AC/DC Power Controller for Dimmable LED Drivers with Internal High-Voltage MOSFET

1 Description

The iW3658 is a highly integrated, high-performance off-line power supply controller for phase-cut dimmable LED luminaires. It uses patented ***PrimAccurate™*** primary-side sensing technology to regulate output current accurately without the need of feedback circuit. The iW3658 operates at boundary conduction mode to achieve high efficiency and low EMI.

With advanced dimming control technology, the iW3658 can operate with most wall dimmers including leading-edge dimmers (R-type or R-L type) and trailing-edge dimmers (R-C type). The iW3658 operates in buck-boost mode to regulate current to the output LEDs.

Dialog's innovative technology maximizes the iW3658 performance with integrated high-voltage MOSFET in a SO-7 package, which provides an extra pin spacing between high voltage MOSFET's drain and low voltage pins. With Dialog's proprietary V_{CC} regulation circuit, the iW3658's V_{CC} level is well maintained regardless of the LED voltage and dimmer phase angle, which eliminates the possibility of low end flickering.

2 Features

- Isolated/non-isolated off-line $120V_{AC}/230V_{AC}$ LED driver up to 15W (Note 1)
- Wide line frequency range (45Hz – 66Hz)
- Excellent dimmer compatibility
  - » Leading-edge dimmer
  - » Trailing-edge dimmer
- Low BOM cost
- Integrated high-voltage MOSFET
- Single-winding inductor
- Internal start-up without the need for high voltage circuit
- Closed-loop constant current regulation
- Built-in LED current derating at high temperature
- Built-in over-temperature shut-down
- LED open and short protection
- Fast start-up (< 0.5s without dimmer)
- Resonant control to achieve high efficiency (typical > 85%)
- Supports Buck-Boost Topology

3 Applications

- Dimmable LED retrofit lamps up to 15W (Note 1)

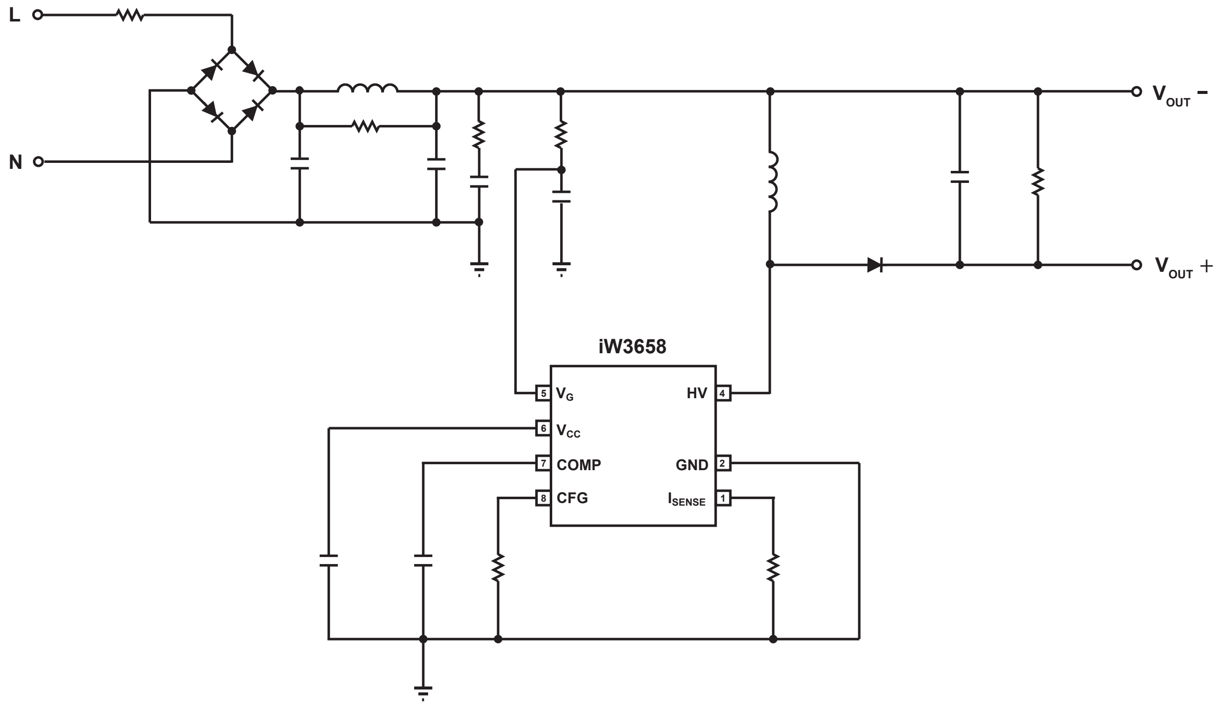


Figure 3.1 : iW3658 Typical Application Circuit

Note 1 : For output power above 12W designs, care should be taken to verify the thermal and reliability constraints on the IC. An IC temperature below 120°C is recommended for proper IC operation.

4 Pinout Description

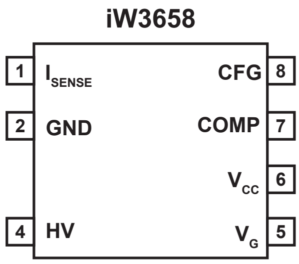


Figure 4.1 : 7-Lead SO Package

Pin Number	Pin Name	Type	Pin Description
1	I_{SENSE}	Analog	Current sense
2	GND	Ground	Ground reference
4	HV	Analog	Internal high voltage MOSFET drain
5	V_G	Analog	Internal high voltage MOSFET gate
6	V_{CC}	Power Input	Power supply to control logic and MOSFET drive
7	COMP	Analog	Constant current regulation loop compensation
8	CFG	Analog	OVP level configuration

5 Absolute Maximum Ratings

Absolute maximum ratings are the parameter values or ranges which can cause permanent damage if exceeded.

Parameter	Symbol	Value	Units
DC supply voltage range (pin 6)	V_{CC}	-0.3 to 6.0	V
V_G (pin 5)		-0.3 to 18.0	V
COMP (pin 7)		-0.3 to 6.0	V
HV (pin 4)		500 or 650	V
I_{SENSE} (pin 1)		-0.3 to 6.0	V
CFG (pin 8)		-0.3 to 6.0	V
Maximum junction temperature	T_{JMAX}	150	°C
Operating junction temperature	T_{JOPT}	-40 to 150	°C
Storage temperature	T_{STG}	-65 to 150	°C
Thermal resistance junction-to-ambient	θ_{JA}	170	°C/W
ESD rating per JEDEC JESD22-A114			V
Latch-up test per JESD78A			mA

6 Electrical Characteristics

V_{IN} = 15V. All values are at T_A = +25°C, unless otherwise specified.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Current regulation (COMP Pin)						
Reference output current	V_{IREF}	iW3658-31		0.25		V
		iW3658-00 / iW3658-10 / iW3658-20		0.35		
		iW3658-01		0.4		
Regulation sourcing/sinking		T_A = 25°C		28.5		µA
High clamp voltage		R_{CFG} < 59kΩ		0.85		V
		59kΩ < R_{CFG} < 85kΩ		0.74		
		R_{CFG} > 85kΩ		0.63		
Low clamp voltage		R_{CFG} < 59kΩ		0.55		V
		59kΩ < R_{CFG} < 85kΩ		0.44		
		R_{CFG} > 85kΩ		0.33		
ON/OFF Timing						
Max ON time	T_{ON_MAX}			9		µs
Min ON time	T_{ON_MIN}			0.3		µs
Maximum OFF time	T_{OFF_MAX}			250		µs
Minimum OFF time	T_{OFF_MIN}	At V_{IN} zero-crossing		5		µs
Current sensing (I_{SENSE} Pin)						
Over current protection				1.3		V
Leading edge blanking				300		ns
Supply (V_{cc} Pin)						
Operating voltage	V_{CC}			5	5.5	V
Start-up threshold	$V_{CC(ST)}$	V_{CC} rising		5.2		V
Under voltage lockout threshold	$V_{CC(UVLO)}$	V_{CC} falling		3.5		V
Operating current	I_{CCQ}			400		µA
Charging current		Before POR		0.8		mA
Discharging current				3		mA
Power FET (HV Pin)						
Conductance	R_{ON}			TBD		Ω
Breakdown voltage	BV_{DSS}			TBD		V
Gate bias (V_G Pin)						
Zener		At biasing current 0.1mA		17.1		V
Configuration (CFG Pin)						
Configuration current	$I_{CFG(CFG)}$	iW3658-00 / iW3658-10/ iW3658-20 / iW3658-31		14		µA
		iW3658-01		7		
Thermal Shutdown						
Shutdown threshold	$T_{OTP(START)}$			150		°C

7 Typical Performance Characteristics

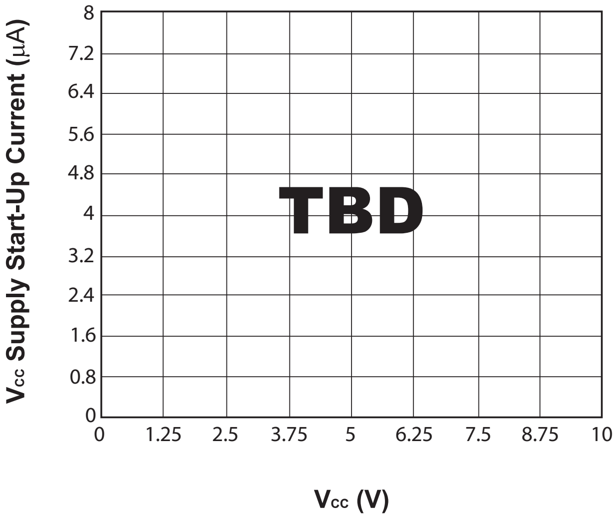


Figure 7.1 : V_{CC} vs. V_{CC} Supply Start-up Current

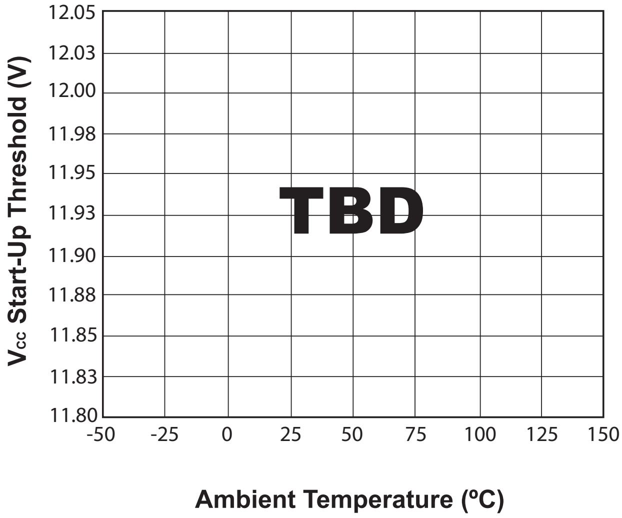


Figure 7.2 : Start-Up Threshold vs. Temperature

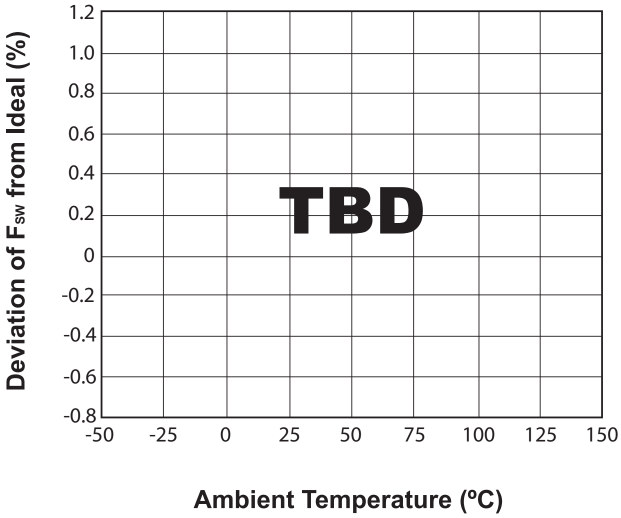


Figure 7.3 : Switching Frequency vs. Temperature

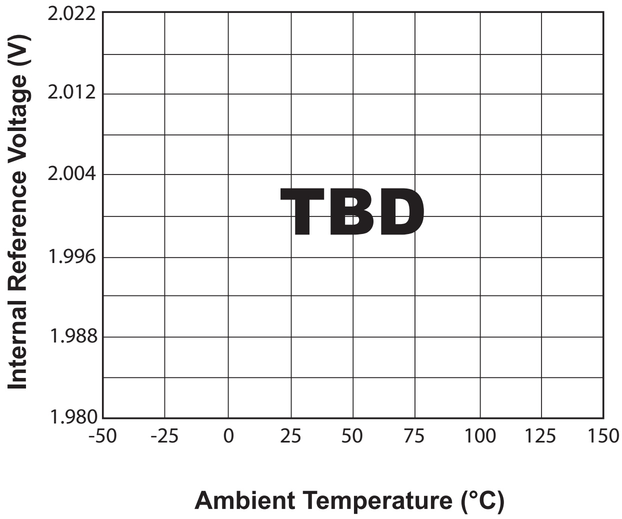


Figure 7.4 : Internal Reference V. vs. Temperature

8 Functional Block Diagram

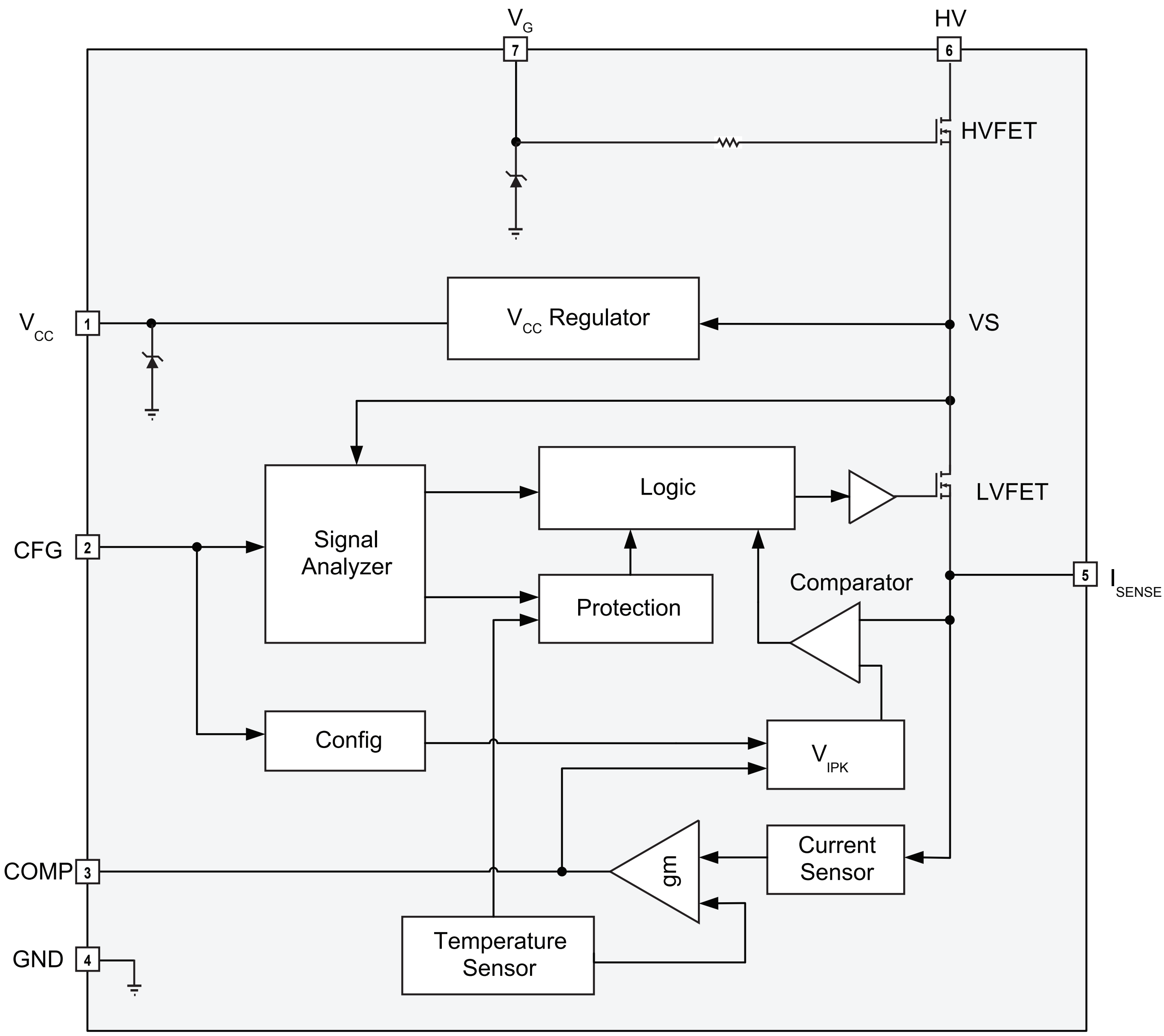


Figure 8.1 : Functional Block Diagram

9 Theory of Operation

9.1 System Startup

When AC voltage is applied, the V_G pin of the iW3658, which is connected to the gate of the internal high voltage MOSFET (HVFET), is charged up through an external pull up resistor. When $V_{GS} > V_{GS(TH)}$, the HVFET is turned on and charges the V_{CC} capacitor. When the V_{CC} voltage reaches the V_{CC} startup threshold, $V_{CC(ST)}$, the iW3658 control circuit is activated and the IC powers up.

After iW3658 is powered up, iW3658 measures the external resistance at the CFG pin in order to configure the control parameters. The CFG pin outputs I_{CFG} current and measures the voltage developed at the pin. The R_{CFG} resistance is used to determine the appropriate maximum COMP pin voltage, $V_{COMP\ (MAX)}$, and the minimum COMP pin voltage, $V_{COMP(MIN)}$. See section 9.7 for details.

Once the configuration cycle finishes, the COMP pin voltage charges to $V_{COMP(MIN)}$, the IC begins to switch the internal low voltage $MOSFET_{(LVFET)}$ and delivers energy to the output.

9.2 Constant Current Regulation

When there is no dimmer, the iW3658 maintains the output current constant. For the buck-boost topology, the output current can be derived by the following equation:

$$I_{OUT} = \frac{1}{2} \times \frac{V_{IPK}}{R_S} \times \frac{T_R}{T_P} \qquad (9.1)$$

In which V_{IPK} is the peak voltage of I_{SENSE} pin and R_S is the current sense resistor value. T_R is the de-magnetizing time of the main power inductor and T_P is the switching period.

The output current feedback, I_{OUT_FB}, is estimated by sampling the peak current sense voltage V_{IPK} and calculated by equation 9.2.

$$V_{IPK} \times \frac{T_R}{T_P} = 2 \times I_{OUT} \times R_S \qquad (9.2)$$

The result is proportional to the output current I_{OUT} and scaled by 2 x R_S. I_{OUT_FB} is then compared with internal current reference V_{IREF} for a closed-loop current control.

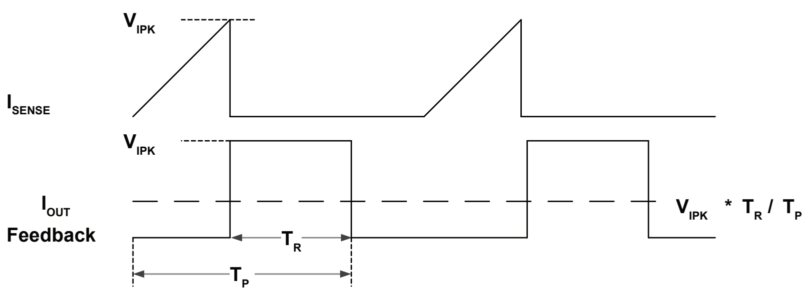


Figure 9.1 : Constant Current Regulation

An external capacitor (2.2µF typical) is connected from the COMP pin to keep the LED current stable.

9.3 Switching Control

The COMP pin voltage is used to regulate the output current sets either the peak current of the main inductor or turn-on time of the LVFET, depending on different iW3658 option.

When steady state is reached, the average of V_{IPK} * T_R / T_P is regulated to the internal V_{IREF}. The LED current is regulated and its value can be adjusted by using different R_S values.

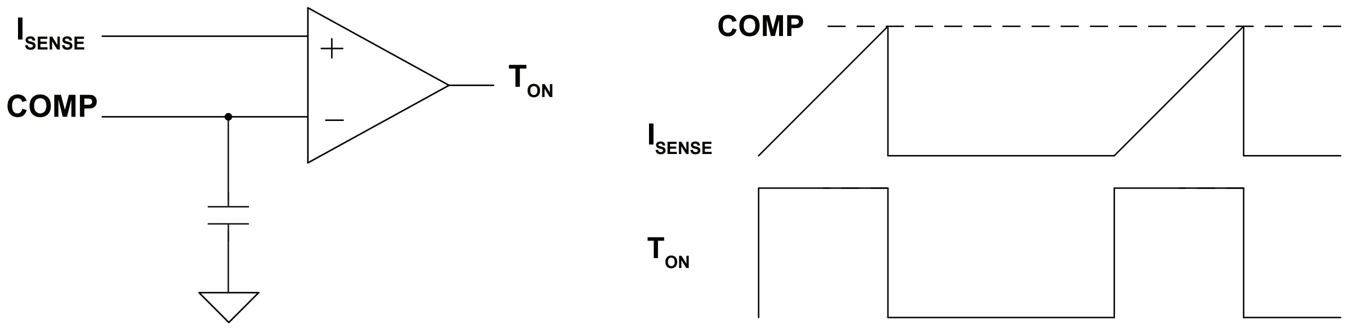


Figure 9.2 : Switching Control

The iW3658 uses Dialog's proprietary ring detection to measure the reset time, T_R, as well as to achieve valley mode switching for best efficiency and EMI. The detection is done at the source of the HVFET, or the drain of LVFET without the need for an external sensing circuit or auxiliary winding.

The iW3658 always operates at CDCM and the switch is turned on at first valley. If the output voltage is too low for the iW3658 to detect the first valley, the iW3658 starts switching at 4kHz, enabling the next switching cycle after approximately 250µs.

9.4 AC line Current Control

The iW3658 has two optional operation modes: constant peak current or constant on-time, T_{ON}.

9.4.1 Constant Peak Current Regulation

In constant current mode, the peak current control value is held constant when AC line voltage is high. Due to the flat distribution of the switching current, the LED current ripple is lower when compared to traditional constant T_{ON} control. At zero-crossing, T_{ON} is clamped to a maximum 9µs to avoid excessive AC current. This mode of operation can achieve power factor in the range of 0.7 to 0.9 depending on the application. The LED current is regulated by controlling the value of peak of I_{SENSE} voltage.

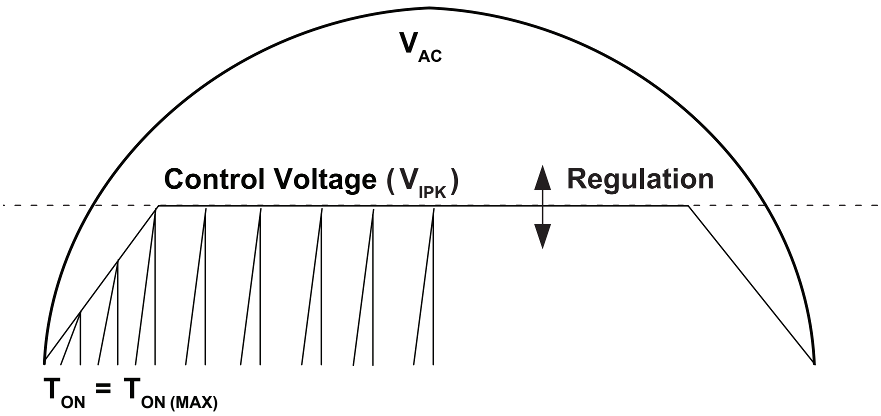


Figure 9.3 : Constant Peak Current Regulation

9.4.2 Constant T_{ON} Regulation

In constant T_{ON} mode the COMP pin voltage is compared with a constant slope ramp. T_{ON} is set by the time that ramp voltage is lower than COMP pin voltage. In this way, constant T_{ON} is achieved throughout the AC half cycle. The LED current is higher when COMP pin voltage is higher or vice versa.

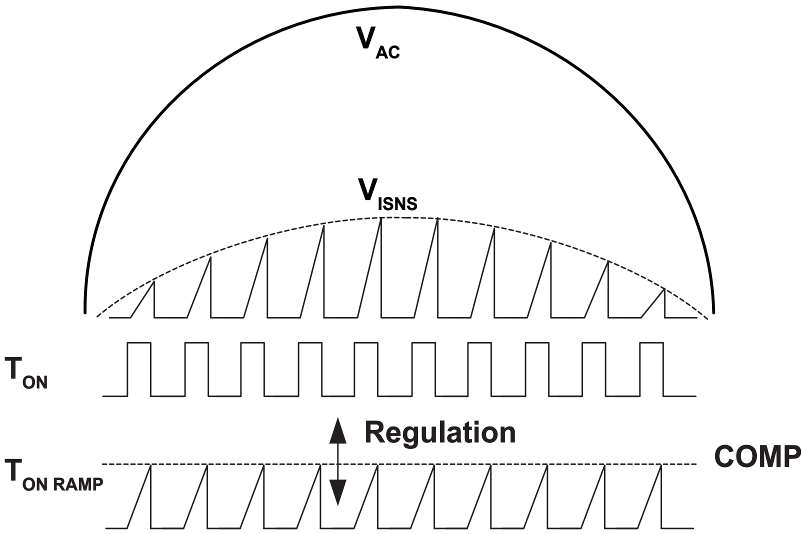


Figure 9.4 : Constant T_{ON} Regulation

9.5 V_{CC} Charging and Maintenance

The iW3658 uses Dialog's proprietary V_{CC} charging technology to achieve V_{CC} maintenance regardless of LED voltage or dimming phase angle. Also, it eliminates the need for high voltage resistors which cause extra power loss and additional BOM component.

The charge of V_{CC} is done by utilizing a portion of the primary inductor current. An internal regulation loop automatically adjusts the pulse width of the V_{CC} charging time under different dimming angles. Although the V_{CC} voltage drops during the phase cut of an AC half cycle, the iW3658 guarantees V_{CC} level is always above $V_{CC(UVLO)}$ when a proper sized V_{CC} capacitor is used.

9.6 Dimming Operation

If there is no dimmer connected to the driver, the iW3658 regulates a constant output current which is set by the current sense resistor, R_S.

If a phase-cut dimmer is used, the iW3658 uses maximum clamp voltage $V_{COMP(MAX)}$ or maximum $T_{ON\text{-}TIME}$ to reduce the output current with phase-cut. $V_{COMP(MAX)}$ or maximum $T_{ON\text{-}TIME}$ are determined by CFG resistance. Refer to section 9.7 for the details of $V_{COMP(MAX)}$.

9.7 Configuration

R_{CFG} is used to set the maximum COMP pin voltage and maximum T_{ON}. Tables 9.1 and 9.2 show $V_{COMP(MAX)}$ according to R_{CFG} value. Based on the operation principle of flyback topology, the higher the output voltage, the lower the R_{CFG} value, thus the higher $V_{COMP(MAX)}$ needs to be. The $V_{COMP(MIN)}$ is 0.3V below high limit.

R_{CFG} Range	$V_{COMP(MAX)}$	T_{ON} High Limit In iW3658-20
R_{CFG} < 59kΩ	0.85V	6.80μs
59kΩ < R_{CFG} < 85kΩ	0.74V	5.92μs
R_{CFG} > 85kΩ	0.63V	5.04μs

Table 9.1: R_{CFG} Values at 120V_{AC} Input Voltage

R_{CFG} Range	$V_{COMP(MAX)}$	T_{ON} High Limit In iW3658-20
R_{CFG} < 118kΩ	0.85V	7.65μs
118kΩ < R_{CFG} < 170kΩ	0.74V	6.66μs
R_{CFG} > 170kΩ	0.63V	5.67μs

Table 9.2: R_{CFG} Values at 230V_{AC} Input Voltage

In 120V_{AC} application, 59kΩ maps to 65V output voltage and 85kΩ maps to 45V output voltage. In 230V application, 118kΩ maps to 65V output voltage and 170kΩ maps to 45V output voltage.

9.8 Protections

9.8.1 Output Over-Voltage Protection (OVP)

The iW3658 detects the output over-voltage condition indirectly by measuring the reset time of the main inductor using the following equation:

$$V_{OUT} = \frac{V_{IPK}}{T_R} \times \frac{L_M}{R_S} \qquad (9.3)$$

For a certain V_{IPK}, which is known to the iW3658, the inductor reset time T_R is inversely proportional to the output voltage. Therefore, for given L_M/R_S and V_{IPK} values, the output voltage can be detected by the reset time T_R. By setting a time value T_{R_OVP}, as the target over voltage threshold, if the measured T_R is shorter than T_{R_OVP}, then the output voltage is considered to be too high and will trigger the OVP protection.

The iW3658 sets the OVP level via the R_{CFG} resistor by the following equation:

$$V_{OVP} = \frac{\frac{L_M}{R_S}}{R_{CFG}} \times 5 \times 10^9 \qquad (9.4)$$

9.8.2 Inductor Peak Current Limit

The maximum I_{SENSE} voltage is clamped at 1.3V. Once the I_{SENSE} voltage reaches 1.3V, the power switch will be turned off immediately, then start again in the next switching cycle.

9.8.3 Output Over-Current Protection

If the output is short circuited, the iW3658 will operate at approximately 4kHz to reduce the power.

9.8.4 Thermal Derating and Over-Temperature Protection (OTP)

The iW3658 has an internal OTP shutdown at 150°C junction temperature. The iW3658 also has built-in LED current derating. The derating start point is at 130°C junction temperature.If the junction temperature reaches 130°C, the iW3658 reduces current to the LEDs at a rate of 10% per 6°C. The picture below shows the OTP de-rating curve. The maximum derating range is down to 70% of full output current.

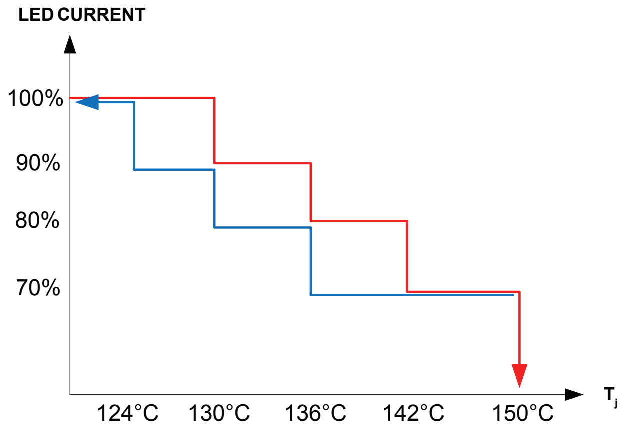


Figure 9.5 : Over-Temperature Derating Protection Characteristic

9.9 Application Guide

9.9.1 Current Sense Resistor (R_S)

LED current is set by current sense resistor. R_S value can be determined by the following equation. It does not depend on AC or LED voltage.

$$R_{SNS} = \frac{V_{IREF}}{2 \times I_{LED} \times \eta} \qquad (9.5)$$

In which, V_{IREF} is an internal output current reference; η is power stage efficiency, 92% is a good estimate to start with; I_{LED} is the full power output current.

9.9.2 Configuration Resistor (R_{CFG})

R_{CFG} sets the over voltage protection threshold. It can be determined by the following equation:

$$R_{CFG} = \frac{\frac{L_M}{R_S}}{V_{OVP}} \times 5 \text{ x } 10^9 \Omega \qquad (9.6)$$

9.9.3 Main inductor (L_M)

L_M determines the switching frequency. The following equation is recommended:

For $120V_{AC}$ application:

$$\frac{L_M}{R_S} = 800\mu H/\Omega \text{ to } 1200\mu H/\Omega \qquad (9.7)$$

For $230V_{AC}$ application:

$$\frac{L_M}{R_S} = 1600\mu H/\Omega \text{ to } 2000\mu H/\Omega \qquad (9.8)$$

9.9.4 V_{CC} Capacitor, COMP Capacitor and V_G Pull-Up Resistor and Capacitor

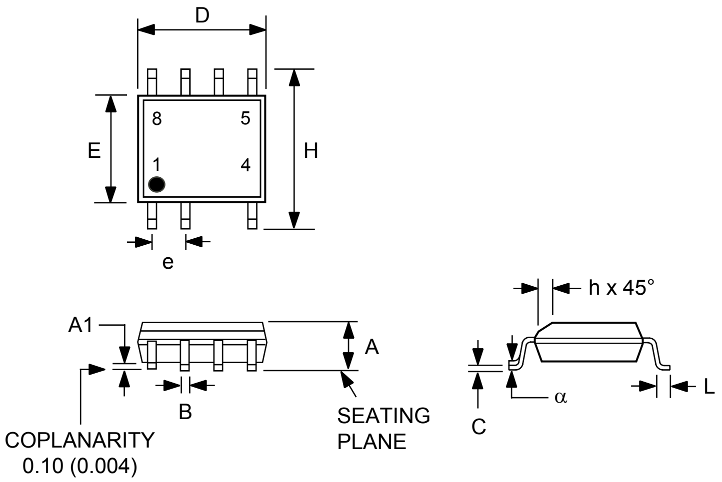
Table 9.3 shows recommended values and voltage ratings for different key components.

Item	Value	Rating
V_{CC} cap	6.8µF to 22µF	10V
COMP cap	2.2µF	10V
V_G cap	0.1µF to 0.22µF	50V
V_G resistor	1MΩ for 120V/2MΩ for 230V	250V/400V

Table 9.3: Recommended capacitor and resistor values for VCC, COMP and VG

10 Physical Dimensions

7-Lead Small Outline (SOIC) Package



Symbol	Inches		Millimeters	
	MIN	MAX	MIN	MAX
A	—	0.069	—	1.75
A1	0.004	0.0098	0.1	0.25
B	0.013	0.02	0.33	0.51
C	0.0075	0.0098	0.19	0.25
D	0.189	0.197	4.8	5
E	0.151	0.157	3.84	3.99
e	0.05 BSC		1.27 BSC	
H	0.2284	0.244	5.8	6.2
h	—	—	—	—
L	0.02	0.03	0.51	0.76
α	—	—	0°	8°

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 < 260˚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.

11 Ordering Information

Part no.	Options	Package	Description
iW3658-00	$120V_{AC}$ Input, 500V/3A MOSFET	SO-7	Tape & Reel[1]
iW3658-01	$230V_{AC}$ Input, 650V/2A MOSFET	SO-7	Tape & Reel[1]
iW3658-10	$120V_{AC}$ Input, 500V/2A MOSFET	SO-7	Tape & Reel[1]
iW3658-20	$120V_{AC}$ Input, 500V/2A MOSFET, optimized for high power factor	SO-7	Tape & Reel[1]
iW3658-31	$230V_{AC}$ input, 650V/2A MOSFET, optimized for high voltage load	SO-7	Tape & Reel[1]

Note 1: Tape and reel packing quantity is 3,000/reel. Minimum ordering quantity is 3,000.

Disclaimer

RoHS Compliance

Dialog Semiconductor's suppliers certify that its products are in compliance with the requirements of Directive 2011/65/EU of the European Parliament on the restriction of the use of certain hazardous substances in electrical and electronic equipment. RoHS certificates from our suppliers are available on request.

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