HT7L5502/HT7L5503
Primary-Side Regulation Dimmable LED Driver with Active PFC

Features

- Primary-side current regulation without secondary-side feedback circuitry
- Power factor higher than 0.9
- Compatible with wide dimming range
    - ♦ PWM dimming range: 5%~100%
    - ♦ Analog dimming range: 10%~100%
- Tight LED constant current regulation of ±3%
- Line compensation for enhanced LED current accuracy
- Constant voltage regulation when LED is turned off
- Full protection functions for enhanced safety
    - ♦ Output over voltage protection
    - ♦ Output short-circuit protection
    - ♦ VCC over voltage protection
    - ♦ VCC under voltage lockout
    - ♦ External/internal over temperature protection
- Package type: 8-pin SOP

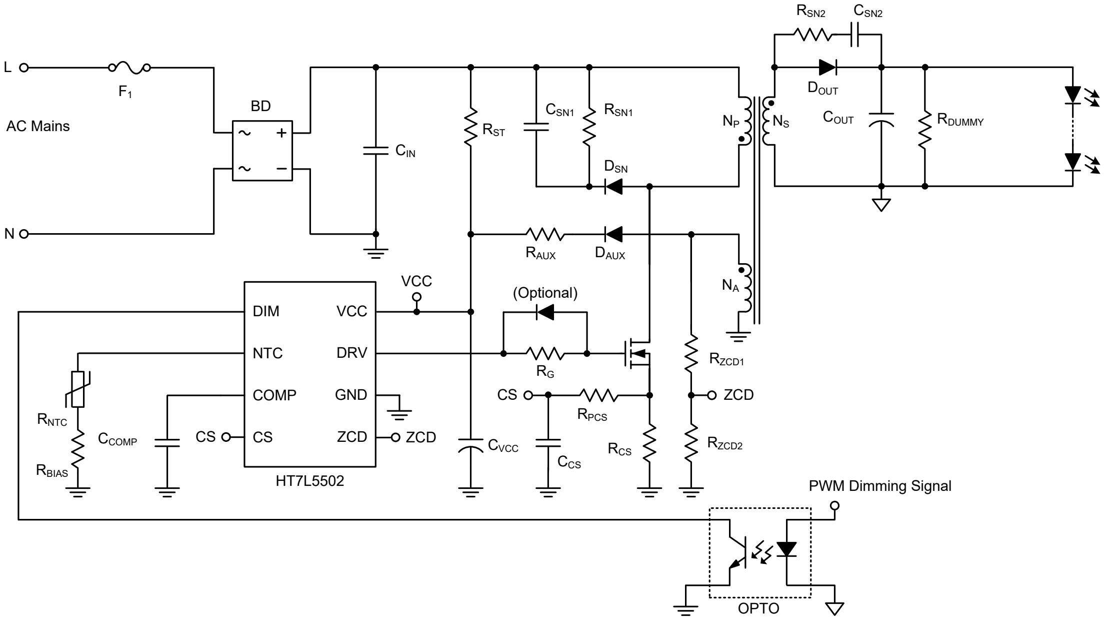
Applications

- General illumination
- E26/27, T5/T8 LED lamps
- Smart lighting applications

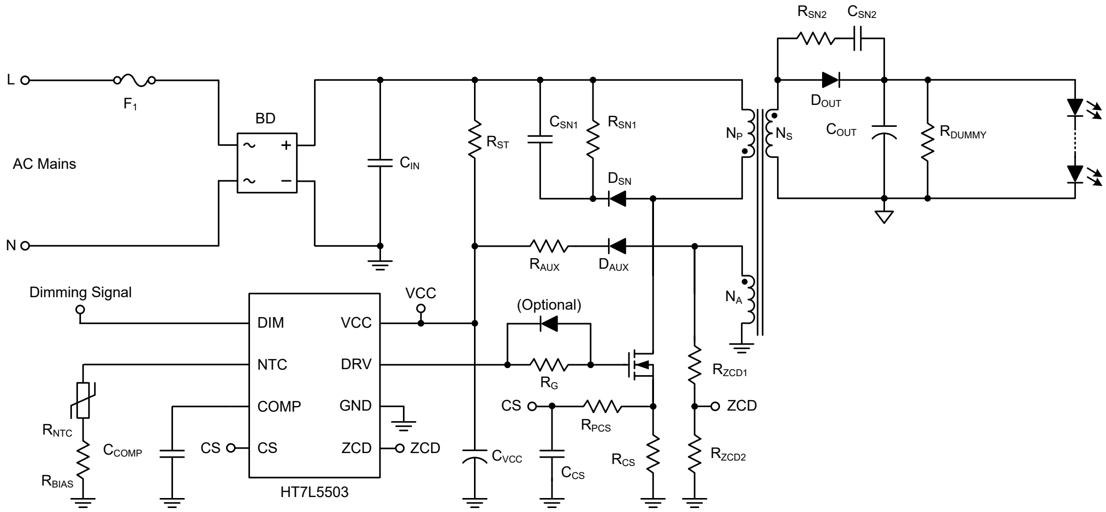
General Description

The HT7L5502/03 is a controller for implementing constant current LED driver with power factor correction (PFC). By using primary-side regulation, it controls the LED output current accurately without the need of secondary-side feedback components. The HT7L5502/03 operates in the quasi-resonant mode to achieve higher efficiency. The output current can be modulated by the DIM pin. The HT7L5502/03 integrates robust protection functions, including output over voltage protection, output short-circuit protection (SCP), VCC over voltage protection, VCC under voltage lockout and over temperature protection (OTP).

Typical Application Circuit

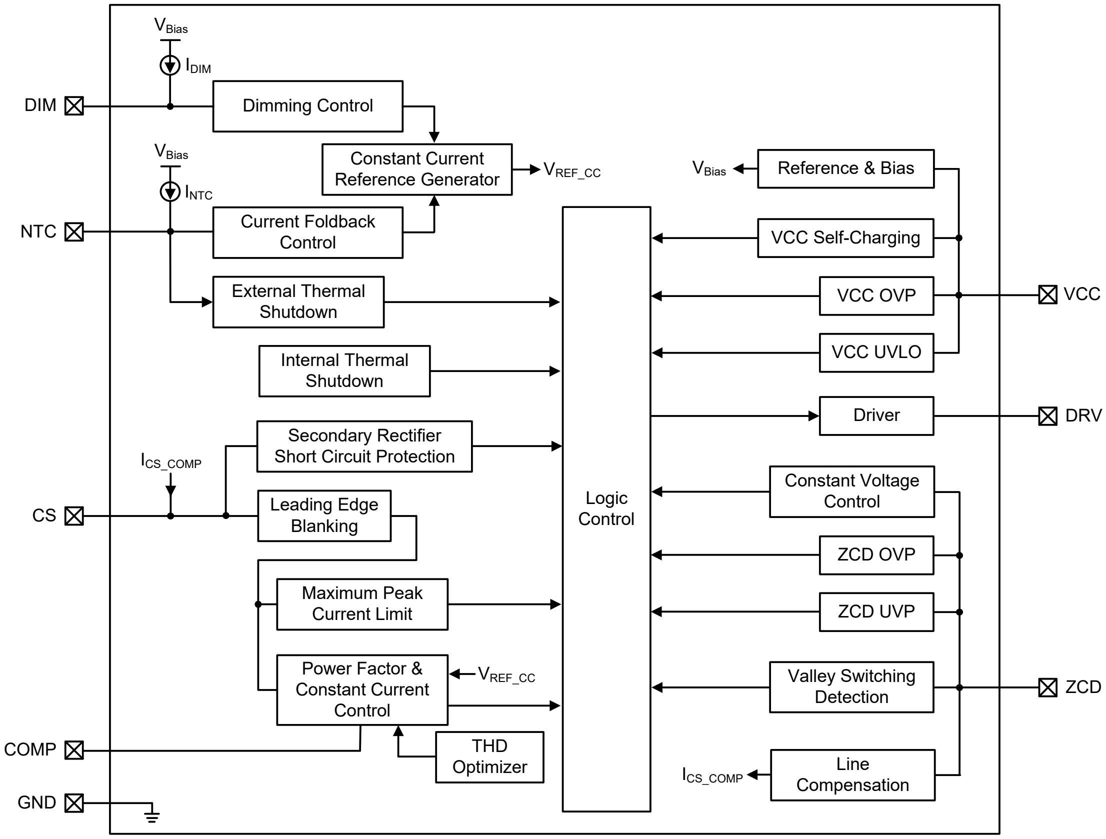


HT7L5502 Application Circuit for Dimming Signal from Secondary-Side

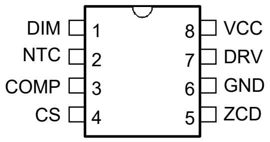


HT7L5503 Application Circuit for Dimming Signal from Primary-Side

Block Diagram



Pin Assignment



HT7L5502/HT7L5503
8 SOP-A

Pin Description

Pin No.	Pin Name	Type	Pin Description
1	DIM	I	Dimming signal input
2	NTC	I	Connect an NTC resistor to this pin for programmable thermal protection
3	COMP	I	Loop compensation pin. A capacitor should be placed between COMP and GND
4	CS	I	Current sense pin. A resistor is connected to sense the MOSFET's current
5	ZCD	I	Connected to a resistor divider from the auxiliary winding to sense the valley and the output voltage
6	GND	G	Ground pin
7	DRV	O	Gate driver output for driving the external power MOSFET
8	VCC	P	Power supply input

Legend: I=Input, O=Output, P=Power, G=Ground.

Absolute Maximum Ratings

Parameter		Value	Unit
VCC Supply Voltage, VCC to GND		-0.3 ~ +48	V
DRV to GND		-0.3 ~ +20	V
COMP, DIM, NTC, ZCD, CS to GND		-0.3 ~ +6	V
Maximum Junction Temperature		+150	°C
Lead Temperature (Soldering 10sec)		+260	°C
Storage Temperature Range		-60 ~ +150	°C
ESD Susceptibility	Human Body Model	±2000	V
	Machine Model	±200	V

Recommended Operating Range

Parameter	Value	Unit
VCC Supply Voltage	10 ~ 40	V
Ambient Temperature	-40 ~ 105	°C

Electrical Characteristics

V_{CC}=15V, Ta=25°C

Symbol	Parameter		Test Conditions	Min.	Typ.	Max.	Unit
Supply Voltage							
V_{CC_OVP}	VCC Over Voltage Protection		—	—	44	—	V
V_{CC_ON}	VCC Turn-On Threshold Voltage		—	—	18	—	V
V_{CC_OFF}	VCC Turn-Off Threshold Voltage		—	—	7.5	—	V
V_{CC_ET}	Entry VCC Self-Charging Threshold Voltage		V_{CC} Falling	—	8.5	—	V
V_{CC_EX}	Exit VCC Self-Charging Threshold Voltage		V_{CC} Rising	—	9	—	V
I_{CC_ST}	Start-up Current		$V_{CC} = V_{CC\_ON}$ - 1V	—	10	—	μA
I_{CC_QU}	Quiescent Current		ZCD Pin and DRV Pin Open Circuit	—	1.2	—	mA
Constant Current Control							
V_{REF_MAX}	Constant Current Maximum Reference Voltage		—	—	300	—	mV
V_{CS_MAX}	Maximum Current Sense Limit Voltage for Over Load Protection		$V_{ZCD} > V_{ZCD\_UVP}$	—	1.55	—	V
V_{CS_MIN}	Minimum Current Sense Limit Voltage for Output Under Voltage Protection		$V_{ZCD} \le V_{ZCD\_UVP}$ or $V_{DIM} \le V_{DIM\_DIS}$	—	0.4	—	V
t_{LEB}	Leading Edge Blanking Time		—	—	400	—	ns
t_{D_OCP}	Over Current Protection Debounce Time		$V_{COMP} \ge 4.8V$	—	100	—	ms
Zero Current and Output Voltage Detector							
V_{ZCD_OVP}	ZCD Pin Over Voltage Protection Threshold Voltage		—	—	3.6	—	V
V_{ZCD_CV}	Constant Voltage Threshold Voltage		—	—	0.8	—	V
V_{ZCD_UVP}	ZCD Pin Under Voltage Protection Threshold Voltage		—	—	0.6	—	V
t_{D_ZCDUVP}	ZCD Pin Under Voltage Protection Debounce Time		—	—	16	—	ms
t_{BK_ZCD}	ZCD Pin Blanking Time		$V_{CS\_PK} \ge 150mV$	—	1.12	—	μs
			$V_{CS\_PK} < 150mV$	—	0.77	—	μs
Timing Control							
t_{OFF_CCMIN}	Minimum Off Time for CC Mode	CC Mode	$V_{DIM} > V_{DIM\_DIS}$	—	2.2	—	μs
t_{OFF_CCMAX}	Maximum Off Time for CC Mode		$V_{DIM} > V_{DIM\_DIS}$	—	150	—	μs
t_{OFF_GM}	Green Mode Fixed Off Time for CV Mode	CV Mode	$V_{DIM} < V_{DIM\_DIS}$	—	40	—	μs
t_{OFF_STMAX}	Maximum Start Timer Period for CV Mode		$V_{DIM} < V_{DIM\_DIS}$	—	10	—	ms
t_{ON_MAX}	Maximum On Time		—	—	22	—	μs
Gate Driver							
I_{DRV_SOURCE}	DRV Pin Source Current		—	—	400	—	mA
I_{DRV_SINK}	DRV Pin Sink Current		—	—	500	—	mA
V_{DRV_CLAMP}	DRV Pin Clamp Voltage		—	—	12	—	V
Dimming Control							
V_{DIM_OP}	DIM Pin Open Voltage		—	—	5.4	—	V
V_{DIM_HIGH}	DIM Pin High Threshold Voltage		—	—	3	—	V
V_{DIM_LOW}	DIM Pin Low Threshold Voltage		—	—	300	—	mV
V_{DIM_DIS}	DIM Pin Disable Threshold Voltage		—	—	250	—	mV
t_{D_DIMDIS}	DIM Pin Disable Debounce Time		—	—	15	—	ms

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{DIM}	DIM Pin Current Source	For HT7L5502	—	1	—	mA
		For HT7L5503	—	10	—	μA
Current Foldback with Thermal Regulation						
V_{NTC_OP}	NTC Pin Open Voltage	—	—	3.7	—	V
I_{NTC}	NTC Pin Current Source	—	—	85	—	μA
V_{CF_START}	Start Current Fold-back Threshold Voltage	—	—	1.0	—	V
V_{CF_STOP}	Stop Current Fold-back Threshold Voltage	—	—	0.5	—	V
V_{NTC_RESET}	External Thermal Shutdown Reset Voltage	—	—	1.0	—	V
t_{D_NTCSD}	NTC Pin Thermal Shutdown Debounce Time	—	—	16	—	ms
Internal Over Temperature Protection						
T_{OTP_SD}	Internal Thermal Shutdown Protection	—	—	150	—	°C
T_{OTP_SDHYS}	Internal Thermal Shutdown Protection Hysteresis	—	—	25	—	°C

Functional Description

The HT7L5502/03 is a dimmable constant current LED controller designed for isolated LED lighting applications. The controller can achieve high power factor values and low total harmonic distortion (THD) values without additional circuits and can also generate high accuracy LED driving currents with very few external components.

LED Current Setting

The HT7L5502/03 regulates the LED current (I_{LED}) by sensing the primary-side information. The maximum LED current (I_{LED_MAX}) can be calculated by the following equation:

$$I_{LED\_MAX} \approx \frac{1}{2} \times \frac{V_{REF\_MAX}}{R_{CS}} \times \frac{N_P}{N_S}$$

where N_P is the turns of the primary winding, N_S is the turns of the secondary winding, V_{REF_MAX} is the maximum current reference voltage for I_{LED_MAX}, and R_{CS} is the external current sensing resistor.

Dimming Function

The HT7L5502/03 provides the analog and PWM dimming functions on the DIM pin. If the average voltage on the DIM pin (V_{DIM}) is within V_{DIM_HIGH} and V_{DIM_LOW}, the I_{LED} is linearly proportional to V_{DIM}. The I_{LED} of analog dimming can be expressed as:

$$I_{LED} = I_{LED\_MAX} \qquad \text{if } V_{DIM} \geq V_{DIM\_HIGH}$$

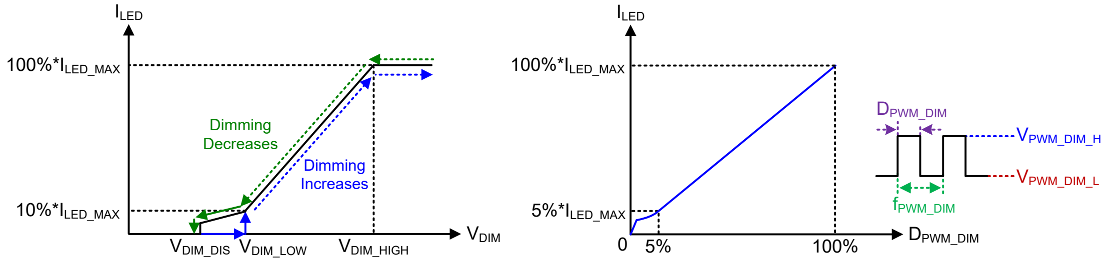
$$I_{LED} = \frac{V_{DIM}}{V_{DIM\_HIGH}} \times I_{LED\_MAX} \qquad \text{if } V_{DIM\_HIGH} > V_{DIM} > V_{DIM\_DIS}$$

For better dimming performance at the analog low dimming level, a 0.1μF capacitor is recommended to be placed between the DIM pin and GND. If the DIM pin inputs the PWM signal directly, it is recommended that the high-level voltage ($V_{PWM\_DIM\_H}$) is 3.3V and the low-level voltage ($V_{PWM\_DIM\_L}$) is 0V. The PWM frequency (f_{PWM_DIM}) is between 500Hz and 1kHz. When the PWM duty cycle (D_{PWM_DIM}) is reduced from 100% to 5%, the I_{LED} is decreased from 100% to 5% of I_{LED_MAX}, the I_{LED} is linearly proportional to D_{PWM_DIM}. The I_{LED} of PWM dimming can be expressed as:

$$I_{LED} = D_{PWM\_DIM} \times I_{LED\_MAX} \qquad \text{if } 100\% \geq D_{PWM\_DIM} \geq 5\%$$

Note that when the PWM duty cycle is lower than 5%, the LED current will not be proportional to it. In addition, to have a good LED current regulation and prevent flicker, it is recommended to power the dimming controller (ex. MCU) through another power supply. If V_{DIM} is lower than the dimming disable threshold voltage (V_{DIM_DIS})

for a period of t_{D_DIMDIS}, the HT7L5502/03 will enter the constant-voltage regulation mode until V_{DIM} is higher than V_{DIM_LOW}. If DIM pin is open, the V_{DIM} will be pulled up to the internal bias voltage, and output a current of I_{LED_MAX}. The analog and PWM dimming curves are shown below.



(a) Analog Dimming Curve **(b) PWM Dimming Curve**

LED Dimming Curves

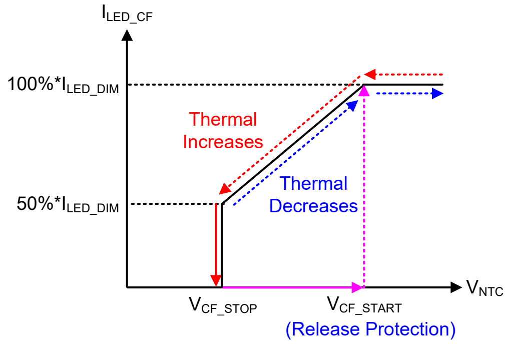
Current Foldback with Thermal Regulation

The HT7L5502/03 provides an NTC pin to limit the maximum output current with an external 100kΩ NTC resistor. In response to a high temperature, the maximum output current is clamped by the foldback current I_{LED_CF}. As shown in the figure below, for PWM dimming applications, the LED current is gradually reduced according to the decreasing of V_{NTC}. The foldback current (I_{LED_CF}) can be determined by the following equation:

$$I_{LED\_CF} = I_{LED\_DIM} \qquad \text{if } V_{NTC} \geq V_{CF\_START}$$

$$I_{LED\_CF} = \frac{V_{NTC}}{V_{CF\_START}} \times I_{LED\_DIM} \qquad \text{if } V_{CF\_START} > V_{NTC} > V_{CF\_STOP}$$

When V_{NTC} reaches the thermal shutdown threshold voltage V_{CF_STOP} for t_{D_NTCSD}, the controller will enter the auto-recovery mode until V_{NTC} is higher than V_{CF_START}.



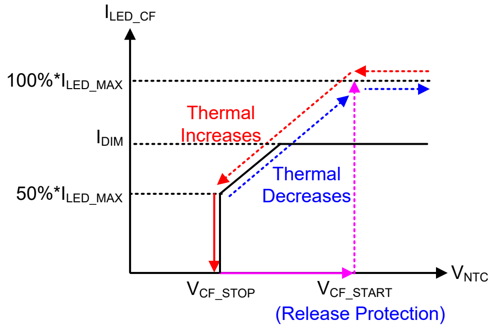
LED Current Foldback Curve – PWM Dimming

As shown in the following figure, for analog dimming applications, when V_{NTC} is decreasing, the LED current (I_{DIM}) is not clamped until it is higher than the foldback current (I_{LED_CF}). I_{LED_CF} can be determined by the following equation:

$$I_{LED\_CF} = I_{LED\_MAX} \qquad \text{if } V_{NTC} \geq V_{CF\_START}$$

$$I_{LED\_CF} = \frac{V_{NTC}}{V_{CF\_START}} \times I_{LED\_MAX} \qquad \text{if } V_{CF\_START} > V_{NTC} > V_{CF\_STOP}$$

When V_{NTC} reaches the thermal shutdown threshold voltage V_{CF_STOP} for t_{D_NTCSD}, the controller will enter the auto-recovery mode until V_{NTC} is higher than V_{CF_START}.



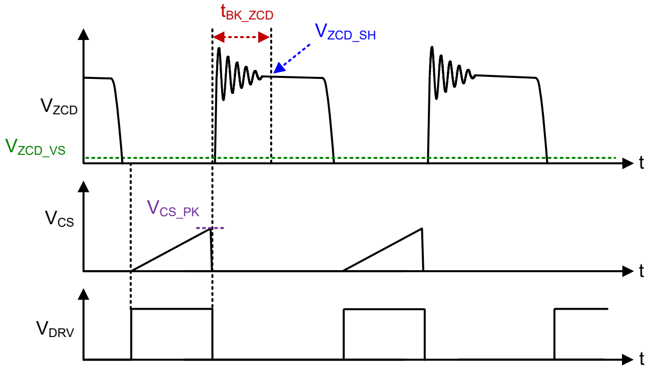
LED Current Foldback Curve – Analog Dimming

Constant Voltage Control

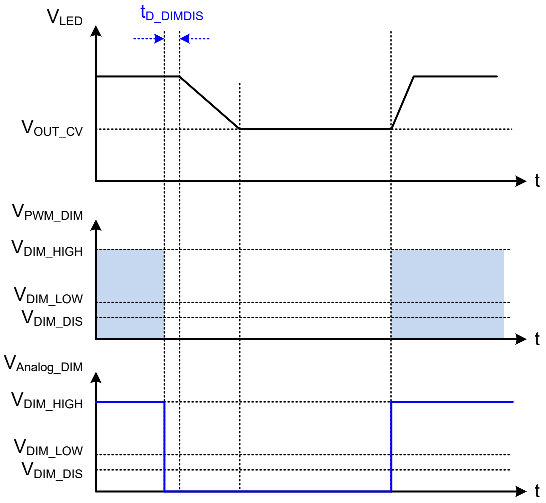
When the V_{DIM} is lower than V_{DIM_DIS} for t_{D_DIMDIS}, the HT7L5502/03 will enter the constant voltage mode, and the output voltage is regulated by sensing the ZCD voltage (V_{ZCD_SH}). The following first figure shows that the ZCD pin samples the V_{ZCD} after the blanking time (t_{BK_ZCD}) when the MOSFET is turned off. The t_{BK_ZCD} is adjusted by the peak current voltage of the CS pin (V_{CS_PK}), and the output voltage can be adjusted by R_{ZCD1} and R_{ZCD2} as shown in the application circuit. Therefore, the output constant voltage (V_{OUT_CV}) can be designed by the following equation:

$$V_{OUT\_CV} = V_{ZCD\_CV} \times (1 + \frac{R_{ZCD1}}{R_{ZCD2}}) \times \frac{N_S}{N_A} - V_D$$

where N_S is the turns of the secondary winding, N_A is the turns of the auxiliary winding, and V_D is the forward voltage of the secondary-side rectifier diode. As shown in the following second figure, if V_{DIM} is lower than V_{DIM_DIS} for more than t_{D_DIMDIS}, the controller will enter the constant voltage operating mode. The controller will return to constant current operating mode immediately when V_{DIM} is higher than V_{DIM_LOW}.



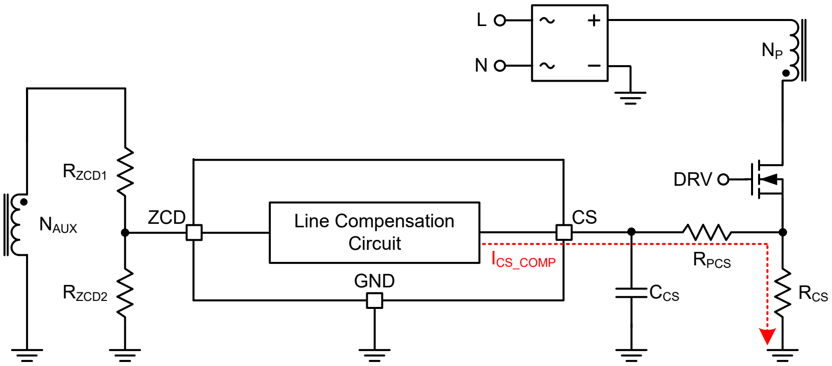
ZCD Pin Voltage Sampling Method



CC/CV Mode Operation

Line Compensation

When the MOSFET is turned off, the propagation delay under different input voltages will cause the CS pin voltage deviation (ΔV_{CS}), which will affect the LED current accuracy. The HT7L5502/03 has integrated a line compensation for current regulation errors due to different AC line inputs. As illustrated by the figure below, the input voltage is sensed by ZCD pin and converted to the current to CS pin. By adding an external compensation resistor (R_{PCS}) in series between the R_{CS} and CS pin, the voltage offset will be added to the CS pin and is proportional to the input voltage when the MOSFET is turned on.



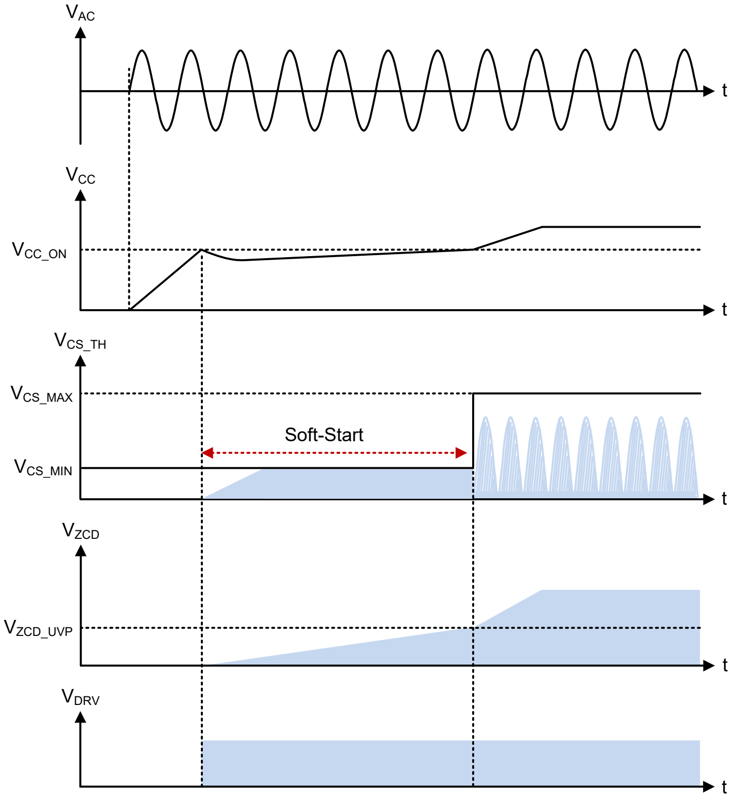
Line Compensation for LED Current Accuracy

Boundary Conduction Mode (BCM)

The power MOSFET is turned on by inductor current zero-crossing detection. When the inductor current is falling to the zero-crossing point, the voltage on the ZCD pin will detect the zero voltage and turn on the MOSFET. The BCM control provides low turn-on switching losses and high conversion efficiency.

Soft-Start

When the VCC pin reaches the turn-on threshold voltage (V_{CC_ON}) after power-on, the MOSFET will be turned on and the CS pin will set the minimum current sense threshold voltage (V_{CS_MIN}) to limit the power so as to reduce the voltage spike on the MOSFET. In the soft-start period, the on-time of DRV is determined by V_{CS_MIN} and the maximum off-time of QR operation is limited by t_{OFF_CCMAX}. When the V_{ZCD} is higher than V_{ZCD_UVP}, the controller will set the maximum current sense threshold voltage (V_{CS_MAX}) and operate in normal operation, as shown below. The on-time and minimum switching off-time of DRV is determined by V_{COMP}.



Waveform in Start-up Condition

VCC Self-Charging Mode

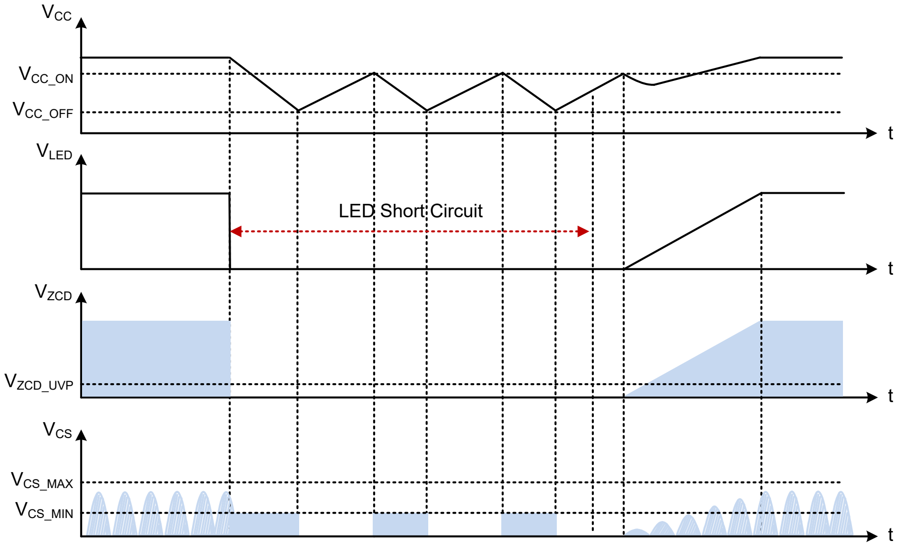
When the VCC pin voltage reaches the self-charging threshold voltage (V_{CC_ET}), the HT7L5502/03 will enter the VCC self-charging mode to charge VCC to avoid triggering VCC UVLO during start-up or light load. It is highly recommended to design the VCC operating voltage higher than V_{CC_ET} to avoid the output voltage out of regulation.

Over Current Protection (OCP)

The HT7L5502/03 includes an over current protection function on the CS pin. In normal operation, an internal circuit detects the current level and when the current is larger than the over current protection threshold level (V_{CS_MAX}), the MOSFET will be turned off.

Output Short Circuit Protection (SCP)

The HT7L5502/03 determines whether the LED is shorted by detecting V_{ZCD}. When the LED is short-circuited and the V_{ZCD} is lower than V_{ZCD_UVP}, the controller will set the current sense limit voltage to V_{CS_MIN} to limit a lower output power so as to protect the power components, as shown in the following figure.



Waveform in LED Short Circuit Condition

VCC Over Voltage Protection (VCC OVP)

In order to prevent PWM controller damage, the HT7L5502/03 integrates a VCC OVP function. When the VCC voltage is higher than the OVP threshold voltage (V_{CC_OVP}), the PWM controller will stop operating immediately. If the VCC voltage decreases below the UVLO threshold voltage (V_{CC_OFF}), the controller will reset.

VCC Under Voltage Lockout (VCC UVLO)

The HT7L5502/03 has an integrated UVLO function which includes a hysteresis of 10.5V (Typ.). The PWM controller will switch on when the VCC voltage exceeds V_{CC_ON}. It will switch off when the VCC voltage is less than V_{CC_OFF}. The wide hysteresis characteristics will ensure that the device can be powered by an input capacitor during start-up. When the output voltage increases to a certain value after start-up, the VCC will be charged through the auxiliary winding.

Internal Over Temperature Protection (In-OTP)

The HT7L5502/03 also has an internal over temperature protection (In-OTP). When the junction temperature exceeds the internal thermal shutdown temperature (T_{OTP_SD}), the controller will immediately turn off the DRV terminal. When the VCC decreases below the V_{CC_OFF}, the controller will reset.

Component Selection Guide

ZCD Divider Resistor

The upper resistor (R_{ZCD1}) of the voltage divider is determined by the following equation:

$$R_{ZCD1} = 335 \times \frac{N_A}{N_P} \times 10^3 \quad \Omega$$

where N_P is the turns of the primary winding and N_A is the turns of the auxiliary winding. The lower resistor (R_{ZCD2}) is determined by:

$$R_{ZCD2} = R_{ZCD1} / \left(\frac{(V_{OUT\_OVP} + V_D) \times N_A}{N_S \times V_{ZCD\_OVP}} - 1\right)$$

The ZCD pin senses the positive voltage of the auxiliary winding to detect the output over-voltage condition of V_{OUT}. When the sensed voltage is higher than V_{ZCD_OVP}, the IC stops switching.

NTC Resistor

An external NTC resistor is used to program the thermal shutdown temperature. With the internal current source (I_{NTC}) and the shutdown threshold (V_{CF_STOP}), a 5.8kΩ thermistor shutdown threshold is determined. If the NTC resistance stays lower than 5.8kΩ for more than t_{D_NTCSD}, the IC stops switching. The NTC resistance must increase to greater than 11.8kΩ to enter a normal start-up. The bias resistor (R_{BIAS}) is used to adjust the thermal shutdown temperature for different thermistors.

CS Compensation Resistor

The propagation delay (t_{PD}) of the IC and MOSFET leads to the ΔV_{CS} deviation, which can be calculated as:

$$\Delta V_{CS} = \frac{\sqrt{2}V_{AC} \times t_{PD} \times R_{CS}}{L_m}$$

in which L_m is the primary inductance. An internal current sourcing from the CS pin creates the offset voltage to compensate the propagation delay effect. In the beginning, the propagation compensation resistor can be calculated by:

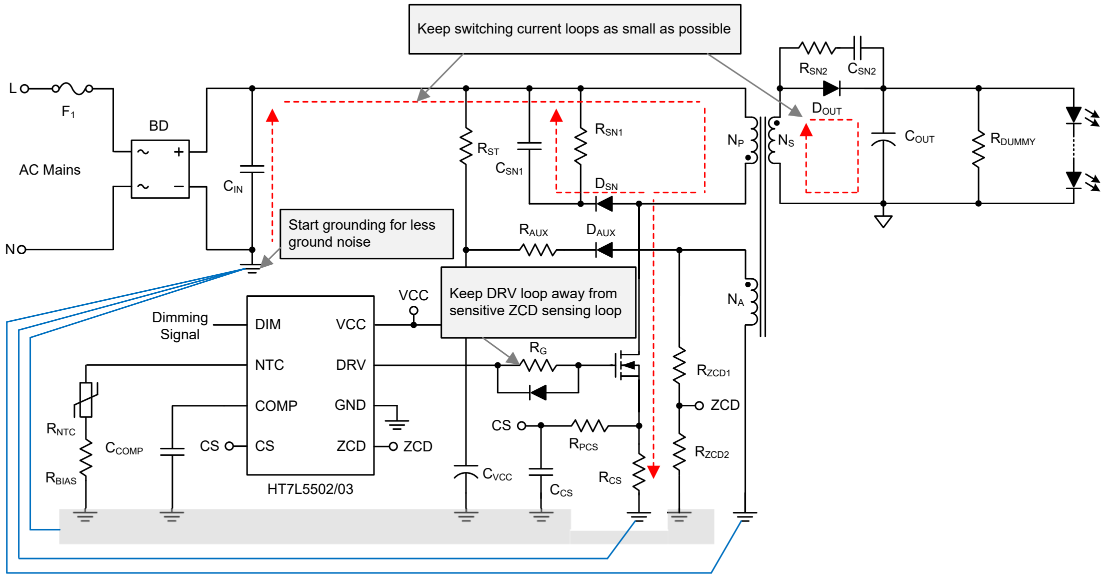
$$R_{PCS} = \frac{t_{PD} \times R_{CS} \times R_{ZCD1} \times N_P}{L_m \times 0.044 \times N_A}$$

If the LED current is higher at high line, increase R_{PCS}. Conversely, if the LED current is lower at high line, increase C_{CS}.

Layout Guide

When designing switching power supply, good layout can improve the system performance and reliability. The following layout practices are recommended.

- Keep switching current loops as small and straight as possible to decrease noise coupling.
- RCD snubber loop is a high switching loop. Keep it as small as possible.
- The DRV pin trace is also a high frequency loop. Keep it away from sensitive ZCD feedback loop.
- The resistor divider connected to ZCD is recommended to be placed beside the IC.
- Separate signal and power ground. Connect grounds close to C_{IN}.



Keep switching current loops as small as possible

Start grounding for less ground noise

Keep DRV loop away from sensitive ZCD sensing loop

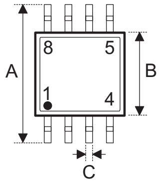
Package Information

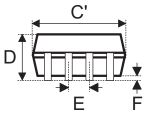
Note that the package information provided here is for consultation purposes only. As this information may be updated at regular intervals users are reminded to consult the Holtek website for the latest version of the Package/Carton Information.

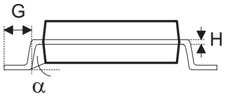
Additional supplementary information with regard to packaging is listed below. Click on the relevant section to be transferred to the relevant website page.

- Package Information (include Outline Dimensions, Product Tape and Reel Specifications)
- Packing Meterials Information
- Carton information

8-pin SOP (150mil) Outline Dimensions







Symbol	Dimensions in inch		
	Min.	Nom.	Max.
A		0.236 BSC	
B		0.154 BSC	
C	0.012	—	0.020
C′		0.193 BSC	
D	—	—	0.069
E		0.050 BSC	
F	0.004	—	0.010
G	0.016	—	0.050
H	0.004	—	0.010
α	0°	—	8°

Symbol	Dimensions in mm		
	Min.	Nom.	Max.
A		6.00 BSC	
B		3.90 BSC	
C	0.31	—	0.51
C′		4.90 BSC	
D	—	—	1.75
E		1.27 BSC	
F	0.10	—	0.25
G	0.40	—	1.27
H	0.10	—	0.25
α	0°	—	8°

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