CR1510

Off-Line Digital Green-Mode LED Driver Integrated with Power BJT

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1.0 Features

- No-load power consumption < 30mW at 230V_{AC} with typical application circuit

- Supports universal input voltage range (90V_{AC} to 277V_{AC})

- Isolated design without opto-coupler

- Internal 750V power bipolar junction transistor (BJT)

- Very tight LED current regulation (±5%) across line and load, and within primary inductance tolerance (±20%)

- Supports wide range of capacitive loads (from 33µF to 2000µF or higher)

- **EZ-EMI®** design enhances manufacturability

- Intrinsically low common mode noise

- Adaptively controlled soft start-up enables fast and smooth LED current start-up

- Optimized 64kHz maximum PWM switching frequency achieves best size and efficiency

- Quasi-resonant operation for highest overall efficiency

- Dynamic base current control to drive internal BJT

- No external compensation components required

- Built-in short circuit protection and output overvoltage protection

- No audible noise over entire operating range

2.0 Description

The CR1510 is a high performance AC/DC power supply control device which uses digital control technology to build peak current mode PWM flyback power supplies. This device includes an internal power BJT and operates in quasi-resonant mode to provide high efficiency along with a number of key built-in protection features while minimizing the external component count, simplifying EMI design, and lowering the total bill of material cost. The CR1510 removes the need for secondary feedback circuit while achieving excellent line and load regulation. It also eliminates the need for loop compensation components while maintaining stability in all operating conditions. The built-in power limit function enables optimized transformer design in universal off-line applications and allows for a wide input voltage range.

iWatt's innovative proprietary technology ensures that power supplies built with the CR1510 can achieve the highest average efficiency, lowest standby power consumption, and fast smooth startup with a wide range of output voltage, that are ideal for LED lighting applications.

3.0 Applications
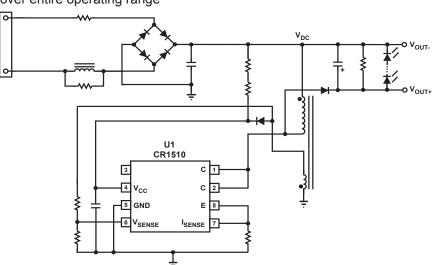
- Solid-state LED lighting

- LED lighting ballast

Figure 3.1: CR1510 Typical Application Circuit (Non-Isolated Application)

WARNING:
The CR1510 is intended for high voltage AC/DC offline applications. Contact with live high voltage offline circuits or improper use of components may cause lethal or lif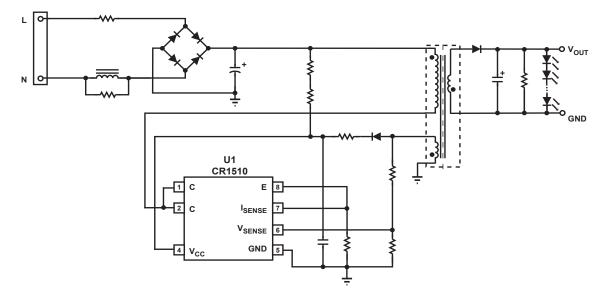e threatening injuries or property damage. Only qualified professionals with safety training and proper precaution should operate with high voltage offline circuits.

Figure 3.2: CR1510 Typical Application Circuit (Isolated Application)

4.0 Pinout Description

Figure 4.1: 7-Lead SOIC Package

Pin #	Name	Type	Pin Description
1	C	BJT Collector	Collector of internal bipolar junction transistor (BJT).
2	C	BJT Collector	Collector of internal BJT.
4	V_{CC}	Power Input	Power supply for control logic.
5	GND	Ground	Ground.
6	V_{SENSE}	Analog Input	Auxiliary voltage sense (used for primary-side regulation).
7	I_{SENSE}	Analog Input	Primary current sense. Used for cycle-by-cycle peak current control and current limit.
8	E	BJT Emitter	Emitter of internal BJT (pin 7 and pin 8 must be shorted externally on the PCB).

5.0 Absolute Maximum Ratings

Absolute maximum ratings are the parameter values or ranges which can cause permanent damage if exceeded. For maximum safe operating conditions, refer to Electrical Characteristics in Section 7.0. (T_A = 25°C, unless otherwise noted). Proper design precautions must be made to ensure that the internal die junction temperature of the CR1510 does not exceed 150°C. Otherwise permanent damage to the device may occur.

Parameter	Symbol	Value	Units
DC supply voltage range (pin 4, I_{CC} = 20mA max)	V_{CC}	-0.3 to 18	V
Continuous DC supply current at V_{CC} pin (V_{CC} = 15V)	I_{CC}	20	mA
V_{SENSE} input (pin 6, I_{VSENSE} ≤ 10mA)		-0.7 to 4.0	V
I_{SENSE} input (pin 7)		-0.3 to 4.0	V
ESD rating per JEDEC JESD22-A114		2,000	V
Latch-up test per JEDEC 78		±100	mA
Collector-Emitter breakdown voltage (Emitter and base shorted together; I_C = 1mA, R_{EB} = 0Ω)	V_{CES}	750	V
Collector current[1]	I_C	1.5	A
Collector peak current[1] (t_p < 1ms)	I_{CM}	3	A
Maximum junction temperature	$T_{J\ MAX}$	150	°C
Storage temperature	T_{STG}	-55 to 150	°C
Lead temperature during IR reflow for ≤ 15 seconds	T_{LEAD}	260	°C

Notes:

1. Limited by maximum junction temperature.

6.0 Thermal Characteristics

Parameter	Symbol	Value	Units
Thermal Resistance Junction-to-Ambient[1]	θ_{JA}	132	°C/W
Thermal Resistance Junction-to-GND pin (pin 5)[2]	ψ_{JB}	71	°C/W
Thermal Resistance Junction-to-Collector pin (pin 1)[2]	ψ_{J-BJT}	49	°C/W

Notes:

1. θ_{JA} is measured in a one-cubic-foot natural convection chamber.

2. ψ_{JB} [Psi Junction to Board] provides an estimation of the die junction temperature relative to the PCB [Board] surface temperature. ψ_{J-BJT} [Psi Junction to Collector pin] provides an estimation of the die junction temperature relative to the collector pin [internal BJT Collector] surface temperature. ψ_{JB} is measured at the ground pin (pin 5) without using any thermal adhesives.

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7.0 Electrical Characteristics

V_{CC} = 12V, -40°C ≤ T_A ≤ +85°C

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
V_{SENSE} SECTION (Pin 6)						
Input leakage current	I_{BVS}	V_{SENSE} = 2V			1	µA
Nominal voltage threshold	$V_{SENSE(NOM)}$	T_A=25°C, negative edge	1.518	1.533	1.548	V
Output OVP threshold	$V_{SENSE(MAX)}$	T_A=25°C, negative edge		1.834		V
I_{SENSE} SECTION (Pin 7)						
Over-current threshold	V_{OCP}		1.11	1.15	1.19	V
I_{SENSE} regulation upper limit[1]	$V_{IPK(HIGH)}$			1.0		V
I_{SENSE} regulation lower limit[1]	$V_{IPK(LOW)}$			0.23		V
Input leakage current	I_{LK}	I_{SENSE} = 1.0V			1	µA
V_{CC} SECTION (Pin 4)						
Maximum operating voltage[1]	$V_{CC(MAX)}$				16	V
Start-up threshold	$V_{CC(ST)}$	V_{CC} rising	10.0	11.0	12.0	V
Under-voltage lockout threshold	$V_{CC(UVL)}$	V_{CC} falling	3.8	4.0	4.2	V
Start-up current	$I_{IN(ST)}$	V_{CC} = 10V	1.0	1.7	3.0	µA
Quiescent current	I_{CCQ}	No I_B current		2.7	4.0	mA
Zener breakdown voltage	V_{ZB}	Zener current = 5mA T_A=25°C	18.5	19.5	20.5	V

7.0 Electrical Characteristics (cont.)

V_{CC} = 12V, -40°C ≤ T_A ≤ +85°C

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
BJT Section (Pin 1, Pin 2, and Pin 8)						
Collector cutoff current	I_{CB0}	V_{CB} = 750V, I_E = 0A			0.01	mA
Collector-Emitter cutoff current	I_{CES}	V_{CE} = 750V, R_{EB} = 0Ω T_A = 25°C			0.01	mA
		V_{CE} = 750V, R_{EB} = 0Ω T_A = 100°C			0.02	
		V_{CE} = 500V, R_{EB} = 0Ω T_A = 25°C			0.005	
DC Current Gain[2]	h_{FE}	V_{CE} = 5V, I_C = 0.2A	15		40	
		V_{CE} = 5V, I_C = 0.3A	10		30	
		V_{CE} = 5V, I_C = 1mA	10			
Collector-Base breakdown voltage	V_{CB0}	I_C = 0.1mA	750			V
Collector-Emitter breakdown voltage (Emitter and base shorted together)	V_{CES}	I_C = 1mA, R_{EB} = 0Ω	750			V
Collector-Emitter sustain voltage	$V_{CEO(SUS)}$	I_C = 1mA, L_M = 25mH	500			V
Collector-Emitter saturation voltage[2]	$V_{CE(SAT)}$	I_C = 0.1A, I_B = 0.02A		0.1	0.3	V
PWM switching frequency[3]	f_{SW}	> 50% load		64		kHz

Notes:

1. These parameters are not 100% tested and guaranteed by design and characterization.

2. Impulse t_p ≤ 300μs, duty cycle ≤ 2%.

3. Operating frequency varies based on the load conditions, see Section 10.6 for more details.

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8.0 Typical Performance Characteristics

Figure 8.1: V_{CC} UVLO vs. Temperature

Figure 8.2: Start-Up Threshold vs. Temperature

Figure 8.3: Switching Frequency vs. Temperature [1]
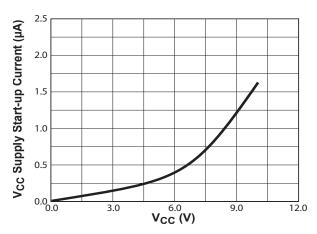

Figure 8.4: Internal Reference vs. Temperature

Figure 8.5: V_{CC} vs. V_{CC} Supply Start-up Current

Notes:

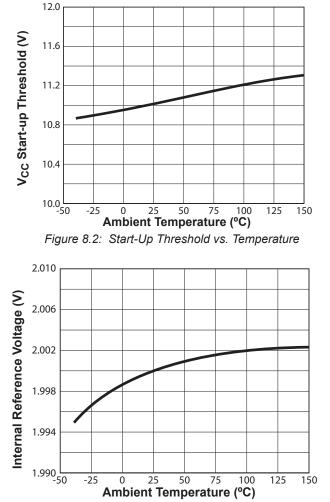1. Operating frequency varies based on the load conditions, see Section 10.6 for more details.

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9.0 Functional Block Diagram

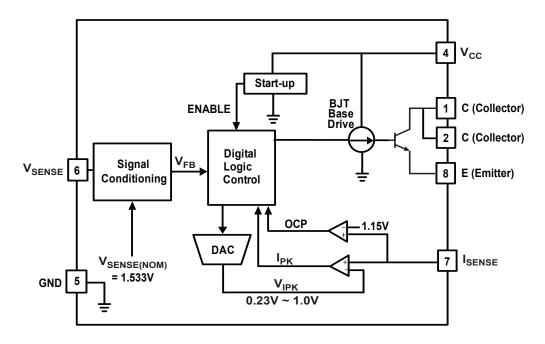*Figure 9.1: CR1510 Functional Block Diagram*

10.0 Theory of Operation

The CR1510 is a digital controller integrated with a power BJT. It uses a proprietary primary-side control technology to eliminate the opto-isolated feedback and secondary regulation circuits required in traditional designs. This results in a low-cost solution for low power LED driver. The core PWM processor uses fixed-frequency Discontinuous Conduction Mode (DCM) operation at higher power levels and switches to variable frequency operation at light loads to maximize efficiency. Furthermore, iWatt's digital control technology enables tight output regulation, low no-load power consumption, and full-featured circuit protection with primary-side control.

The block diagram in Figure 9.1 shows the digital logic control block generates the switching on-time and off-time information based on the output voltage and current feedback signal and provides instructions to dynamically control the internal BJT base current. The I_{SENSE} is an analog input configured to sense the primary current in a voltage form. In order to achieve the peak current mode control and cycle-by-cycle current limit, the V_{IPK} sets the threshold for the I_{SENSE} to compare with, and it varies in the range of 0.23V (typical) and 1.00V (typical) under different line and load conditions. The system loop is automatically compensated

internally by a digital error amplifier. Adequate system phase margin and gain margin are guaranteed by design and no external analog components are required for loop compensation. The CR1510 uses an advanced digital control algorithm to reduce system design time and increase reliability.

Furthermore, accurate secondary constant-current operation is achieved without the need for any secondary-side sense and control circuits.

The CR1510 uses adaptive multi-mode PWM/PFM control to dynamically change the BJT switching frequency for efficiency, EMI, and power consumption optimization. In addition, it achieves unique BJT quasi-resonant switching to further improve efficiency and reduce EMI. The built-in single-point fault protection features include over-voltage protection (OVP), output-short-circuit protection (SCP), over-current protection (OCP), and I_{SENSE} fault detection.

iWatt's digital control scheme is specifically designed to address the challenges and trade-offs of power conversion design. This innovative technology is ideal for balancing new requirements for green mode operation with more

practical design considerations such as the lowest possible cost, smallest size and high performance output control.

10.1 Pin Detail

Pin 1 and Pin 2 - C

Collector pin of the internal power BJT.

Pin 4 – V_{CC}

Power supply for the controller during normal operation. The controller will start up when V_{CC} reaches 11.0V (typical) and will shut-down when the V_{CC} voltage is 4.0V (typical). A decoupling capacitor should be connected between the V_{CC} pin and GND.

Pin 5 – GND

Ground.

Pin 6 – V_{SENSE}

Sense signal input from auxiliary winding. This provides the secondary voltage feedback used for output regulation.

Pin 7 – I_{SENSE}

Primary current sense. It is used for cycle-by-cycle peak current control and limit.

Pin 8 – E

Emitter pin of the internal power BJT. This pin must be shorted to pin 7 (the I_{SENSE} pin).

10.2 Adaptively Controlled Soft Start-up

The CR1510 features a proprietary soft-start scheme to achieve fast build-up of output voltage and smooth ramp-up of LED current for a variety of output conditions including output voltage up to 100V or above and output capacitor ranging from 33µF to 2000µF or higher. Prior to the start-up, the V_{CC} pin is charged through startup resistors. When V_{CC} bypass capacitor is fully charged to a voltage higher than the start-up threshold $V_{CC(ST)}$, the ENABLE signal becomes active to enable the control logic, and the CR1510 commences the soft-start function. During the soft-start process, the primary-side peak current is limited cycle by cycle by the I_{PEAK} comparator. The whole soft-start process can break down into several stages based on the output voltage levels, which is indirectly sensed by V_{SENSE} signal at

the primary side. At different stages, the CR1510 adaptively controls the switching frequency and primary-side peak current such that the output voltage can always build up very fast at the early stages before LEDs light up, and smoothly transition to the desired regulation current level, regardless of any capacitive loads that the applications may incur.
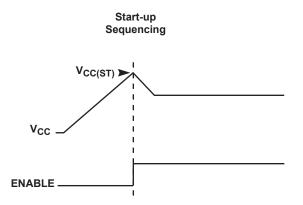

Figure 10.1: Start-up Sequencing Diagram

10.3 Understanding Primary Feedback

Figure 10.2 illustrates a simplified flyback converter. When the switch Q1 conducts during $t_{ON}(t)$, the current $i_g(t)$ is directly drawn from the rectified sinusoid $v_g(t)$. The energy $E_G(t)$ is stored in the magnetizing inductance L_M. The rectifying diode D1 is reverse biased and the load current I_O is supplied by the secondary capacitor C_O. When Q1 turns off, D1 conducts and the stored energy $E_g(t)$ is delivered to the output.
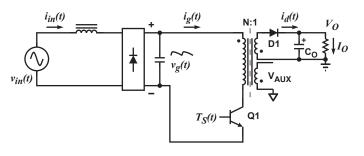

Figure 10.2: Simplified Flyback Converter

In order to tightly regulate the output voltage, accurate information about the output voltage and load current must be accurately conveyed. In the DCM flyback converter, this information can be read via the auxiliary winding or the primary magnetizing inductance (L_M). During the Q1 on-time, the load current is supplied from the output filter

capacitor C_O. The voltage across L_M is $v_g(t)$, if the voltage dropped across Q1 is zero. The current in Q1 ramps up linearly at a rate of:

$$\frac{di_g(t)}{dt} = \frac{v_g(t)}{L_M} \qquad (10.1)$$

At the end of on-time, the current ramps up to:

$$i_{g\_peak}(t) = \frac{v_g(t) \times t_{ON}}{L_M} \qquad (10.2)$$

This current represents a stored energy of:

$$E_g = \frac{L_M}{2} \times i_{g\_peak}(t)^2 \qquad (10.3)$$

When Q1 turns off at t_O, $i_g(t)$ in L_M forces a reversal of polarities on all windings. Ignoring the communication-time caused by the leakage inductance L_K at the instant of turn-off t_O, the primary current transfers to the secondary at a peak amplitude of:

$$i_d(t) = \frac{N_P}{N_S} \times i_{g\_peak}(t) \qquad (10.4)$$

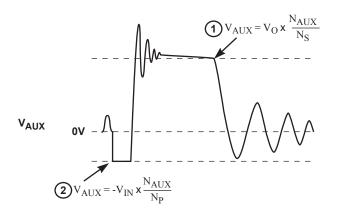Assuming the secondary winding is master, and the auxiliary winding is slave,

Figure 10.3: Auxiliary Voltage Waveforms

The auxiliary voltage is given by:

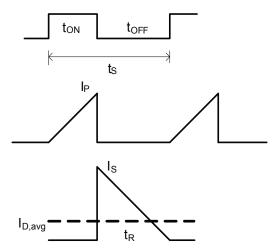$$V_{AUX} = \frac{N_{AUX}}{N_S}(V_O + \Delta V) \qquad (10.5)$$

and reflects the output voltage as shown in Figure 10.3.

The voltage at the load differs from the secondary voltage by a diode drop and IR losses. Therefore, if the secondary voltage is always read at a constant secondary current, the difference between the output voltage and the secondary voltage is a fixed ΔV. Furthermore, if the voltage can be read when the secondary current is small, ΔV is also small. With the CR1510, ΔV can be ignored.

The real-time waveform analyzer in the CR1510 reads this information cycle by cycle. The part then generates a feedback voltage V_{FB}. The V_{FB} signal accurately represents the output voltage under most circumstances and is used to regulate the output voltage.

10.4 Constant Current Operation

The CR1510 employs a patented primary-side-only technology to regulate output current. It senses the load current indirectly through the primary current. The primary current is detected by the I_{SENSE} pin through a resistor from the BJT emitter to ground.

Figure 10.4: Constant Current Operation

The cycle-by-cycle averaged current of the secondary diode current is determined by:

$$I_{D,avg} = \frac{1}{2} \times N_{PS} \times \frac{V_{IPK}}{R_{CS}} \times \frac{t_R}{t_S} \qquad (10.6)$$

where the N_{PS} is the transformer turns-ratio (primary over secondary), and R_{CS} is the current sense resistor connected from the I_{SENSE} pin to GND.

In the CR1510, the current $I_{D,\,avg}$ is controlled in order to achieve good current regulation, while avoiding continuous conduction mode operation.

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During constant current (CC) operation, the output voltage regulation is not guaranteed. The point 1 in Figure 10.3, which reflects output voltage is not regulated to $V_{SENSE(NOM)}$ (i.e. 1.533V). For LED applications, where current regulation is critical, design needs to ensure the point 1 is well below $V_{SENSE(NOM)}$ with some margin.

10.5 Constant Voltage Operation

The CR1510 also incorporates constant voltage (CV) operation, where output voltage maintains constant by regulating the point 1 indicated in Figure 10.3 to $V_{SENSE(NOM)}$ (1.533V typically). During constant voltage operation, the CR1510 may operate in pulse-width-modulation (PWM) mode or pulse-frequency-modulation (PFM) mode, depending on load conditions. In particular, the CR1510 allows the switching frequency to drop as low as 1.8kHz at PFM mode, which helps system stay regulated at very light load condition, thus achieving <30mW no-load power consumption and meanwhile improving active operating efficiency by using large pre-load resistor.

Figure 10.5 shows power envelope for the CR1510. After soft-start is completed, the digital control block measures the output conditions. It determines output power levels and adjusts the control system to operate either in CV mode or CC mode.
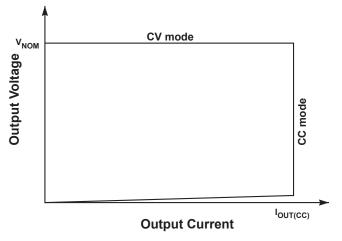

Figure 10.5: Power Envelope

If no voltage is detected on V_{SENSE}, it is assumed that the auxiliary winding of the transformer is either open or shorted and the CR1510 shuts down.

10.6 Variable Frequency Operation Mode

During each of the switching cycles, the falling edge of V_{SENSE} is checked. If the falling edge of V_{SENSE} is not detected, the off-time is extended until the falling edge of V_{SENSE} is detected. This results in the variable switching frequency operation. In particular, the CR1510 may work in constant-current PWM (CC-PWM) mode at high load and costant-current PFM (CC-PFM) mode at ligh load. With CC-PWM mode, the switching frequency is at 64kHz, while during CC-PFM mode, the V_{IPK} is fixed at 0.76V, and the switching frequency varies for different output loads.

In the CR1510, the maximum transformer reset time allowed is 125µs. When the transformer reset time reaches 125µs, the CR1510 shuts off.

10.7 Internal Loop Compensation

The CR1510 incorporates an internal Digital Error Amplifier with no requirement for external loop compensation. For a typical power supply design, the loop stability is guaranteed to provide at least 45 degrees of phase margin and -20dB of gain margin.

10.8 Voltage Protection Features

The secondary maximum output DC voltage is limited by the CR1510. When the V_{SENSE} signal exceeds the output OVP threshold at point 1 (as shown in Figure 10.3), the CR1510 shuts down.

The CR1510 protects against input line under-voltage by setting a maximum T_{ON} time. Since output power is proportional to the squared $V_{IN}T_{ON}$ product, for a given output power, the T_{ON} increases as the V_{IN} decreases. Thus by knowing when the maximum T_{ON} time occurs, the CR1510 detects that the minimum V_{IN} is reached, and then it shuts down. The maximum t_{ON} limit is set to 15.6µs. Also, the CR1510 monitors the voltage on the V_{CC} pin and when the voltage on this pin is below UVLO threshold the IC shuts down immediately.

When any of these faults is met the IC remains biased to discharge the V_{CC} supply. Once V_{CC} drops below the UVLO threshold, the controller resets itself and then initiates a new soft-start cycle. The controller continues attempting start-up until the fault condition is removed.

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10.9 LED Open and Short Protections

The constant voltage operation in the CR1510 provides protection against LED open fault. During normal operation, the CR1510 operates in CC mode with the output voltage below the nominal voltage set by $V_{SENSE(NOM)}$. After LED is open, the output voltage will be pushed higher momentarily. Depending on the output capacitor and LED operating current, system may gradually settle down and stay regulated at constant voltage operation at no-load condition. Or, if the output voltage overshoot exceeds the output OVP threshold set by $V_{SENSE(OVP)}$ in Section 7.0, the CR1510 shuts down.

LED short fault is detected via V_{SENSE} pin. When the point 1 in Figure 10.3 is below 115mV for several consecutive cycles, the CR1510 shuts down.

When any of these faults are met the IC remains biased to discharge the V_{CC} supply. Once V_{CC} drops below UVLO threshold, the controller resets itself and then initiates a new soft-start cycle. The controller continues attempting start-up until the fault condition is removed.

10.10 PCL, OCP and SRS Protection

The peak-current limit (PCL), over-current protection (OCP) and sense-resistor short protection (SRSP) are built-in features in the CR1510. With the I_{SENSE} pin the CR1510 is able to monitor the peak primary current. This allows for cycle-by-cycle peak current control and limit. When the peak primary current multiplied by the I_{SENSE} resistor is greater than 1.15V, over-current protection (OCP) is detected and the IC immediately turns off the base driver until the next cycle. The output driver sends out a switching pulse in the next cycle, and the switching pulse continues if the OCP threshold is not reached; or, the switching pulse turns off again if the OCP threshold is reached. If the OCP occurs for several consecutive switching cycles, the CR1510 shuts down.

If the I_{SENSE} resistor is shorted, there is a potential danger that the over-current condition is not detected. Thus, the IC is designed to detect this sense-resistor-short fault after start-up and immediate shutdown. The V_{CC} is discharged since the IC remains biased. Once the V_{CC} drops below the UVLO threshold, the controller resets itself and then initiates a new soft-start cycle. The controller continues attempting to start up, but does not fully start up until the fault condition is removed.

10.11 Dynamic Base Current Control

An important feature of the CR1510 is that it directly drives an internal BJT switching device with dynamic base current control to optimize performance. The BJT base current ranges from 10mA to 31mA, and is dynamically controlled according to the power supply load change. The higher the output power, the higher the base current. Specifically, the base current is related to V_{IPK}, as shown in Figure 10.6.
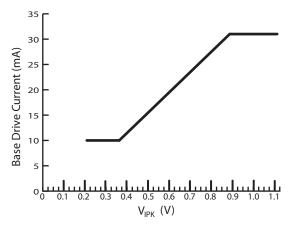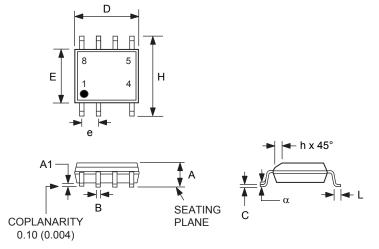

Figure 10.6: Base Drive Current vs. V_{IPK}

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11.0 Physical Dimensions

7-Lead Small Outline (SOIC) Package

Symbol	Inches		Millimeters	
	MIN	MAX	MIN	MAX
A	0.060	0.068	1.52	1.73
A1	0.004	0.008	0.10	0.20
B	0.014	0.018	0.36	0.46
C	0.007	0.010	0.18	0.25
D	0.188	0.197	4.78	5.00
E	0.150	0.157	3.81	3.99
e	0.050 BSC		1.270 BSC	
H	0.230	0.244	5.84	6.20
h	0.010	0.016	0.25	0.41
L	0.023	0.029	0.58	0.74
α	0°	8°		

Figure 11.1: Physical dimensions, 7-lead SOIC package

Compliant to JEDEC Standard MS12F

Controlling dimensions are in inches; millimeter dimensions are for reference only

This product is RoHS compliant and Halide free.

Soldering Temperature Resistance:
  [a] Package is IPC/JEDEC Std 020D Moisture Sensitivity Level 1
  [b] Package exceeds JEDEC Std No. 22-A111 for Solder Immersion Resistance; package can withstand
       10 s immersion < 270˚C

Dimension D does not include mold flash, protrusions or gate burrs. Mold flash, protrusions or gate burrs shall not exceed 0.15 mm per end. Dimension E1 does not include interlead flash or protrusion. Interlead flash or protrusion shall not exceed 0.25 mm per side.

The package top may be smaller than the package bottom. Dimensions D and E1 are determined at the outermost extremes of the plastic bocy exclusive of mold flash, tie bar burrs, gate burrs and interlead flash, but including any mismatch between the top and bottom of the plastic body.

12.0 Ordering Information[1]

Part Number	Package	Description
CR1510-00	SOIC-7	Tape & Reel[1]

Notes:

1. Tape & Reel packing quantity is 2,500 per reel. Minimum ordering quantity is 2,500.

Trademark Information

Contact Information

Web: https://www.iwatt.com

E-mail: info@iwatt.com

Phone: +1 (408) 374-4200

Fax: +1 (408) 341-0455

iWatt Inc.
675 Campbell Technology Parkway, Suite 150
Campbell, CA 95008

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