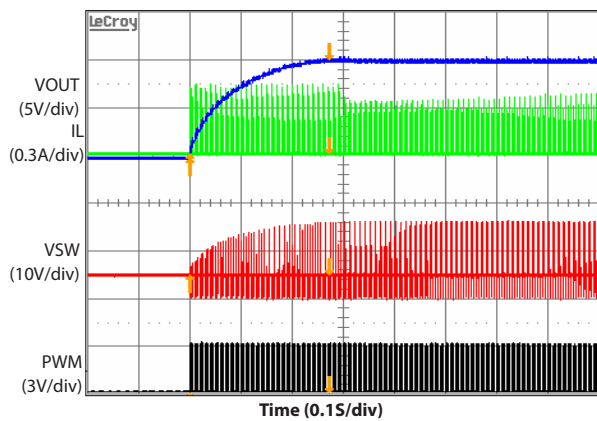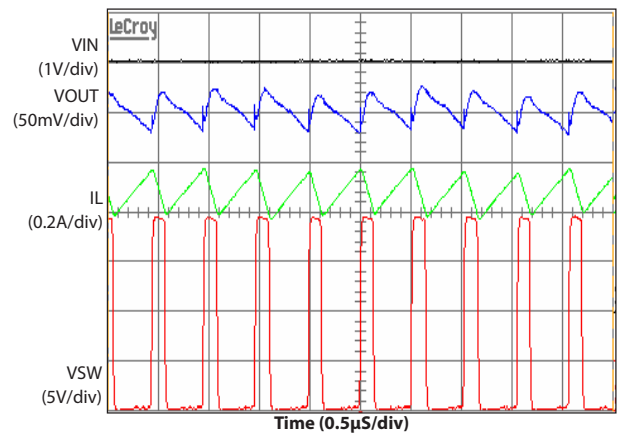
Start-up — by V_{IN}

VIN (2.5V/div)
VOUT (5V/div)
IL (0.2A/div)
VSW (10V/div)

Time (2mS/div)

Shut Down

VIN (2.5V/div)
VOUT (5V/div)
IL (0.2A/div)
VSW (10V/div)

Time (5mS/div)
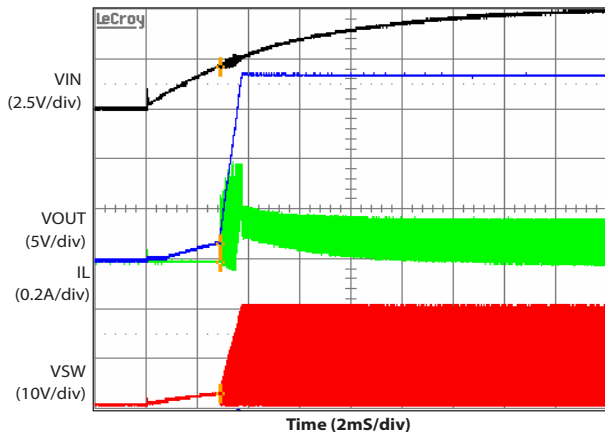
Start-up — by PWM

300Hz PWM Dimming, 0.1% Duty Cycle

VOUT (5V/div)
IL (0.3A/div)
VSW (10V/div)
PWM (3V/div)

Time (0.1S/div)

Main Power Switching

VIN (1V/div)
VOUT (50mV/div)
IL (0.2A/div)
VSW (5V/div)

Time (0.5µS/div)

VIN Fluctuation — Rising

5VIN to 12VIN

VIN (5V/div)
VOUT (1V/div)
VSW (10V/div)

Time (2µS/div)
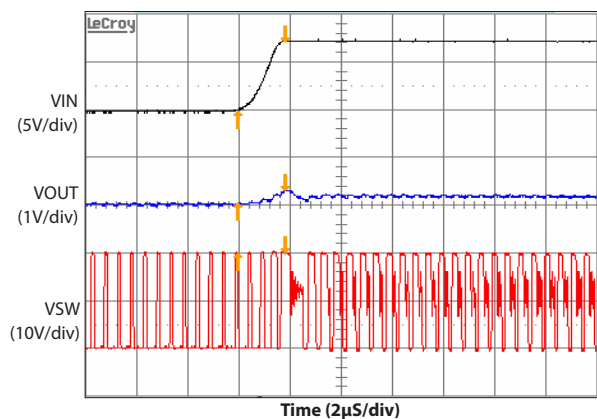
VIN Fluctuation — Falling

12VIN to 5VIN
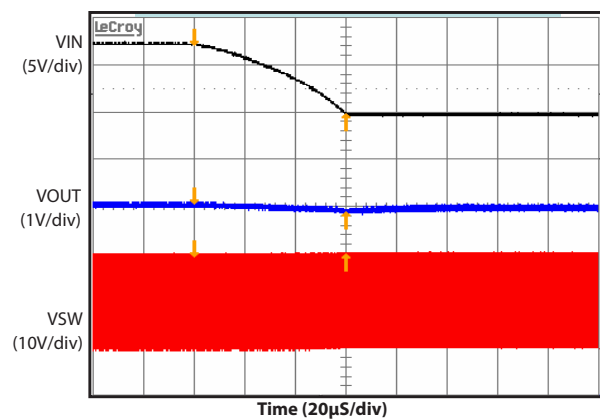
VIN (5V/div)
VOUT (1V/div)
VSW (10V/div)

Time (20µS/div)

Typical Characteristics (continued)

Conditions: 5V$_{IN}$, 20mA ,6 LEDs in series, C$_{IN}$/C$_{OUT}$=1µF, L=10µH
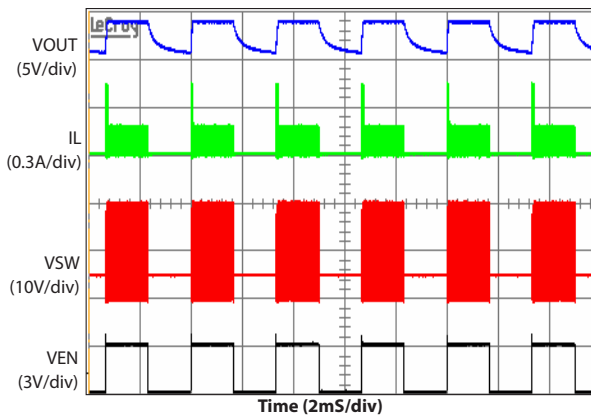
Over Voltage Protection

VIN
(3V/div)

VOUT
(5V/div)

IL
(0.4A/div)

VSW
(10V/div)

Time (0.1mS/div)
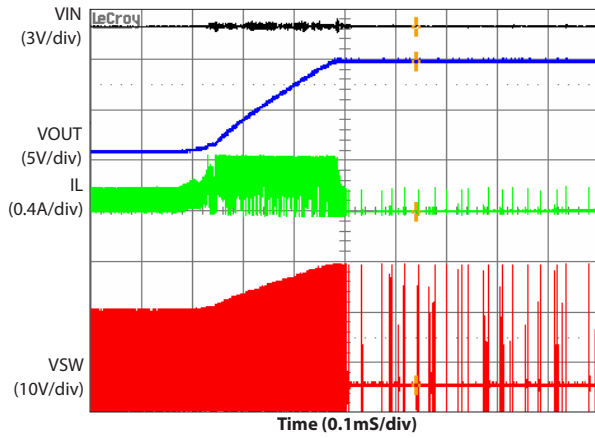
PWM Dimming (0.1% duty cycle)

300Hz PWM Dimming, 0.1% Duty Cycle

VOUT
(5V/div)

IL
(0.3A/div)

VSW
(10V/div)

VEN
(3V/div)

Time (0.5mS/div)
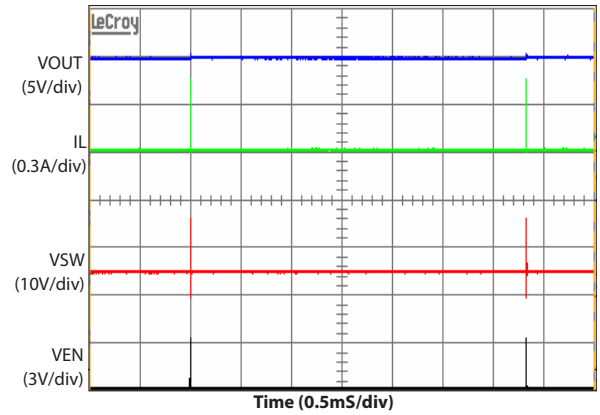
PWM Dimming (50% duty cycle)

300Hz PWM Dimming, 50% Duty Cycle

VOUT
(5V/div)

IL
(0.3A/div)

VSW
(10V/div)

VEN
(3V/div)

Time (2mS/div)

Pin Descriptions

Pin # MLPD-WL6	Pin # SOT23-6	Pin Name	Pin Function
1	3	IN	Input supply pin — add a ceramic capacitor between this pin and ground.
2	2	GND	Ground pin — connect to external ground plane.
3	1	SW	Collector of the internal power transistor — connect this pin to the boost inductor.
4	6	OUT	Output voltage pin — this pin is the output of the internal Schottky diode. Connect this pin to a ceramic output (1µF typical) capacitor and current sense resistor.
5	5	FB	LED current feedback pin — connect this pin to anode of the topmost LED in the string and the current sense resistor to set the total current in the LED string(s). LED current is set by : $200/R_{SENSE}$ (mA), where R_{SENSE} is in Ohms.
6	4	EN	Enable and PWM control pin for LED string — pulling this pin logic high enables the device.
T	N/A	Thermal Pad	Pad for heat sinking purposes — connect to the external ground plane using multiple vias when using MLPD-UT6 package. Not electrically connected internally. The SOT23-6 does not have a thermal pad.

Block Diagram

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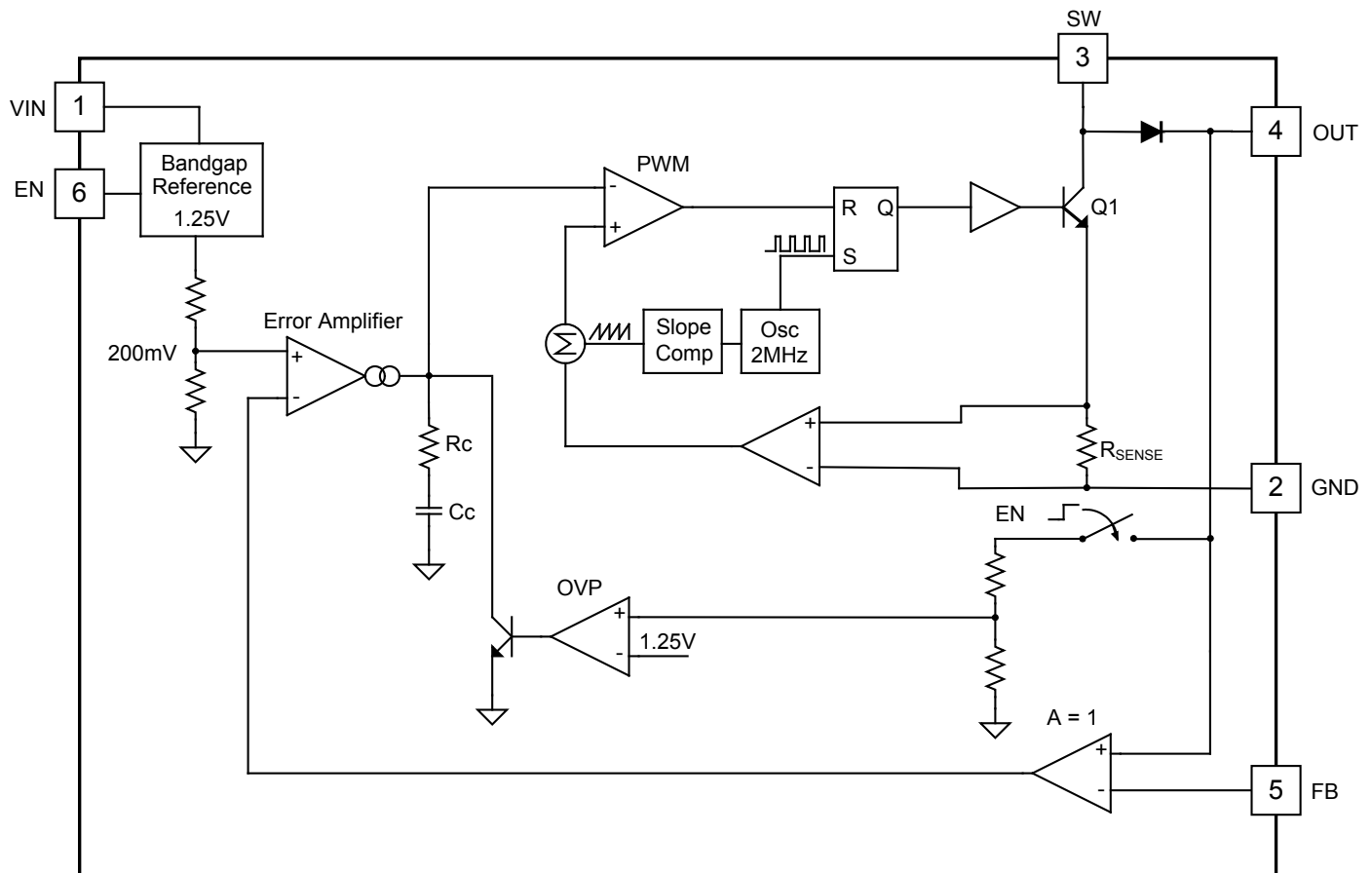
Applications Information

Operation
The SC4541 is a fixed frequency step-up current-mode switching regulator with an integrated Schottky diode and power transistor (see the Block Diagram for more information).

When EN is low, the device is in shutdown mode and draws less than 1µA of current. The internal circuitry is enabled and turns on when EN is logic high. The voltage drop across OUT and FB is reflected to ground and fed to the negative input of the error amplifier and a 200mV reference signal is fed to the positive input of the error amplifier. The output of the error amplifier is one input to the PWM comparator. The device is designed to be stable without additional external compensation components.

Switch current is sensed with an integrated sense resistor and is summed with the slope-compensating ramp which is then fed as the modulating ramp input to the PWM comparator. The latch is reset and Q1 is turned off when the modulating ramp intersects the error amplifier output. The latch will also be reset if the current in Q1 exceeds the current limit threshold, typically 350mA. The latch is set and Q1 turns on at the beginning of every oscillator clock cycle.

The SC4541 has a built-in Schottky diode. When input voltage is applied an inrush current flows through the inductor and the Schottky diode and charges up the output capacitor connected to OUT. The Schottky diode inside the SC4541 can sustain a maximum current of 1A.

Programming the LED Current
The circuit will maintain the necessary output voltage to ensure 200mV across OUT and FB pins. Refer to the Typical Application Circuit on page 1. The LED current is programmed by connecting a resistor (R_{SENSE}) between the OUT pin and FB pin. The LED current, in mA, is set by using the following relationship.

$$I_{LED} = 200/R_{SENSE}$$

where R_{SENSE} value is in Ohms.
  I_{LED} value is in mA.

The feedback voltage has a direct effect on the converter efficiency. Because the voltage drop across the feedback resistor does not contribute to the output power (LED brightness), the lower the feedback voltage, the higher the efficiency. The internal oscillator sets a high switching frequency of 2.0MHz which further reduces the total solution size by minimizing external L/C filter size.

Over-Voltage Protection (OVP)
An integrated over-voltage protection circuit prevents the OUT voltage from exceeding the maximum switch voltage rating (28V). When EN is high, a resistor divider from OUT to GND is switched in to monitor OUT for over-voltage protection. If OUT rises higher than the OVP threshold, typically 27V, the OVP comparator will trip and reset the latch to turn Q1 off. When OUT drops back below the OVP threshold, Q1 will turn back on in the next oscillator cycle. This sequence will repeat for as long as the over-voltage condition persists.

Enable and PWM Dimming
The EN pin could be toggled for direct PWM dimming. In a typical application, a microcontroller sets a register which varies the pulse width on a GPIO which is tied to EN pin. Direct PWM dimming can be used to control LED brightness when a PWM signal (up to 1kHz) with wide duty ratio is applied.

Inductor Selection
The inductance value affects the converter's steady state operation, transient response, and its loop stability. Attention must be given to inductor parameters; including inductance, DC resistance, and saturation current. The inductance and operating conditions determine the inductor ripple current. The converter can operate in continuous conduction mode (CCM) or discontinuous conduction mode (DCM). The inductor DC current or input current can be calculated using the following equation.

$$I_{IN} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta}$$

I_{IN} - Input current;

I_{OUT} – Output current;

V_{OUT} – Boost output voltage;

V_{IN} – Input voltage;

η – Efficiency of the boost converter.

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Applications Information (continued)

The converter has higher efficiency under CCM and the inductor peak current is calculated by the following equation.

$$I_{L\_PEAK} = I_{IN} + \frac{V_{IN} \times D}{2 \times F_S \times L}$$

Assuming CCM, the duty ratio is calculated using the following equation.

$$D = \frac{V_{OUT} - V_{IN} + V_D}{V_{OUT} + V_D}$$

V_D is the forward voltage drop of the internal Schottky rectifier.

The inductor ripple current is further shown by the following equation.

$$I_{L\_RIPPLE} = \frac{V_{IN} \times D}{F_S \times L}$$

The recommended inductance shown in Table 1 is based on operation with regulated 5V input, dual Li-ion or three Li-ion battery packs. Increased inductance is required for higher input and output voltage configurations.

Table 1 — Inductance Requirements, Driving 6 bWLED

Input Type	Input Voltage Range	L1 Inductance
Regulated 5V	4.5 to 5.5V	10µH
Dual Lithium Ion Battery Pack	5.4 to 8.4V	22µH
Three Lithium Ion Battery Pack	8.1 to 12.6V	33µH

Output Capacitor Selection

Ceramic capacitors are placed near IN and OUT pins to ground in order to minimize ripple voltage. The minimum capacitance needed for a given ripple can be estimated using the following equation.

$$C_{OUT} = \frac{(V_{OUT} - V_{IN}) \times I_{OUT}}{V_{OUT} \times F_S \times V_{RIPPLE}}$$

V_{RIPPLE} = Peak to peak output voltage ripple
I_{OUT} = Output current
V_{OUT} = Boost output voltage
V_{IN} = Input voltage
F_S = Switching frequency

A 1µF ceramic input and output capacitor should be adequate for most applications. Larger capacitance reduces voltage ripple, overshoot and undershoot during load transient as well as improving loop stability margin. Recommended ceramic capacitor manufacturers are listed in Table 1.

Table 2 — Recommended Ceramic Capacitor Manufacturers

Vendor	Phone	Website
Kemet	408-986-0424	www.kemet.com
Murata	814-237-1431	www.murata.com
Taiyo Yuden	408-573-4150	www.t-yuden.com

Applications Information (continued)

PCB Layout Considerations

Poor layout can degrade the performance of the DC-DC converter and can be a contributory factor in EMI problems, ground bounce, thermal issues, and resistive voltage losses. Poor regulation and instability can result. A typical application schematic is shown in Figure 1. A typical PCB layout is shown in Figure 4.

The following design rules are recommended:

- Place the inductor and filter capacitors as close to the device as possible and use short, wide traces between the power components.
- Use a ground plane to further reduce noise interference on sensitive circuit nodes.

L1: MURATA LQH3NPN100NM0 (10µH/ 550mA/ 3x3x1.4(mm)
C2: MURATA GRM188R7YA105K(1µF/ X7R/ 35V/ 0603)
C3: MURATA GRM188R71C105K(1µF/ X7R/ 16V/ 0603)
LED1 to 6: Everlight 12-21C/T3D-CP1Q2B12Y/2C
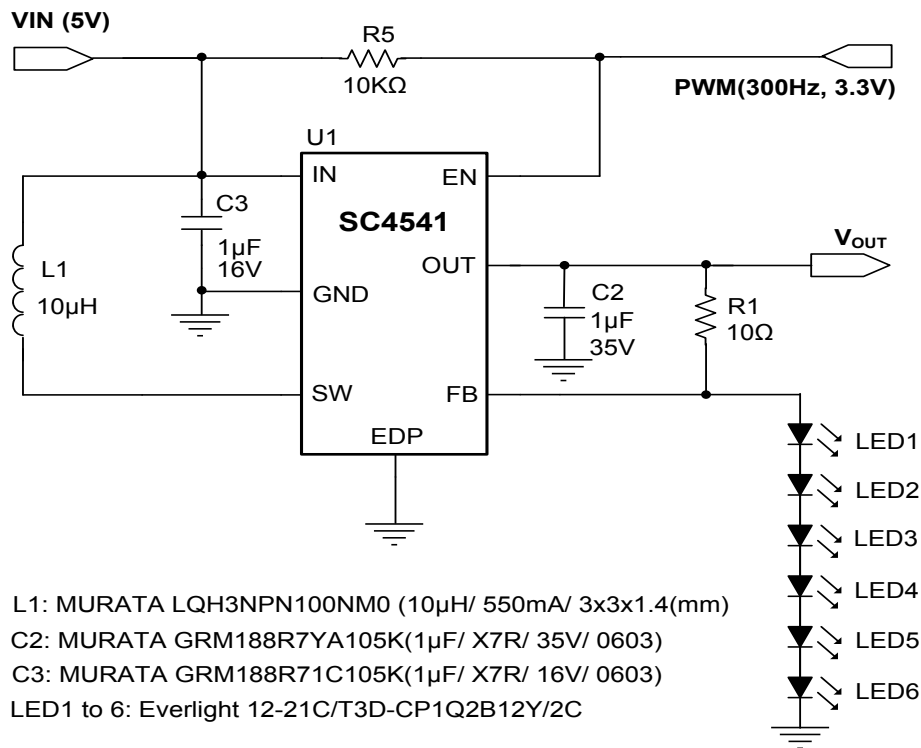
Figure 1 — Typical Application Schematic, Boost Topology

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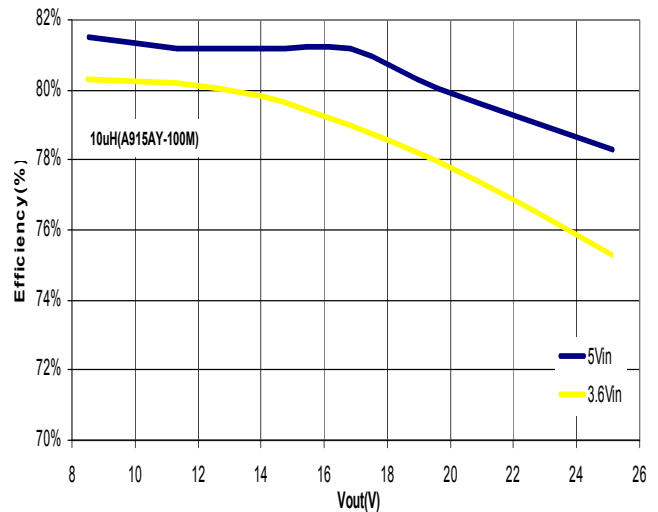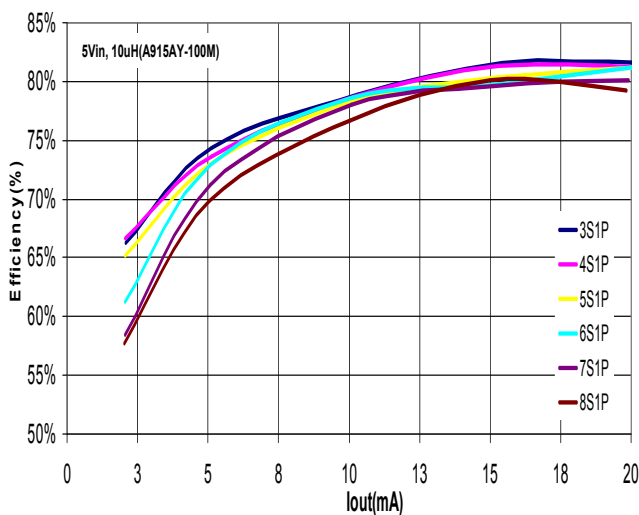
Applications Information (continued)

(1) L1: Murata LQH3NPN100MM0L
(2) C2,C5: Murata GRM188R7YA105K
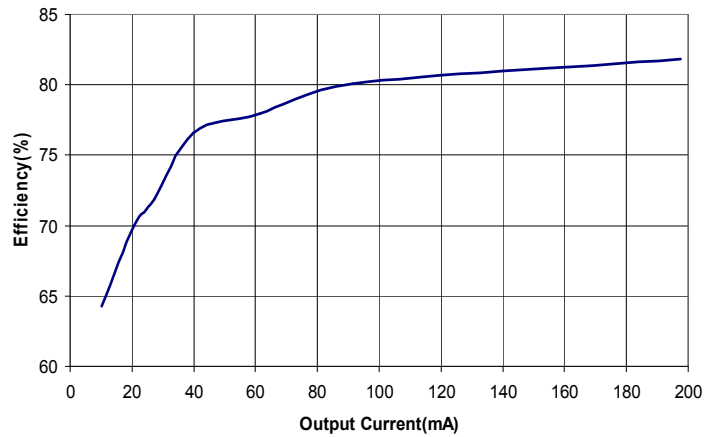
Figure 2 — Typical Application Schematic, Buck Topology
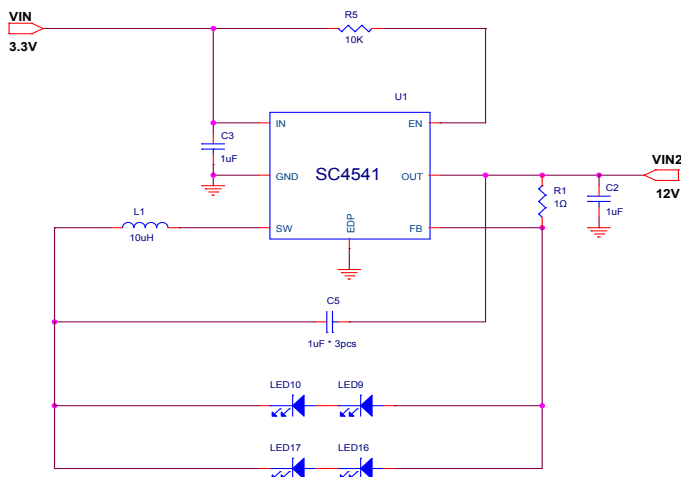
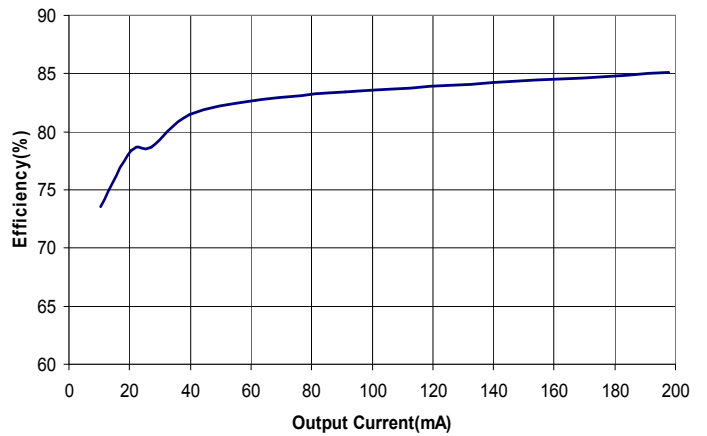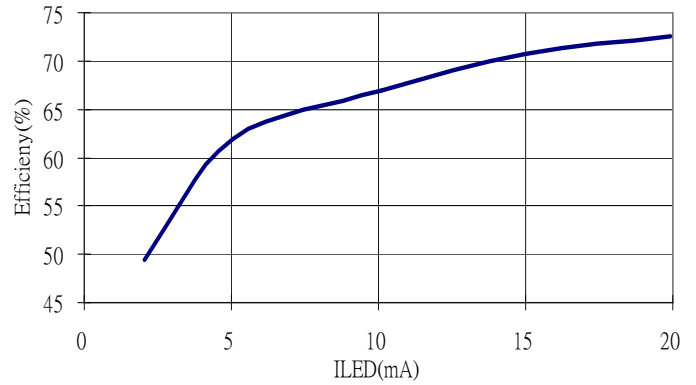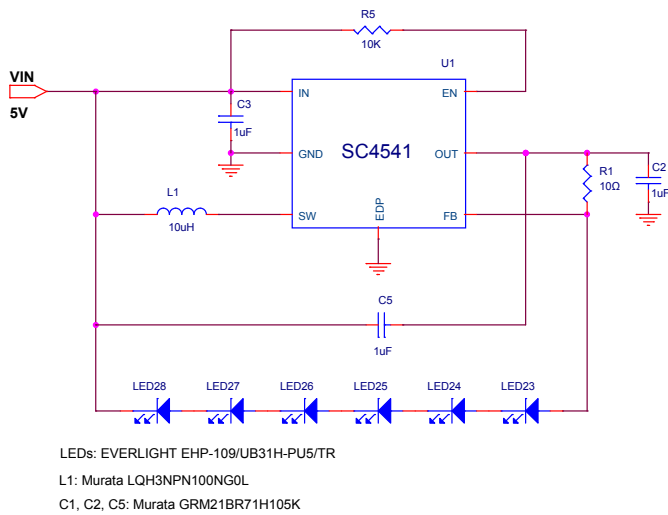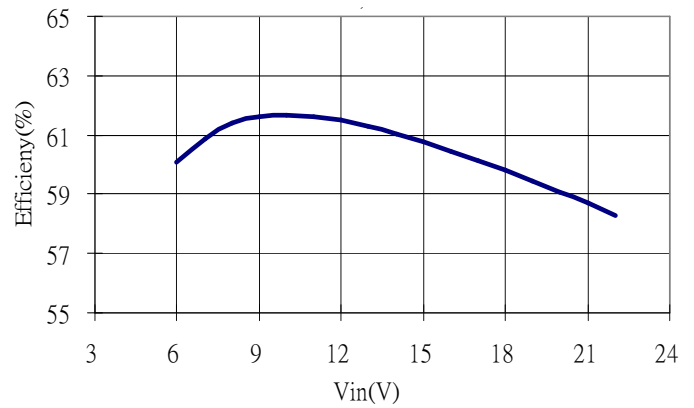(1) L1: Murata LQH3NPN100MM0L
(2) C2, C3,C5: Murata GRM188R7YA105K

Figure 3 — Typical Application Schematic, High Efficiency of Buck Topology

Applications Information (continued)

LEDs: EVERLIGHT EHP-109/UB31H-PU5/TR
L1: Murata LQH3NPN100NG0L
C1, C2, C5: Murata GRM21BR71H105K

Figure 4 — Typical Application Schematic, Floating Buck-Boost Topology

LEDs: EVERLIGHT EHP-109/UB31H-PU5/TR
L1: Cooper SD52-220-R
C1, C2: Murata GRM21BR71H105K
C5: Murata GRM31CR71H475K
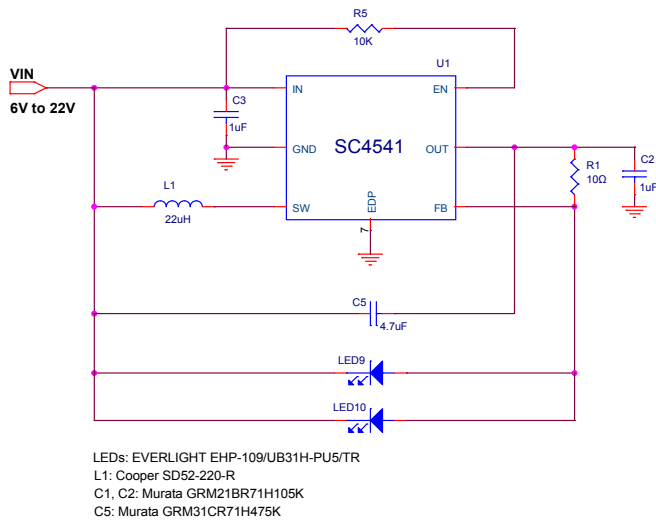
Figure 5 — Typical Application Schematic, Floating Buck-Boost Topology

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Applications Information (continued)
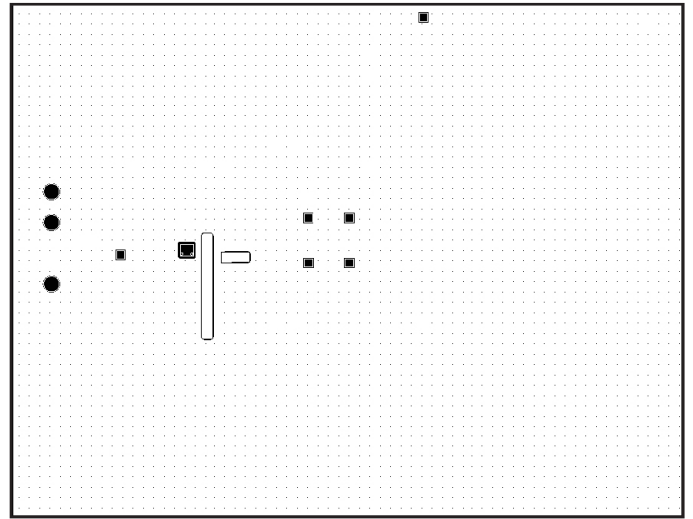
(TOP layer)   (Bottom layer)

Figure 4 — Typical PCB Layout

Outline Drawing — 2x2 MLPD-UT6
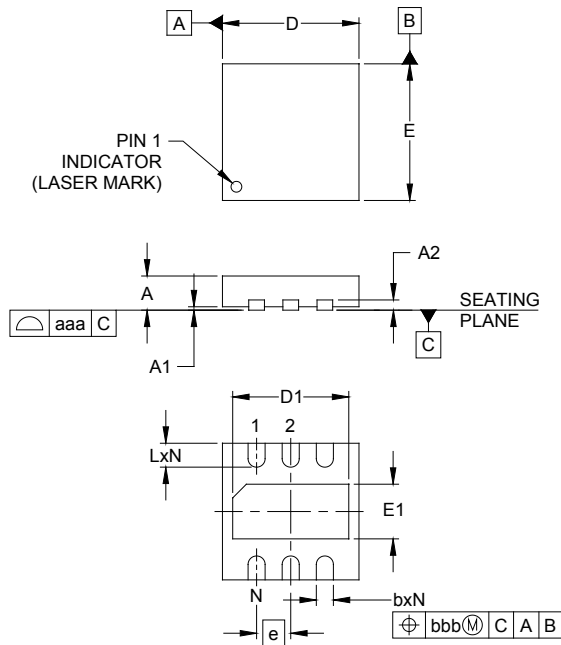
DIMENSIONS						
DIM	INCHES			MILLIMETERS		
	MIN	NOM	MAX	MIN	NOM	MAX
A	.020	-	.024	0.50	-	0.60
A1	.000	-	.002	0.00	-	0.05
A2		(.006)			(0.152)	
b	.007	.010	.012	0.18	0.25	0.30
D	.075	.079	.083	1.90	2.00	2.10
D1	.061	.067	.071	1.55	1.70	1.80
E	.075	.079	.083	1.90	2.00	2.10
E1	.026	.031	.035	0.65	0.80	0.90
e		.020 BSC			0.50 BSC	
L	.010	.014	.018	0.25	0.35	0.45
N		6			6	
aaa		.003			0.08	
bbb		.004			0.10	

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).

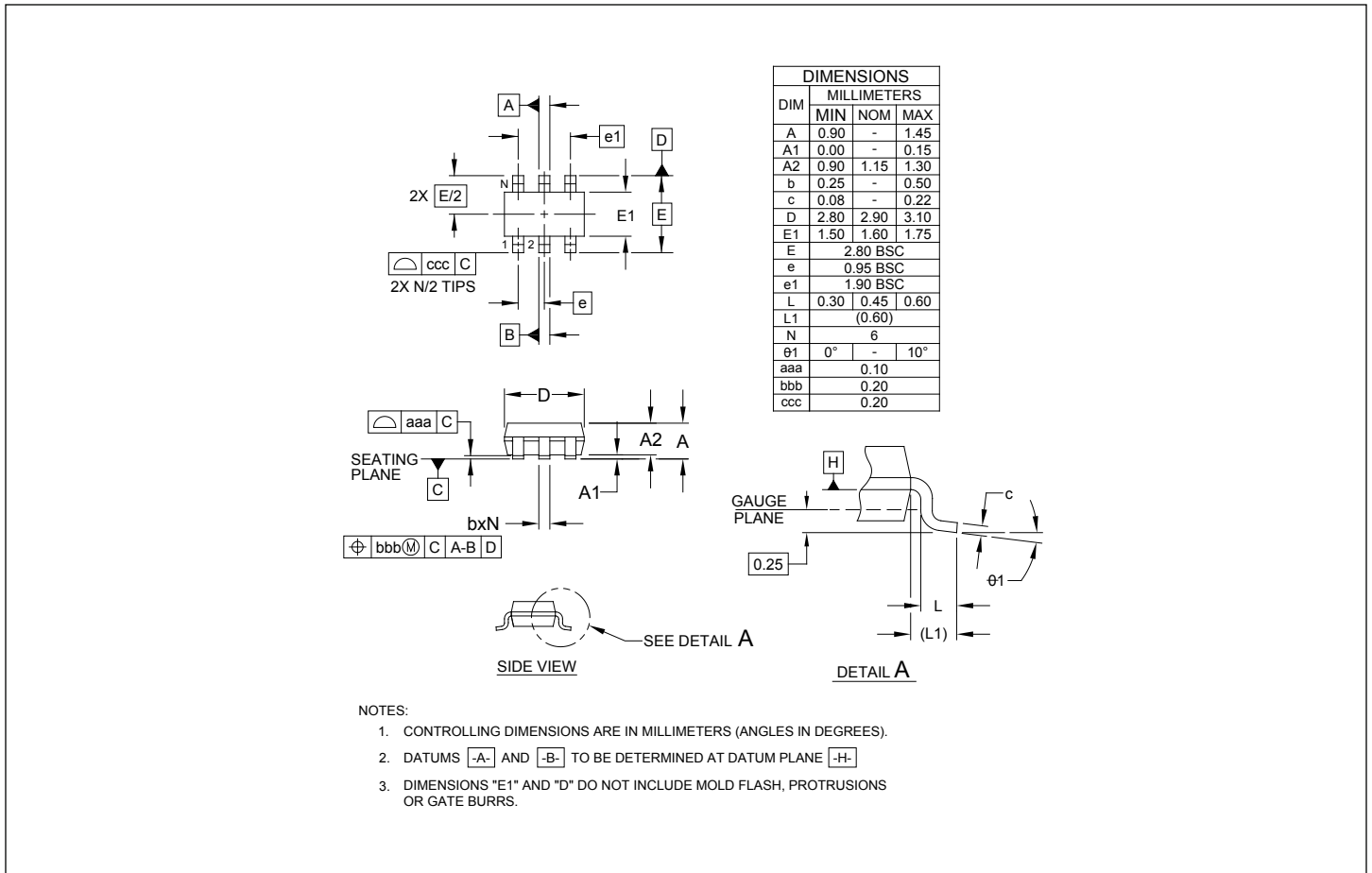2. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS TERMINALS.

Land Pattern — 2x2 MLPD-UT6
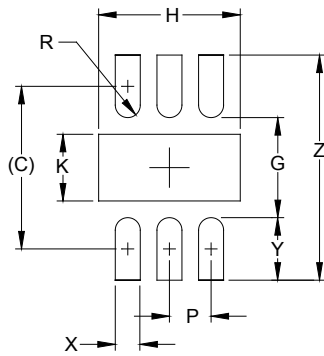
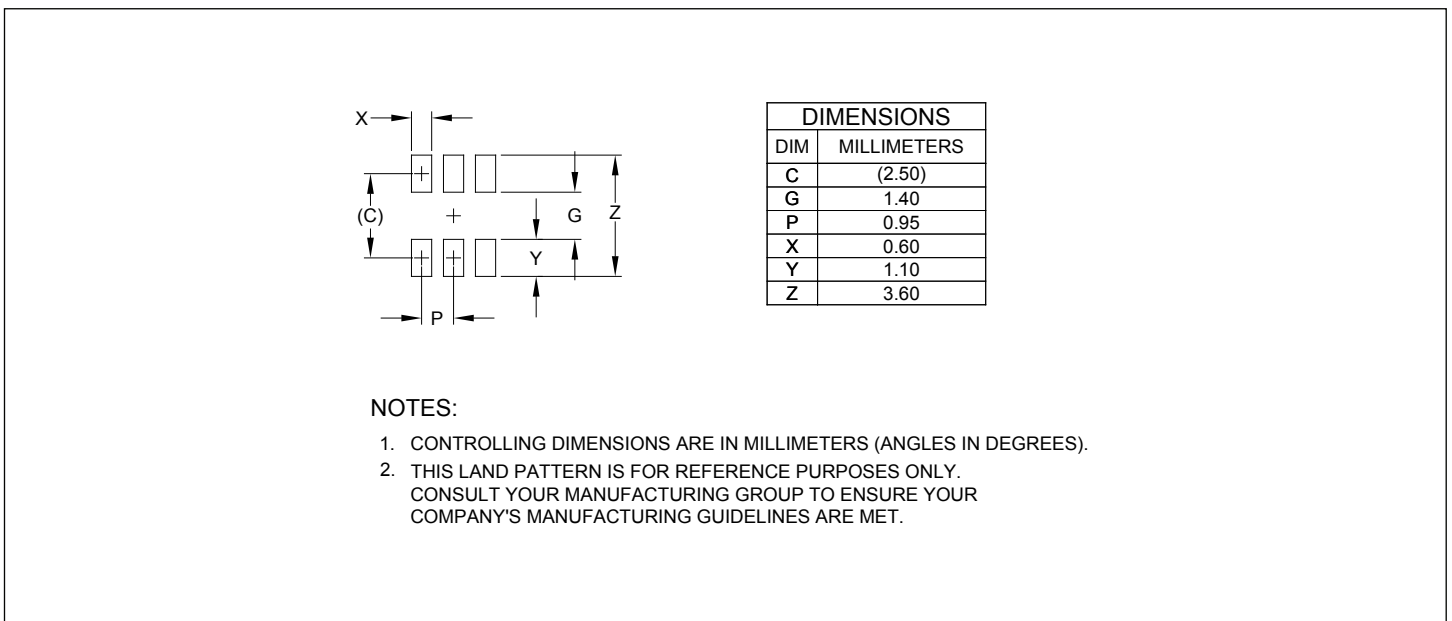| DIMENSIONS		
DIM	INCHES	MILLIMETERS
C	(.077)	(1.95)
G	.047	1.20
H	.067	1.70
K	.031	0.80
P	.020	0.50
R	.006	0.15
X	.012	0.30
Y	.030	0.75
Z	.106	2.70

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).

2. THIS LAND PATTERN IS FOR REFERENCE PURPOSES ONLY.
   CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR
   COMPANY'S MANUFACTURING GUIDELINES ARE MET.

3. THERMAL VIAS IN THE LAND PATTERN OF THE EXPOSED PAD
   SHALL BE CONNECTED TO A SYSTEM GROUND PLANE.
   FAILURE TO DO SO MAY COMPROMISE THE THERMAL AND/OR
   FUNCTIONAL PERFORMANCE OF THE DEVICE.

SEMTECH

Outline Drawing — SOT23-6

DIMENSIONS			
DIM	**MILLIMETERS**		
	MIN	NOM	MAX
A	0.90	-	1.45
A1	0.00	-	0.15
A2	0.90	1.15	1.30
b	0.25	-	0.50
c	0.08	-	0.22
D	2.80	2.90	3.10
E1	1.50	1.60	1.75
E	2.80 BSC		
e	0.95 BSC		
e1	1.90 BSC		
L	0.30	0.45	0.60
L1	(0.60)		
N	6		
θ1	0°	-	10°
aaa	0.10		
bbb	0.20		
ccc	0.20		

NOTES:
1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. DATUMS -A- AND -B- TO BE DETERMINED AT DATUM PLANE -H-
3. DIMENSIONS "E1" AND "D" DO NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.

Land Pattern — SOT23-6

DIMENSIONS	
DIM	**MILLIMETERS**
C	(2.50)
G	1.40
P	0.95
X	0.60
Y	1.10
Z	3.60

NOTES:
1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. THIS LAND PATTERN IS FOR REFERENCE PURPOSES ONLY. CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR COMPANY'S MANUFACTURING GUIDELINES ARE MET.

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