

36V/24V/19V High Efficiency Step-Up LED Driver with PWM Control

Features

- Wide output range: up to 10 series LEDs
- Integrated 40V high current switch (800mA limit)
- High efficiency PWM converter (up to 90%)
- Low 200mV feedback voltage
- High accuracy across full load range
- V_{IN} range: 2.7V to 5.5V
- LED open-circuit (OVP) protection
 - KTD2536: 36V
 - KTD2536B: 24V
 - KTD2536C: 19V
- High switching frequency
 - KTD2536: 900kHz
 - KTD2536B/C: 1.1MHz
- PWM dimming frequency: 100Hz to 200kHz
- Simple, small solution size
- Integrated Soft-start
- Shutdown Current less than 1 μ A
- Small TSOT23-6 Package
- RoHS and Green compliant
- -40°C to +85°C Temperature Range

Brief Description

The KTD2536 is a versatile constant current LED driver with a high efficiency DC-DC step up “boost” converter architecture. The low-side power MOSFET is integrated in the device, minimizing the total number of external components. Unique technology and high 800mA current limit allow KTD2536 to drive up to 36V output (10 LEDs in series), up to 24V using KTD2536B (6 LEDs in series) or up to 19V using KTD2536C (5 LEDs in series). Alternatively, KTD2536 can deliver 160mA total current with 3 series LEDs per string. It can also maximize the current capability while achieving high conversion efficiency. The optimized 0.9MHz and 1.1MHz switching frequencies result in small external component size. The driver allows a wide range of PWM dimming frequencies through the EN pin.

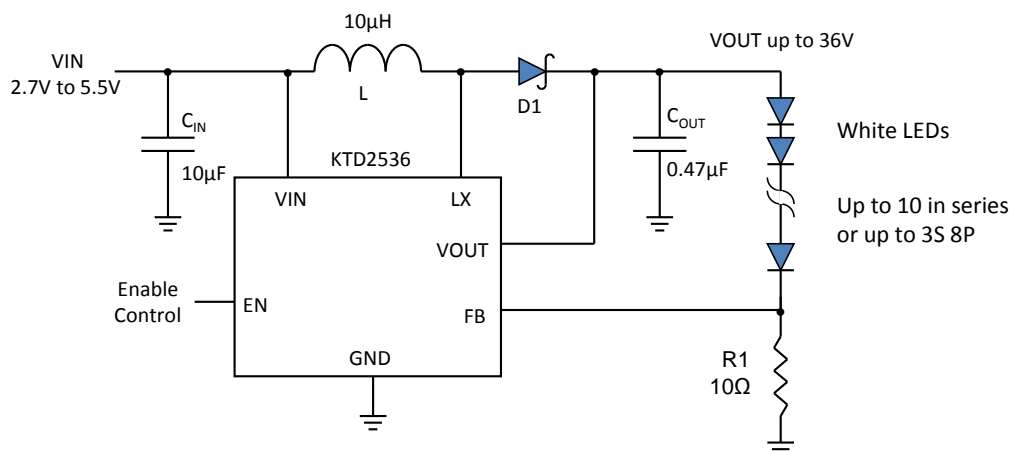
Various protection features are built into the KTD2536, including cycle-by-cycle input current limit protection, LED open-circuit (output over voltage) protection and thermal shutdown protection. The leakage current in shutdown mode is less than 1 μ A.

The KTD2536 is available in a RoHS compliant 6-lead TSOT23 package.

Applications

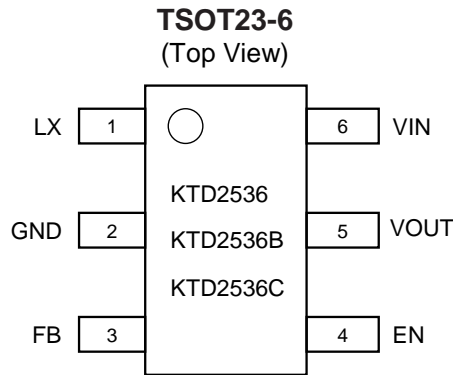
- LED backlighting
- Mobile Phones
- Handheld Devices
- Digital Photo Frames
- Automotive Navigation

Typical Application



Pin Descriptions

Pin #	Name	Function
1	LX	Converter switching node
2	GND	Converter/IC ground
3	FB	Output feedback pin regulated at 0.2V
4	EN	IC enable and PWM dimming control pin. A logic High signal enables converter. A PWM signal on this pin controls LED average conduction current.
5	VOUT	Converter output and over-voltage protection sensing pin
6	VIN	IC supply voltage



Absolute Maximum Ratings¹

(T_A = 25°C unless otherwise noted)

Symbol	Description	Value	Units
VIN	Input voltage	-0.3 to 6.0	V
VOUT	Output voltage	KTD2536	-0.3 to 44
		KTD2536B	-0.3 to 30
		KTD2536C	-0.3 to 24
LX	Switching node ²	KTD2536	-1.2 to 44
		KTD2536B	-1.2 to 30
		KTD2536C	-1.2 to 24
FB, EN	Other pins	-0.3 to VIN+0.3	V
T _J	Operating Temperature Range	-40 to 150	°C
T _s	Storage Temperature Range	-65 to 150	°C
T _{LEAD}	Maximum Soldering Temperature (at leads, 10 sec)	300	°C

1. Stresses above those listed in Absolute Maximum Ratings may cause permanent damage to the device. Functional operation at conditions other than the operating conditions specified is not implied. Only one Absolute Maximum rating should be applied at any one time.

2. LX Switching node can tolerate Absolute Maximum negative voltage rating with maximum 100mA flowing from GND to LX pin.

Thermal Capabilities

Symbol	Description	Value	Units
θ _{JA}	Thermal Resistance – Junction to Ambient ³	190	°C/W
P _D	Maximum Power Dissipation at T _A ≤ 25°C	0.526	W
ΔP _D /°C	Derating Factor Above T _A = 25°C	-5.26	mW/°C

3. Junction to Ambient thermal resistance is highly dependent on PCB layout. Values are based on thermal properties of the device when soldered to an EV board.

Ordering Information

Part Number	OVP Threshold (nominal)	Marking ⁴	Operating Temperature	Package
KTD2536EHD-TR	36V	FSYYZ	-40°C to +85°C	TSOT23-6
KTD2536BEHD-TR	24V	__YYZ	-40°C to +85°C	TSOT23-6
KTD2536CEHD-TR	19V	__YYZ	-40°C to +85°C	TSOT23-6

4. "YYZ" is the date code and assembly code.

Electrical Characteristics⁵

Unless otherwise noted, the *Min* and *Max* specs are applied over the full operation temperature range of -40°C to +85°C, while *Typ* values are specified at room temperature (25°C). $V_{IN} = 3.6V$.

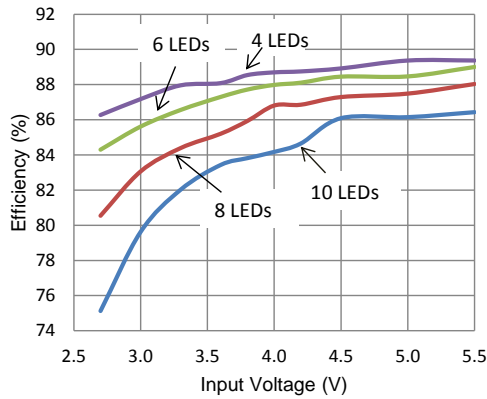
Symbol	Description	Conditions	Min	Typ	Max	Units
IC Supply						
V_{IN}	Input operating range		2.7		5.5	V
UVLO	Input under voltage lockout	Rising edge		2.5	2.65	V
UVLO _{HYST}	UVLO hysteresis			0.15		V
I_Q	IC quiescent current (non-switching)	FB = 0.4V		0.28	0.5	mA
	IC operating current (switching)	FB = 0V		0.7	1.95	mA
I_{SHDN}	VIN pin shutdown current	EN = GND		0.1	1.0	μA
Step-Up Converter						
V_{FB}	FB pin voltage accuracy		0.184	0.2	0.216	V
I_{FB}	FB pin bias current				0.1	μA
$R_{DS(ON)}$	NMOS on-resistance	$T_A = 25^\circ C$		0.65	1.0	Ω
I_{LX}	LX pin leakage current			1		μA
I_{LIM}	Peak NMOS current limit			800		mA
$I_{INRUSH-SU}$	Peak Inductor Current During Startup	KTD2536, $V_{IN} = 4V$, 8 LEDs, $I_{LED} = 20mA$, $L = 10\mu H$, $C_{OUT} = 0.1\mu F$		350		mA
		KTD2536B, $V_{IN} = 4V$, 6 LEDs, $I_{LED} = 20mA$, $L = 10\mu H$, $C_{OUT} = 0.47\mu F$		280		
		KTD2536C, $V_{IN} = 4V$, 4 LEDs, $I_{LED} = 20mA$, $L = 10\mu H$, $C_{OUT} = 0.47\mu F$		200		
$I_{INRUSH-OL}$	Peak Inductor Current During Open-Load Condition	KTD2536, $V_{IN} = 4V$, $L = 10\mu H$, $C_{OUT} = 0.1\mu F$, $V_{OVP} = 36V$		150		mA
		KTD2536B, $V_{IN} = 4V$, $L = 10\mu H$, $C_{OUT} = 0.47\mu F$, $V_{OVP} = 24V$		140		
		KTD2536C, $V_{IN} = 4V$, $L = 10\mu H$, $C_{OUT} = 0.47\mu F$, $V_{OVP} = 19V$		120		
F_{SW}	Oscillator frequency	KTD2536		0.9		MHz
		KTD2536B		1.1		
		KTD2536C		1.1		
D_{max}	Maximum duty cycle		92	95		%
OVP	Over voltage threshold	Measured at VOUT pin	KTD2536		36	V
			KTD2536B		24.4	
			KTD2536C		18.6	
T_S	Start-up time			2000		μs
Control						
V_{TH-L}	Logic low threshold				0.4	V
V_{TH-H}	Logic high threshold		1.4			V
T_{OFF}	EN low to shutdown time			3		ms
F_{EN}	Dimming frequency		0.1		200	kHz
D_{PWM_MIN}	PWM dimming duty cycle resolution	$f_{DIM} = 5kHz$	1			%
		$f_{DIM} = 30kHz$	1			
T_{J-TH}	IC junction thermal shutdown threshold			150		°C
	IC junction thermal shutdown hysteresis			15		°C

5. The KTD2536 is guaranteed to meet performance specifications over the -40°C to +85°C operating temperature range by design, characterization and correlation with statistical process controls.

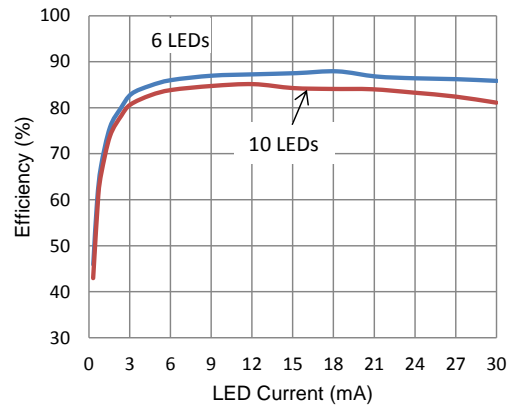
Typical Characteristics

$V_{IN} = 3.6V$, $L = 10\mu H$, $C_{IN} = 10\mu F$, $C_{OUT} = 0.47\mu F$ with 10 LEDs in series at 20mA, $T_{AMB} = 25^{\circ}C$ unless otherwise specified.

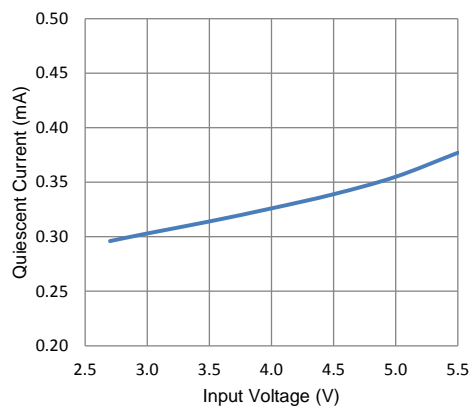
Efficiency vs. Input Voltage



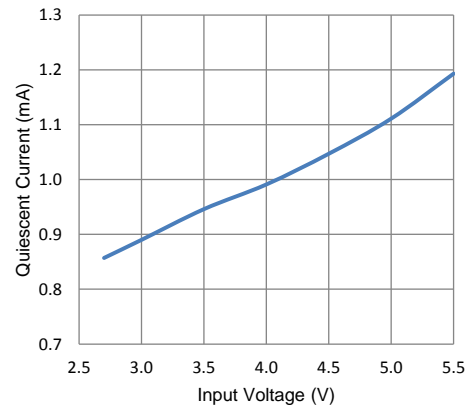
Efficiency vs. LED Current



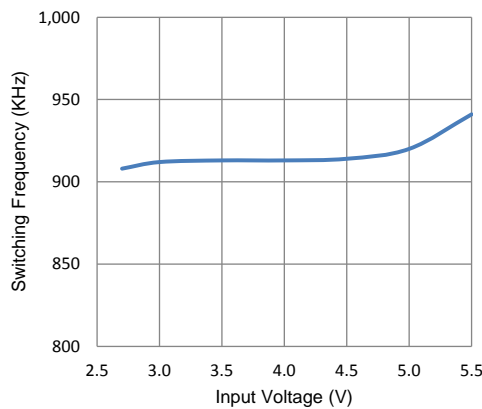
Operating Current (non-switching)



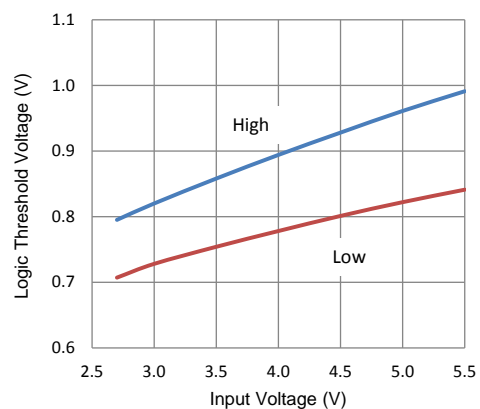
Operating Current (switching)



Switching Frequency



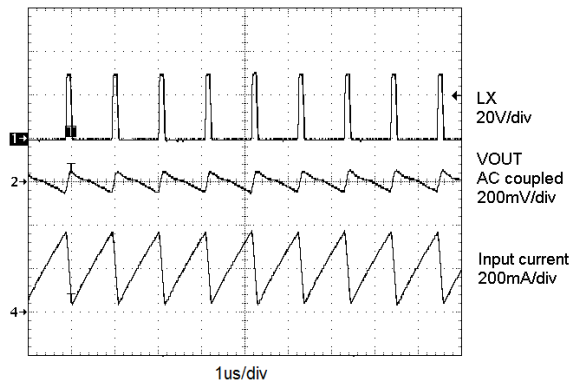
EN Logic Threshold Voltage



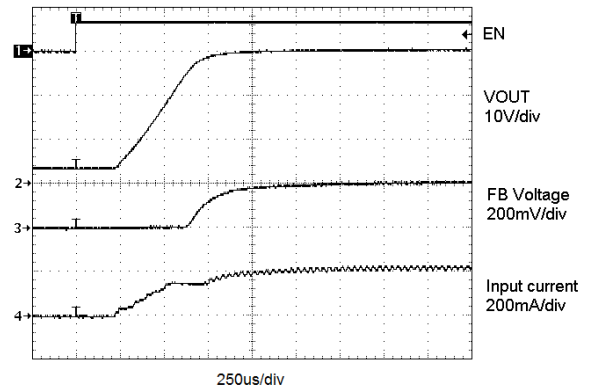
Typical Characteristics (continued)

$V_{IN} = 3.6V$, $L = 10\mu H$, $C_{IN} = 10\mu F$, $C_{OUT} = 0.47\mu F$ with 10 LEDs in series at 20mA, $T_{AMB} = 25^{\circ}C$ unless otherwise specified.

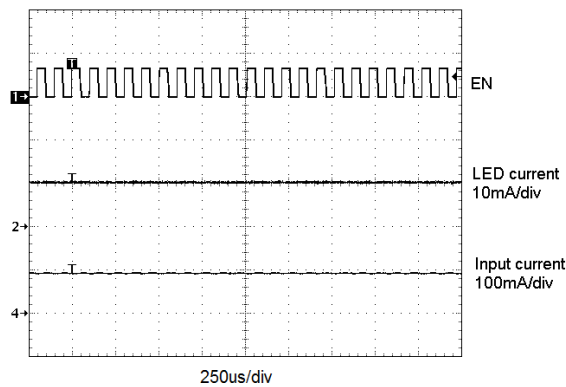
Steady State Switching



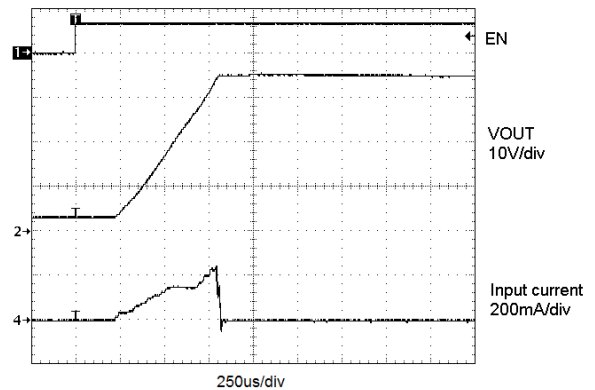
Soft Start Turn On



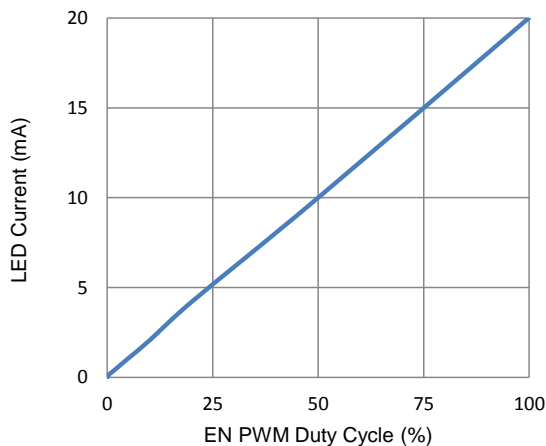
PWM Dimming (10kHz)



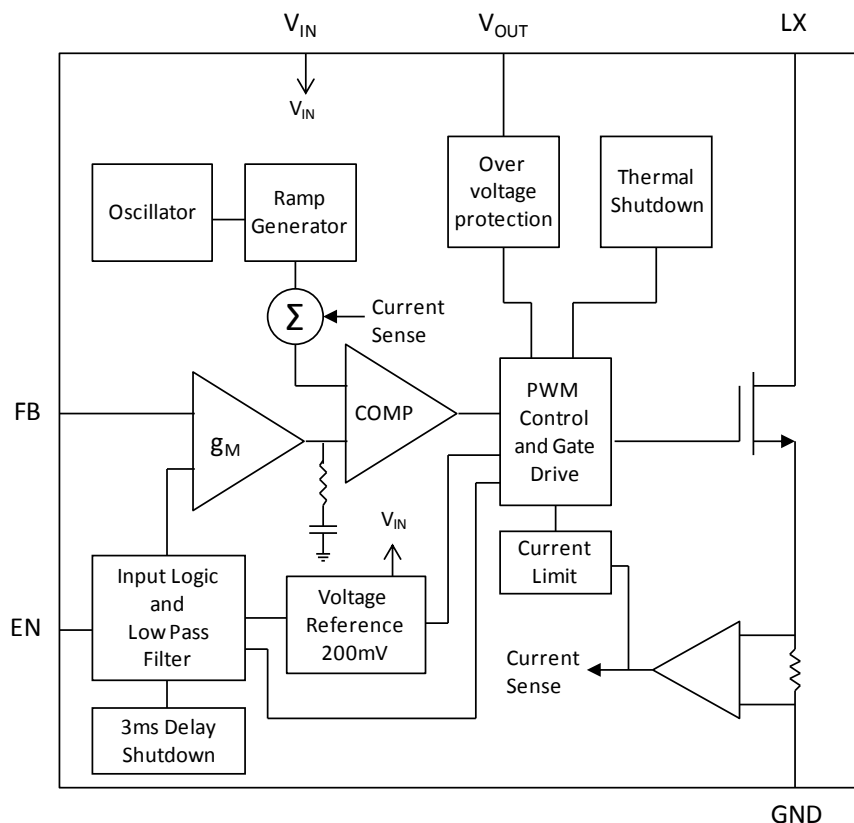
Turn On with LED Open (OVP)



EN PWM Dimming (20kHz)



Functional Block Diagram



Functional Description

The KTD2536 uses a constant-frequency current-mode boost converter architecture to control the LED current by regulating the feedback voltage. Please refer to the functional block diagram above for an explanation of KTD2536 operation. The beginning of each cycle turns on the Power MOSFET. A slope compensation ramp is added to the output of the current sense amplifier and the result is fed into the positive input of the comparator (COMP). When this voltage goes above the output voltage of the error amplifier (g_M), the Power MOSFET is turned off. The voltage at the output of the g_M block amplifies the difference between the reference voltage and the feedback voltage (V_{FB}), so that FB pin voltage can be regulated to the reference voltage.

The KTD2536 has built-in soft-start to limit the inrush current during startup and to limit the amount of overshoot on the output. Protection features in the KTD2536 include over-voltage protection (OVP), cycle-by-cycle current limit protection and thermal shutdown. OVP protects in the event where an LED fails open, which forces the feedback voltage to zero. This causes the boost converter to operate in maximum duty cycle mode, ramping up the output voltage. Switching will stop when the output reaches the OVP threshold. The OVP feature protects the IC from damaging itself by exceeding the voltage rating on LX/VOUT pins.

Application Information

Inductor Selection

A 4.7 μ H to 22 μ H inductor is recommended for 6/5/4-Series LED applications and 3S8P LED applications. For 7 or more LEDs in series, 4.7 μ H to 10 μ H inductor is recommended. If high efficiency is a critical requirement, a low DCR inductor should be selected. The inductor's saturation current rating should also exceed the peak input current, especially for high load current application (like 3S8P).

Table 1. Recommended Inductor Part Numbers

Inductor Part Number	Value (μ H)	DCR (Ω)	Saturation Current (A)	Dimensions (mm)	Manufacturer
VLF4012AT-100MR79	10	0.35	0.79	3.5 x 3.7 x 1.2	TDK
VLF4014AT-100MR90	10	0.26	0.9	3.5 x 3.7 x 1.4	TDK
LPS4018-103ML	10	0.200 max	1.3	4 x 4 x 1.8	Coilcraft
VLCF5020T-100MR	10	0.182 max	1.13	5 x 5 x 2.0	TDK
LQH55DN220M03L	22	0.19	1.2	5.7 x 5.0 x 4.7	Murata
744043220	22	0.185	0.7	4.8 x 4.8 x 2.8	Würth Elektronik

Capacitor Selection

Small size X5R/X7R ceramic capacitors are ideal for the KTD2536 application. A 10 μ F input capacitor and a 0.47 μ F output capacitor are suggested for 10/8/6-Series LED applications. For high output current applications like 3S8P, larger value output capacitors of 2.2 μ F is recommended to minimize the output ripple.

Table 2. Recommended Ceramic Capacitor Vendors

Manufacturer	Website
Murata	www.murata.com
AVX	www.avx.com
Taiyo Yuden	www.t-yuden.com

Diode Selection

Using a schottky diode is recommended in KTD2536 applications because of its low forward voltage drop and fast reverse recovery time. The current rating of the schottky diode should exceed the peak current of the boost converter. The voltage rating should also exceed the target output voltage.

Table 3. Recommended Schottky Diodes

Application	Schottky Diode Part Number	Forward Voltage (V)	Forward Current (mA)	Reverse Voltage (V)	Manufacturer
up to 10 series LEDs	PMEG4010	0.54	1000	40	NXP
4/5/6-series LEDs, 19V/24V OVP	B130	0.52	1000	30	Vishay
8/10-series LEDs, 36V OVP	B150	0.75	1000	50	Vishay

Typical Application Circuits

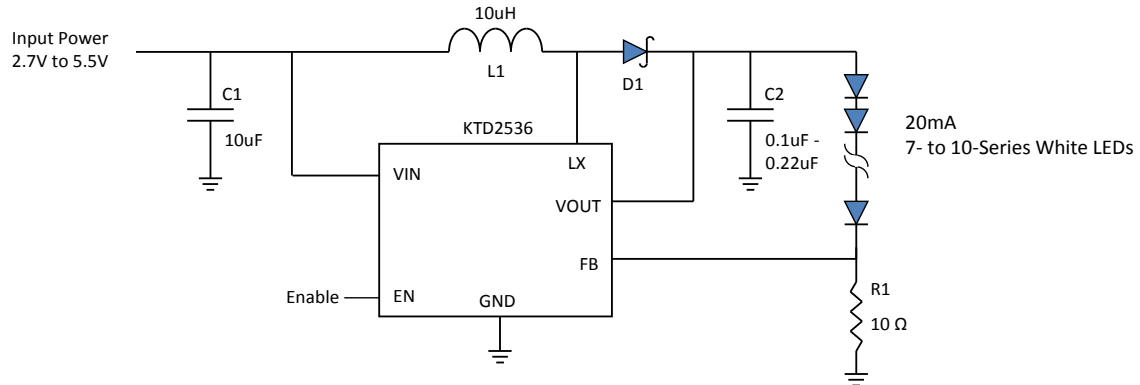


Figure 1. Driving Up to 10 LEDs in Series at 20mA Current

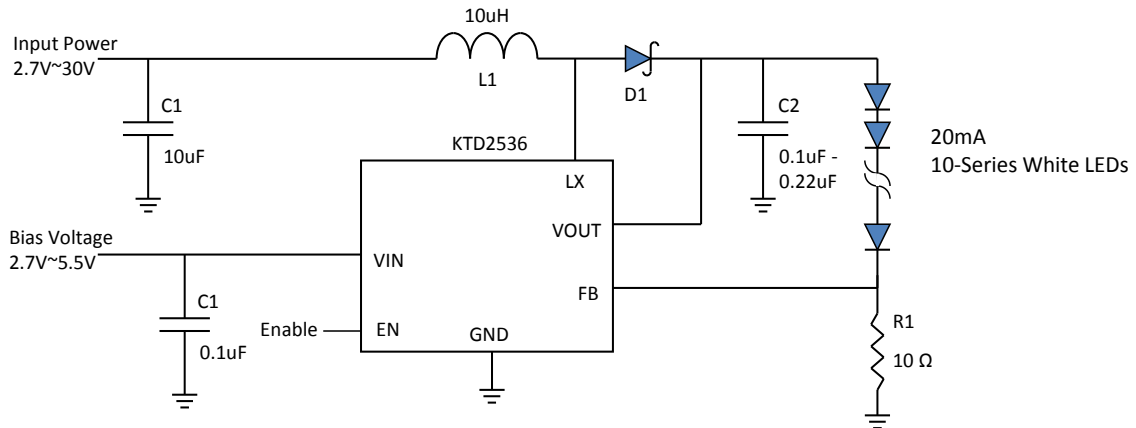


Figure 2. Driving 10 LEDs in Series from Higher Voltage Supply

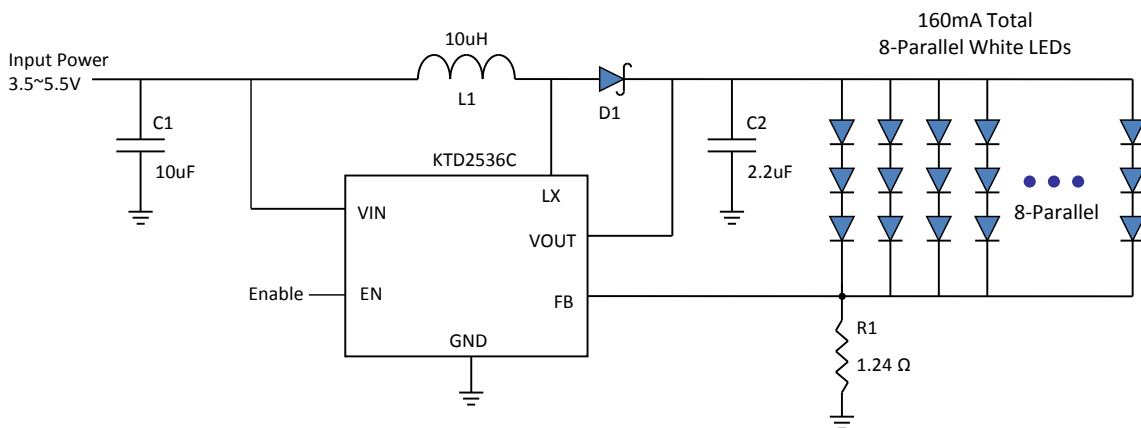


Figure 3. Driving 24 LEDs at 160mA Total Current (3-Series, 8-Parallel)

LED Current Setting

The LED current is determined by the feedback resistor R1. The feedback voltage (V_{FB}) is internally set at 200mV. The LED current is programmed according to the formula $I_{LED} = V_{FB} / R1 = 200mV / R1$. For accurate LED current settings, precision 1% resistors are recommended. The formula and table for R1 selection are shown below.

$$R1 = 200mV / I_{LED}$$

Table 4. Current Setting Resistor (1% Values)

R1 (Ω) 1% Values	LED Current (mA)
200	1
40.2	5
20.0	10
13.3	15
10.0	20
6.65	30
2.00	100
1.33	150
1.00	200
0.768	260

LED Dimming Control

Below there are five different LED dimming control methods described:

1. Using a PWM Signal to EN Pin

With the PWM signal applied to the EN pin, the KTD2536 is correspondingly turned ON or OFF by the PWM signal. The LEDs alternate between zero and full programmed current. The average LED current increases proportionally with the duty cycle of the PWM signal. A 0% duty cycle PWM signal will turn off the KTD2536 and corresponds to zero LED current. A 100% duty cycle PWM signal turns on the LEDs continuously at full current. The typical frequency range of the PWM signal is 100Hz to 200kHz. The magnitude of the PWM signal should be higher than the minimum EN voltage HIGH specification. The KTD2536 has an internal RC filter which creates a DC average of the PWM duty cycle. The -3dB cutoff frequency of the low pass filter is 360Hz. PWM control signals with low frequencies will not be filtered which means a PWM ripple can pass to the output; however, the average output current is continuously proportional to the PWM control signal regardless of the ripple amplitude. For systems which are sensitive to audible noise, it is recommended to use PWM frequencies greater than 5kHz.

2. Using a DC Voltage

For some applications, the preferred method of brightness control is a variable DC voltage to adjust the LED current. The dimming control using a DC voltage is shown in Figure 4. As the DC voltage increases, the voltage drop on R2 increases and the voltage drop on R1 decreases. Thus, the LED current decreases. The selection of R2 and R3 should make the current from the variable DC source much smaller than the LED current and much larger than the FB pin leakage current. The formula for LED current is

$$I_{LED} = \left(1 + \frac{R2}{R3}\right) \times \frac{V_{FB}}{R1} - \frac{R2}{R3} \times \frac{V_{DC}}{R1}$$

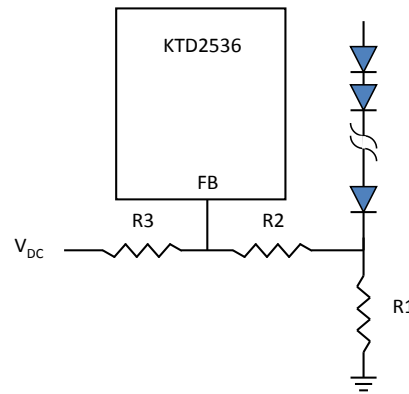


Figure 4. Dimming Control using a DC voltage

3. Using a Filtered PWM Signal

The filtered PWM signal can be considered as an adjustable DC voltage. It can be used to replace the variable DC voltage source in dimming control. The circuit is shown in Figure 5. This method can be used for higher frequency PWM signals compared to method #1 above. The magnitude of the PWM signal will affect the final result. The formula for LED current is

$$I_{LED} = \left(1 + \frac{R2}{R3 + R4} \right) \times \frac{V_{FB}}{R1} - \frac{R2}{R3 + R4} \times \frac{A_{PWM} \cdot D_{PWM}}{R1},$$

where A_{PWM} is the magnitude of the PWM signal, and D_{PWM} is the duty cycle of the PWM signal. This method doesn't have a PWM frequency upper limit, but the minimum PWM duty cycle requirement must be considered from system standpoint when the PWM frequency is high. The lower limit of the PWM frequency is controlled by the RC filter, PWM frequency should be higher than the cutoff frequency of the RC filter.

The following example in Figure 5 shows the LED current dimming range from 0mA to 22mA. The PWM frequency range can vary from 200Hz to 100kHz. In this example, the PWM signal voltage is 0V to 2.5V, 0% duty cycle results in maximum LED current of 22mA, and 95% duty cycle or more results in 0mA LED current. Figure 6 shows the PWM dimming linearity test result with 1kHz PWM frequency. Figure 7 shows the LED current across a range of PWM frequency.

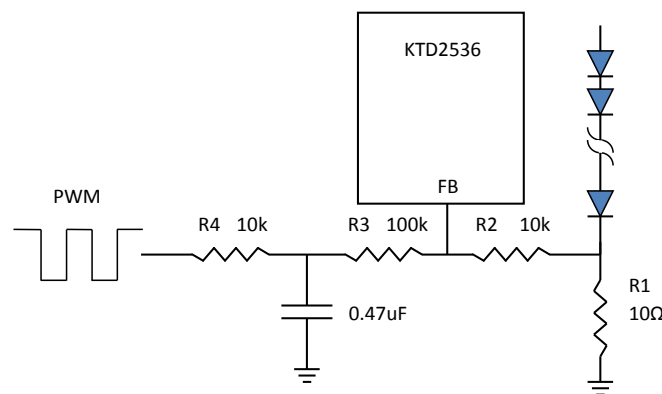


Figure 5. Dimming Control using an RC Filtered PWM Signal



Figure 6. RC Filtered PWM Dimming Linearity (1kHz)

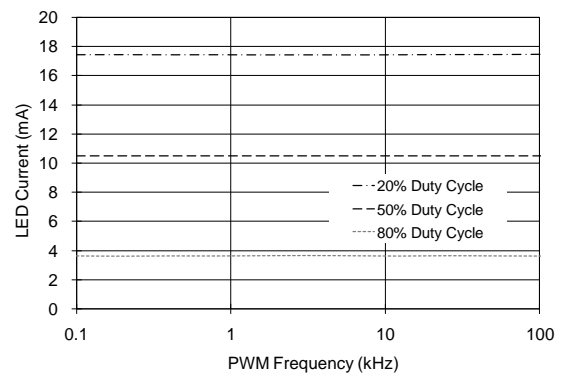


Figure 7. LED Current vs RC Filtered PWM Frequency

4. Using a Logic Signal

For applications that need to adjust the LED current in discrete steps, a logic signal can be used as shown in Figure 8. R1 sets the minimum LED current (when the NMOS is off). R3 sets how much the LED current increases when the NMOS is turned on. The $R_{DS(ON)}$ of the NMOS should be much smaller than R3 in this method.

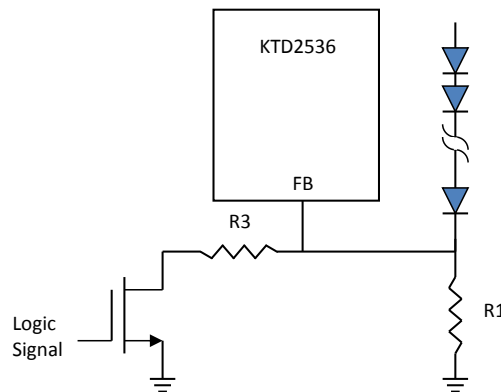


Figure 8. Dimming Control using a Logic Signal

5. Using a Current Sink IC

For applications which do not have PWM or DC dimming signals available or need the highest accuracy at low currents, KTD100 series IC can be used as a current sink to replace the sensing resistor as shown in Figure 9. LED current is regulated by the current sink IC, and system can take advantage of the single wire interface of the current sink IC to program the LED current in 32 steps. The current sink IC's sink node should be connected to KTD2536's FB pin. The boost converter will regulate the FB pin voltage at 200mV nominal, which is high enough for the current sink IC to regulate the sink current. To increase the maximum LED current, sink channels can be connected together. Table 2 lists KTD100 series current sink ICs available for this application.

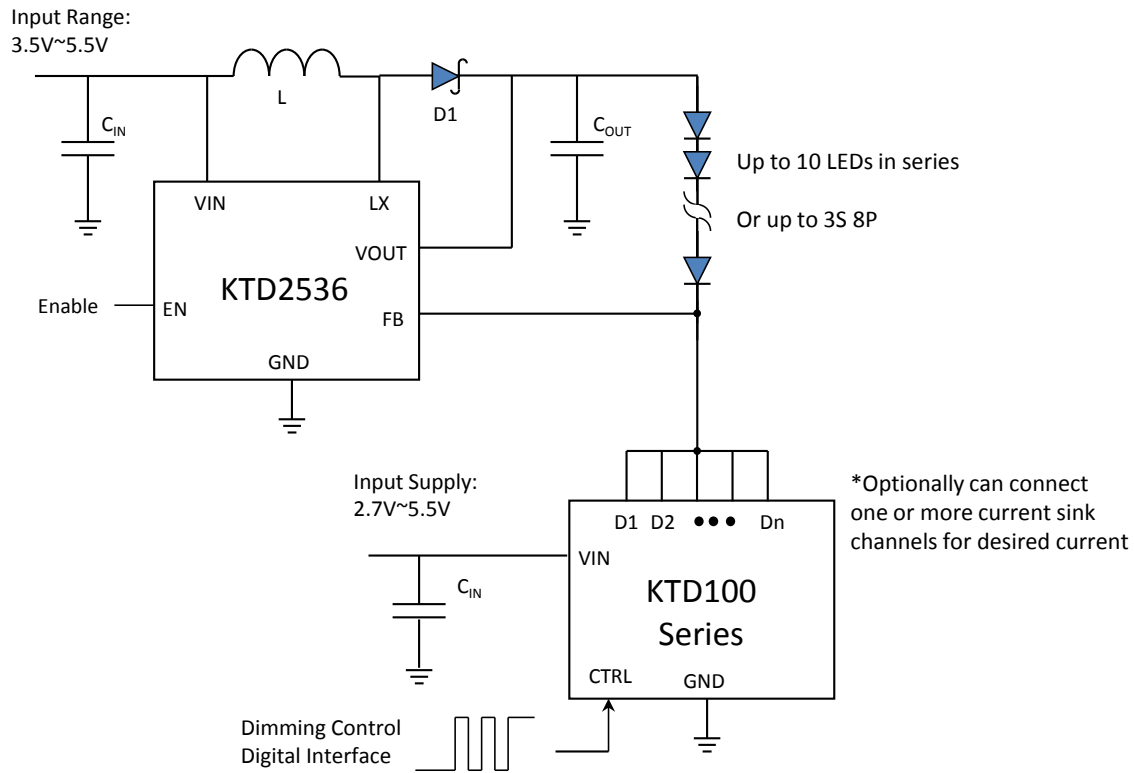


Figure 9. Dimming Control using Digital Serial Interface

Table 5. KTD100 Series Current Sink ICs for use with Dimming Control Method #5

Part Number	Max. Current/Channel (mA)	Number of Channels	Current Steps
KTD101	20	2	32
KTD102	26.75	3	32
KTD104	26.75	4	32
KTD105	26.75	5	32
KTD112	60	5	32
KTD117	26.75	6	32

Layout Considerations

PCB layout is very important for high frequency switching regulators in order to keep the loop stable and minimize noise. The input capacitor should be very close to the IC to get the best decoupling. The path of the inductor, schottky diode and output capacitor should be kept as short as possible to minimize noise and ringing. FB is a sensitive node and it should be kept separate from the LX switching node in the PCB layout.

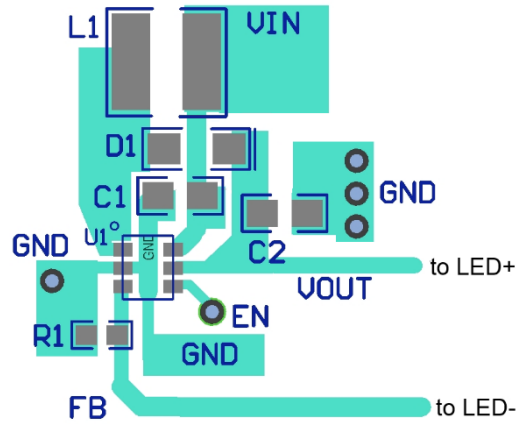
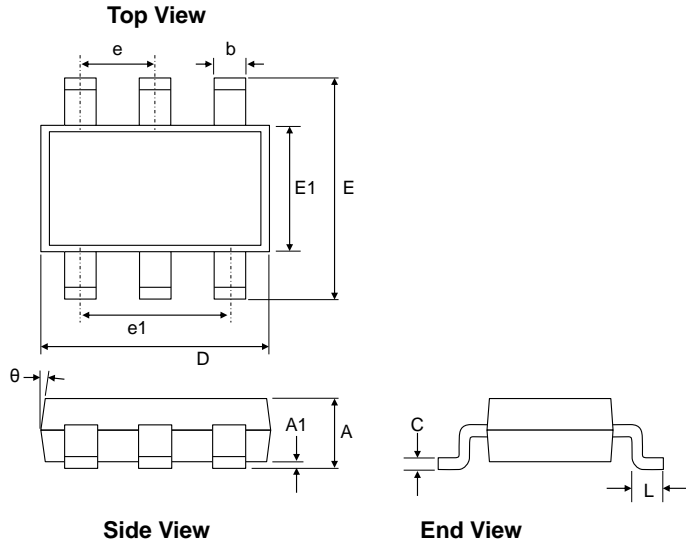


Figure 10. Recommended PCB layout

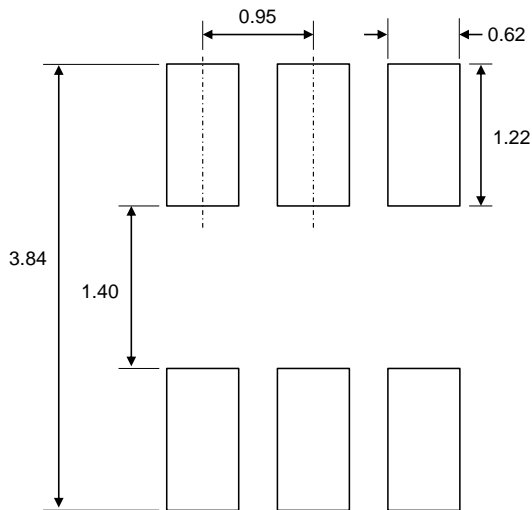
Packaging Information

TSOT23-6



Dimension	mm		
	Min.	Typ.	Max.
A	0.60	0.85	1.10
A1	0.00	0.05	0.10
b	0.30	0.40	0.50
c	0.10	0.15	0.20
D	2.70	2.90	3.10
E	2.60	2.80	3.00
E1	1.40	1.60	1.80
e	0.95BSC		
e1	1.9BSC		
L	0.30		0.60
θ	4°		12°

Recommended Footprint



* Dimensions are in millimeters.

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