High Performance Step-Down DC/DC Controller with High-Resolution True DC Dimming for LED Lighting up to 65V

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1 Description

The iW380 is a DC/DC step-down controller with tight current regulation and exceptional dimming performance for LED lighting. It is designed to be used in the high-side switching buck topology up to 65V input voltage and up to 98% of output voltage/input voltage ratio. With its advanced digital control, the iW380 offers Dialog's True DC Dimming from 100% down to 0.0625% with 0.0625% resolution and guaranteed linearity.

The iW380 features unique dual-dimming pins that significantly simplify application designs where multi-level maximum current settings are needed. The maximum LED current can be programmed through one dimming pin via the analog voltage level or an adjustable resistor. The other dimming port can be used for auto-detectable 3-in-1 dimming: analog voltage, PWM duty or resistor dimming. Internally, the iW380 processes the dimming inputs and regulates the output current percentage by DIM1% x DIM2%.

A dedicated light-off mode in the iW380 turns off the output current when the dimming signal input is less than the light-off threshold. In the light-off mode, the iW380 consumes minimum power while still monitoring the dimming inputs. If the dimming signal input becomes higher than the light-on threshold, the iW380 can immediately wake up and resume output current regulation.

The iW380 provides flexibility to optimize dimming resolution and dimming signal noise immunity. When a noisy analog dimming level or jittering PWM dimming duty is supplied to the iW380, the iW380 can keep the output current stable with some tradeoff to dimming resolution by configuration. Also, the iW380 has configurable minimum startup voltage. This feature can effectively prevent light flicker/flash at power off across different applications.

2 Features

- Input DC voltage range: 22V ~ 65V
- Output/input voltage ratio: up to 98%
- Output power up to 150W
- Multiple operating mode product options:
  - Constant-current (CC) mode
  - Constant-voltage/constant-current (CV/CC) mode
  - Constant-power/constant-current (CP/CC) mode
- True DC dimming
  - Max dimming range: 0.0625% ~ 100%
  - Highest dimming resolution: 0.0625%
- CC line and load regulation < ±3%
- CV line and load regulation < ±3%
- Light-off current consumption < 1mA
- Over temperature current de-rating
- 3-in-1 dimming on both dimming ports
  - RSET resistor
  - PWM Dimming
  - Analog voltage
- Auto dimming signal types detection
- Configurable dimming signal hysteresis
- Configurable startup voltage
- Rich protections:
  - Output over voltage (OVP)
  - Output short circuit (OSP)
  - V_{VIN} over/under voltage
  - Over current protection (OCP)
  - Sense resistor short protection
  - Over temperature protection (OTP)

3 Applications

- Two-stage AC/DC general LED lighting drivers
- Two-stage AC/DC LED light strip drivers
- DC/DC general LED lighting drivers

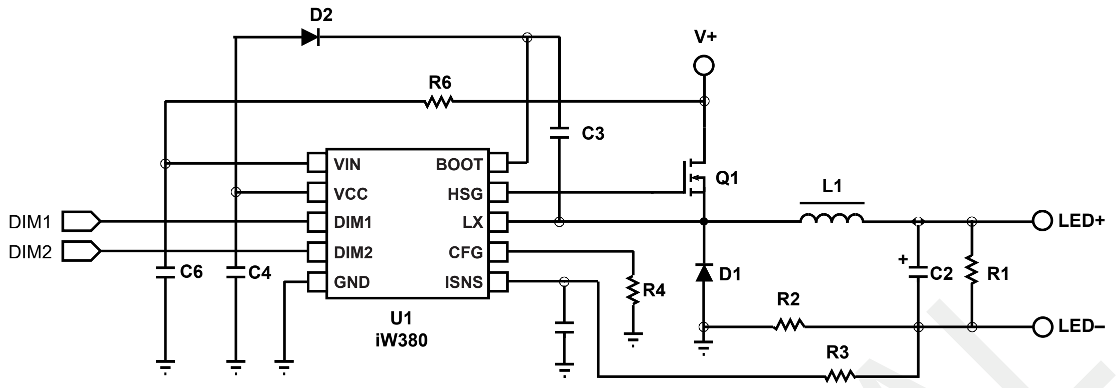


Figure 3.1 : iW380 Typical Application Circuit for CC only and CP/CC variants

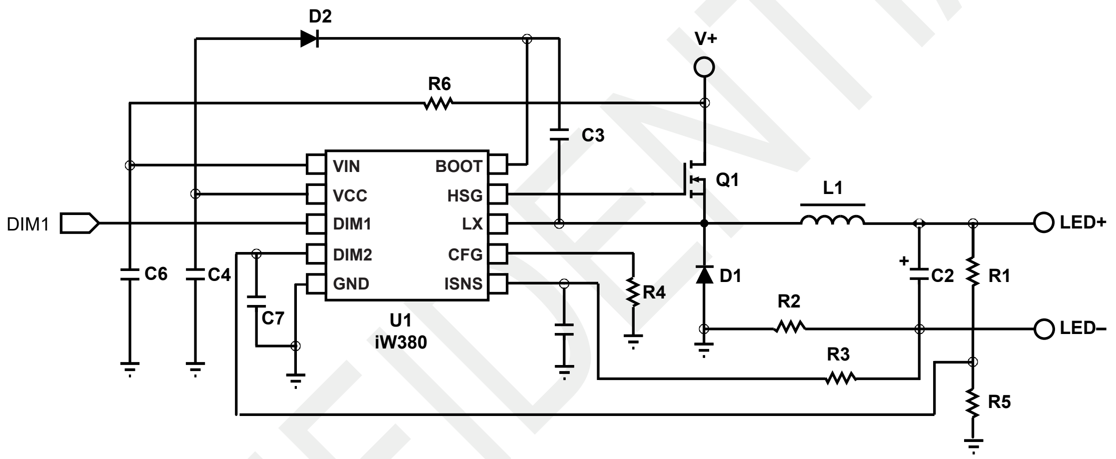


Figure 3.2 : iW380 Typical Application Circuit for CV/CC variants

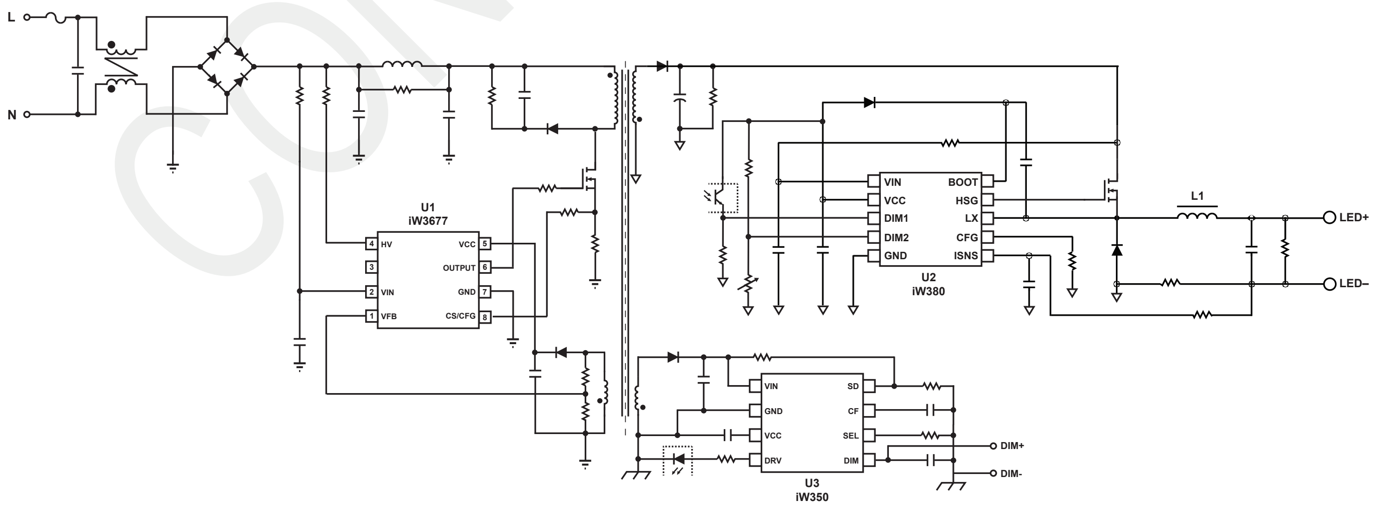


Figure 3.3 : iW380 Dimmable LED Driver Application with iW3677 Front-End Power Factor Correction Flyback and iW350 Interface IC

4 Pinout Description

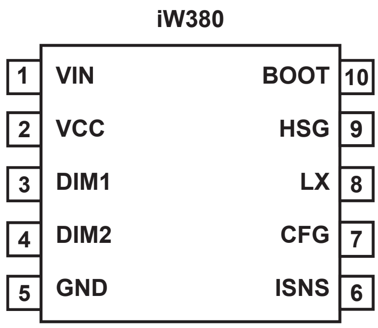


Figure 4.1 : 10-Lead SOIC Package

Pin Number	Pin Name	Type	Pin Description
1	VIN	Power	Power source and input voltage sensing
2	VCC	Power	IC power supply
3	DIM1	Analog Input	Dimming signal input port 1
4	DIM2	Analog Input	Dimming signal input port 2
5	GND	Ground	Ground reference
6	ISNS	Analog Input	Buck inductor current sensing
7	CFG	Analog Input	Configuration input
8	LX	Analog Input	Buck switching node, high-side power MOSFET source
9	HSG	Analog Output	High-side power MOSFET gate drive
10	BOOT	Power	Bootstrap high-side driver power supply

5 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 6.

Parameter	Symbol	Value	Units
DC supply voltage range	V_{VCC}	-0.3 to 6.5	V
Continuous DC supply at VCC pin	I_{VCC}	20	mA
VIN pin		-0.3 to 70	V
DIM1 and DIM2 pin		-0.3 to 6.5	V
ISNS pin		-0.3 to 6.5	V
CFG pin		-0.3 to 6.5	V
LX pin		-0.7 to 70	V
HSG pin (Note 1)		-0.3 to 75	V
BOOT pin (Note 1)		-0.3 to 75	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}	100	°C/W
ESD rating per JEDEC JS-001-2017		±2000	V
Latch-up test per JESD78E		±100	mA

Note 1. BOOT pin and HSG pin respect to LX pin < 6.5V.

6 Electrical Characteristics

V_{VCC} = 5V. All values are at T_A = +25°C, unless otherwise specified.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
VIN Section (Pin 1)						
VIN maximum operating voltage	V_{VIN}				65	V
VIN POR threshold	V_{VIN_POR}		TBD	16	TBD	V
VIN UVLO threshold	V_{VIN_UVLO}		TBD	12	TBD	V
VIN under-voltage threshold (Note 1)	V_{VIN_UVP}			14		V
VIN over-voltage threshold (Note 1)	V_{VIN_OVP}			TBD		V
VIN quiescent current	I_{VIN_OP}	V_{VIN} = 40V		2.67		mA
VIN standby current	I_{VIN_STBY}	V_{VIN} = 40V, light-off mode			TBD	mA
VCC Section (Pin 2)						
VCC output voltage	V_{VCC}		TBD	5.0	TBD	V
DIM Section (Pins 3, 4)						
Highest analog DIM voltage	V_{REF_ADIM}	Internal ADC reference		3.3		V
PWM DIM reference voltage	V_{REF_PDIM}	PWM low threshold	TBD	1	TBD	V
PWM DIM hysteresis (Note 1)	V_{HYST_PDIM}	PWM high threshold above PWM low threshold		0.5		V
Analog DIM 0% threshold (Note 1)	V_{ADIM_LO}			362		mV
Analog DIM 100% threshold (Note 1)	V_{ADIM_HI}			2933		mV
Light-off threshold (Note 1)	L_OFF_TH			0.0625		%
Light-on threshold (Note 1)	L_ON_TH	-01 Option		0.3125		%
		All other options		0.5625		%
ISNS Section (Pin 6)						
ISNS upper regulation limit at no DIM (Note 1)	$V_{IPKP(NO\ DIM)}$			436		mV
ISNS lower regulation limit at no DIM (Note 1)	$V_{IPKN(NO\ DIM)}$			364		mV
OCP voltage threshold	V_{OCP_VTH}		TBD	580	TBD	mV
Short voltage threshold	V_{SHORT_VTH}		TBD	18	TBD	mV
CFG Section (Pin 7)						
Config current range	I_{CFG_RANGE}		TBD	100	TBD	µA
LX Section (Pin 8)						
LX Low detection threshold	$V_{LX\_LOW\_VTH}$		TBD	1.5	TBD	V
Bleeder current	I_{BLD}			28		mA

6 Electrical Characteristics (Cont'd)

V_{VCC} = 5V. All values are at T_A = +25°C, unless otherwise specified.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
HSG Section (Pin 9)						
Pull-up resistance	R_{DSON_P}	V_{BOOT} = 5V		5.8		Ω
Pull-down resistance	R_{DSON_N}	V_{BOOT} = 5V		3.8		Ω
Maximum ON time (Note 1)	$T_{ON(MAX)}$			100		µs
Minimum ON time (Note 1)	$T_{ON(MIN)}$			500		ns
Maximum OFF time (Note 1)	$T_{OFF(MAX)}$			200		µs
Minimum OFF time (Note 1)	$T_{OFF(MIN)}$			300		ns
Propagation delay from I_{SNS} cross regulation threshold to gate turn on (Note 1)	T_{DELAY}			TBD		ns
BOOT Section (Pin 10)						
High-side gate driver POR (Note 1)	V_{GPOR}			TBD		V
High-side gate driver UVLO (Note 1)	V_{GUVLO}			TBD		V
Temperature Sensor						
Over temperature protection threshold (Note 1)	T_{OTP}			150		°C
Max startup temperature (Note 1)	$T_{ST(MAX)}$			140		°C

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

7 Typical Performance Characteristics

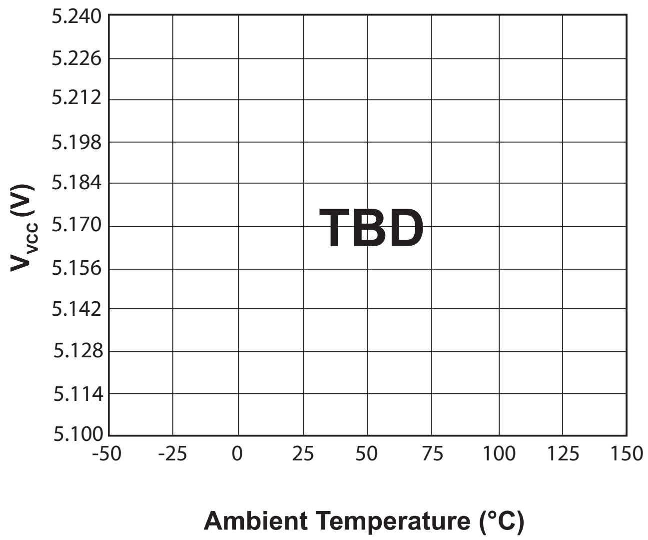


Figure 7.1 : V_{VCC} vs. Temperature

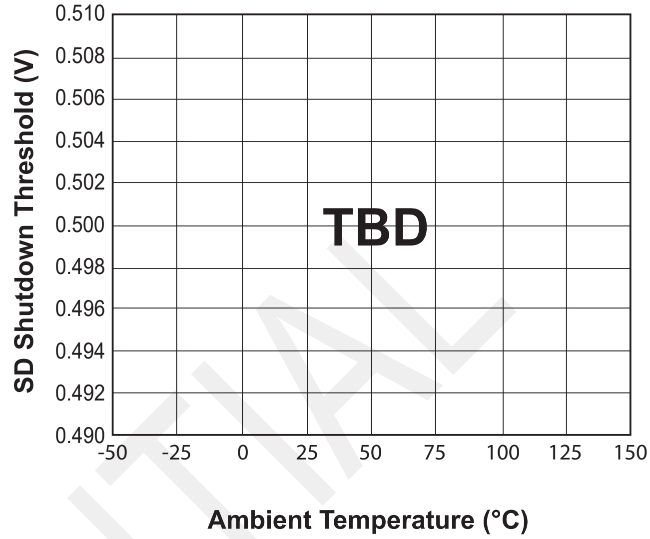


Figure 7.2 : SD Shutdown Threshold vs. Temperature

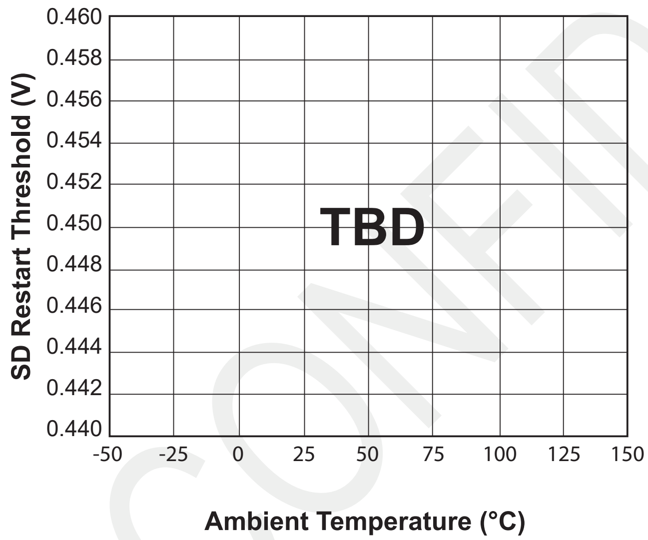


Figure 7.3 : SD Restart Threshold vs. Temperature

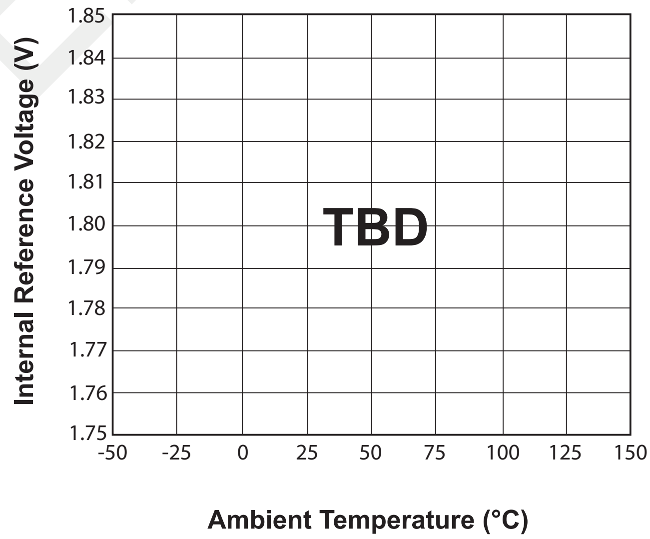


Figure 7.4 : Reference Voltage vs. Temperature

8 Functional Block Diagram

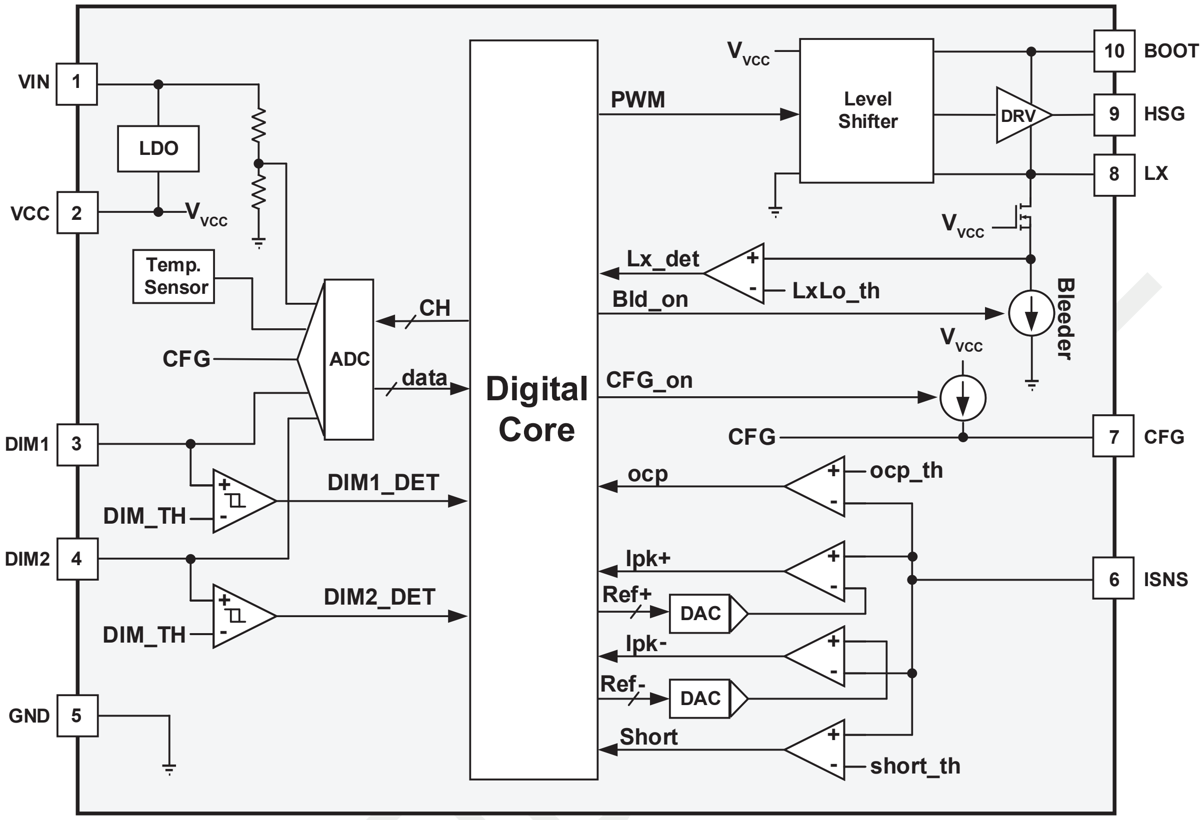


Figure 8.1 : iW380 Functional Block Diagram

9 Theory of Operation

The iW380 high-resolution DC/DC step down converter allows exceptional dimming performance for solid state lighting applications. Dialog's True DC dimming technology enables the highest light quality over the full dimming range from 0.0625% to 100% of the maximum output current. The output current is decreased in amplitude from 100% down to 10% and below 10%, the output current is PWM'ed to continuing dimming down to 0.0625%. This method keeps the output current ripple to a minimum and improves the quality of light output over the full dimming range.

The iW380 detects two dimming signals from external sources and uses advanced digital processing to determine the output current percentage level. This level is mapped to corresponding buck inductor current upper and lower boundaries as well as burst mode on and off timings. The inductor current is sensed via the ISNS pin and compared to the boundaries set by the dimming signal processor. The power MOSFET is then switched on or off when the current reaches the lower and upper boundaries, respectively.

The iW380 operates in hysteretic continuous conduction mode (CCM) and the output current is the average of upper and lower boundaries of inductor current. Therefore, the output current of the iW380 is tightly regulated regardless of the input voltage, output voltage or inductor value.

The absolute input voltage (V_{VIN}) is sensed by the iW380 in real time and the absolute output voltage (V_{OUT}) is calculated in real time using the following equation:

$$V_{OUT} = \left(\frac{T_{ON}}{T_P}\right) \times V_{VIN} \qquad (9.1)$$

By continuously monitoring the input voltage and output voltage, the iW380 can protect from abnormal operating conditions such as over or under voltage conditions on both the input and output. And, it can detect if the input voltage and output voltage are too close in value and take actions to avoid consequences such as flicker or flash.

9.1 Pin Details

Pin 1 VIN

The VIN pin is used to power the V_{VCC} of the iW380 via an internal 5V regulator. It is also used to sense the input voltage level in order to determine if the input voltage is within the normal operating range. The input voltage (V_{VIN}) and power MOSFET on/off timing information are used to calculate the V_{OUT} in the iW380. V_{VIN} is also used for POR/UVLO of the iW380. The VIN pin should connect to the system input voltage via an RC filter (~100Ω and ~220nF).

Pin 2 VCC

The VCC pin is the internal power supply output of the iW380 and is accurately regulated at 5V. The output voltage on the VCC pin is also used as the power of the bootstrap circuit for the high-side power MOSFET driver. Although V_{VCC} is a power rail, it is NOT recommended to use V_{VCC} to power any other device such as the system MCU, which will cause high power dissipation in the iW380. However, V_{VCC} can be used to bias the adjustable or fixed resistor divider to generate a voltage level for DIM pin. The current draw from the VCC pin other than the IC itself should be limited to < 1mA. A low ESR capacitor of 2.2µF to 22µF should be connected from the VCC pin to ground.

Pin 3 DIM1

The DIM1 pin is used with the DIM2 pin to set the maximum output current. The total output current provided to the load is the product of the DIM1 and DIM2 voltages applied at any given time. For example, if a 50% PWM duty cycle is applied to DIM1 and a 50% duty cycle is applied to DIM2, the total output current will be 25% of the maximum programmed output current.

The PWM duty cycle signal needs to be 3.3V (+/- 5%) or 5V (+/-5%) logic with a frequency range within the 0.1kHz ~ 5kHz range. An analog signal can also be used and any voltage below V_{ADIM_LO} maps to 0% output current and any voltage above V_{ADIM_HI} maps to 100% duty cycle. From V_{ADIM_LO} to V_{ADIM_HI}, the relationship between voltage and output current percentage is linear (0% to 100%) - see figure 9.3. The iW380 can automatically determine whether the input signal is PWM or analog at startup as long as the PWM signal complies with the signal requirements.

There are different hysteresis levels and function settings based on the CFG resistor settings. Please see the CFG pin detail and tables 9.2 and 9.3 for additional detail.

Pin 4 DIM2

The DIM2 pin is used with the DIM1 pin to set the maximum output current. The total output current provided to the load is the product of the DIM1 and DIM2 voltages applied at any given time. For example, if a 50% PWM duty cycle is applied to DIM2 and a 50% duty cycle is applied to DIM1, the total output current will be 25% of the maximum programmed output current.

The PWM duty cycle signal needs to be 3.3V (+/- 5%) or 5V (+/-5%) logic with a frequency range within the 0.1kHz ~ 5kHz range. An analog signal can also be used and any voltage below V_{ADIM_LO} maps to 0% output current and any voltage above V_{ADIM_HI} maps to 100% duty cycle. From V_{ADIM_LO} to V_{ADIM_HI}, the relationship between voltage and output current percentage is linear (0% to 100%) - see figure 9.3. The iW380 can automatically determine whether the input signal is PWM or analog at startup as long as the PWM complies with the signal requirements.

There are different hysteresis levels and function settings based on the CFG resistor settings. Please see the CFG pin detail and tables 9.2 and 9.3 for additional detail.

DIM2 can also be used as a feedback pin for constant-voltage (CV) control product options (see figure 3.2 and section 11).

Pin 5 GND
Ground.

Pin 6 ISNS
The ISNS pin is used for buck inductor current sensing. The inductor current is compared to the upper and lower limits in real time for power MOSFET on/off control. The inductor current is tightly regulated and this also enables tight control of the output current across the entire dimming range. In application, the 100% output current absolute value can be set by:

$$100\%\ I_{OUT}\ (mA) = \left(\frac{400mV}{R_S}\right) \qquad (9.2)$$

Where R_S is the current sense resistor value. In figure 3.1, R_S corresponds to R2. An RC filter is recommended to filter high frequency noise. The recommended time constant for the R3/C5 filter (see figure 3.2) is between 1-5ns.

Pin 7 CFG
The CFG pin is used to configure multiple aspects of the iW380. At startup, current equal to I_{CFG_RANGE} is enabled on the CFG pin and generates a voltage drop proportional to the resistance of the CFG resistor. The iW380 reads back the voltage and determines which CFG setting should be implemented.

CFG Setting	Minimum Resistance	Maximum Resistance
1	0.1kΩ	1.62kΩ
2	2.57kΩ	3.97kΩ
3	5.28kΩ	6.74kΩ
4	8.46kΩ	10.06kΩ
5	12.28kΩ	14.08kΩ
6	16.91kΩ	19.08kΩ
7	22.67kΩ	25.29kΩ

Table 9.1 CFG Resistance vs. CFG setting

The CFG settings optimize the device performance for different applications. There are two main factors when deciding configuration:

1. The maximum V_{OUT} of the application determines different startup voltage ($V_{VIN(ST)}$) and OVP threshold ($V_{OVP(TH)}$) to avoid turn off flash or output capacitor over voltage.
2. The dimming pin usage determines different hysteresis for handling different types of signals and different I_{OUT} filter RC time constants. For example, if the PWM dimming signal is from DALI or IoT modules, a small hysteresis is preferred to achieve the highest dimming resolution. Those modules often have embedded I_{OUT} smoothing control for transients. Thus, the I_{OUT} filtering in the iW380 should be minimized to avoid “double-filtering”. On the other hand, if the PWM signal is coming from 0-10V dimmer via an interface IC and an optocoupler, the signal has steady state jitter. A relatively large hysteresis is required to ensure stability of I_{OUT}. With the iW380’s built-in I_{OUT} filter RC time constant, the visual effect of dimming transient is optimized.

CFG	Application	DIM1 Hysteresis	DIM2 Hysteresis	I_{OUT} Filter RC Time	Startup Voltage ($V_{VIN(ST)}$)	OVP Enable	OVP Threshold ($V_{OVP(TH)}$)
1	$V_{OUT(MAX)}$ = 48V ~ 54V, DIM1 = max current set, DIM2 = high resolution dimming	2.00%	0.05%	2.8ms	58V	Yes	57V
2	$V_{OUT(MAX)}$ = 48V ~ 54V, DIM1 = 0-10V dimming, DIM2 = max current set	0.20%	2.00%	25.2ms	58V	Yes	57V
3	$V_{OUT(MAX)}$ = 37V ~ 48V, DIM1 = max current set, DIM2 = high resolution dimming	2.00%	0.05%	2.8ms	49V	Yes	48V
4	$V_{OUT(MAX)}$ = 37V ~ 48V, DIM1 = 0-10V dimming, DIM2 = max current set	0.20%	2.00%	25.2ms	49V	Yes	48V
5	$V_{OUT(MAX)}$ = 20V ~ 36V, DIM1 = max current set, DIM2 = high resolution dimming	2.00%	0.05%	2.8ms	43V	No	N/A
6	$V_{OUT(MAX)}$ = 20V ~ 36V, DIM1 = 0-10V dimming, DIM2 = max current set	0.20%	2.00%	25.2ms	43V	No	N/A
7	$V_{OUT(MAX)}$ = 37V ~ 54V, DIM1 = 0-10V dimming, DIM2 = high resolution dimming	0.20%	0.05%	2.8ms	52V	No	N/A

Table 9.2 CFG setting vs. configuration for CC only and CP/CC variant

For the CV/CC variants, DIM2 is used for CV feedback. The DIM1 pin is used for dimming when the application still uses CC in general and needs CV regulation when V_{OUT} equals the CV limit. For applications which do not require CC limit change, such as LED light strips driver, the dimming function on DIM1 is disabled to reduce power consumption. In this case, the iW380 acts as a DC power supply with current limiting equal to 100% dimming level.

CFG	Application	DIM1 Pin Enabled/Disabled	DIM1 Hysteresis	I_{OUT} Filter RC Time	Startup Voltage ($V_{VIN(ST)}$)
1	LED light strip 12V	Disabled	N/A	N/A	22V
2	LED light strip 24V	Disabled	N/A	N/A	27V
3	DC output = 48V	Disabled	N/A	N/A	52V
4	V_{OUT} = 40V~54V, high resolution dimming, load open = CV	Enabled	0.05%	2.8ms	52V
5	V_{OUT} = 40V~54V, 0-10V dimming, load open = CV	Enabled	0.20%	25.2ms	52V
6	V_{OUT} = 20V~40V, high resolution dimming, load open = CV	Enabled	0.05%	2.8ms	43V
7	V_{OUT} = 20V~40V, 0-10V dimming, load open = CV	Enabled	0.20%	25.2ms	43V

Table 9.3 CFG settings vs. configurations for CV/CC variant

Pin 8 LX
LX pin is the buck switching node as well as the source of the high-side power MOSFET. The LX pin can swing between V_{VIN} and negative V_F of rectifier diode. It is considered the "ground" of the high-side power MOSFET driver. In the iW380, the LX pin also has a bleeder built-in to discharge the LX node and V_{OUT} voltage (via buck inductor) at light-off mode or fault conditions. This way, the high-side driver can be permanently sustained by V_{VCC} via the bootstrap diode. An LX pin voltage sensor is used to determine whether the LX pin has been discharged to GND by the bleeder.

Pin 9 HSG
HSG pin is the high-side driver gate drive pin. It is connected to the high-side power MOSFET gate to turn on and off the MOSFET. When turning on, HSG is about 5V higher than the LX pin. When turning off, HSG is nearly shorted to the LX pin. The absolute voltage of HSG pin to ground is V_{VIN} + V_{BOOT} at turn on.

Pin 10 BOOT
BOOT pin is the high-side gate driver power supply. It is charged by V_{VCC} through the boostrap diode when the inductor is discharging, and LX nearly equals to GND. A capacitor of 100 to 220nF should be connected between the BOOT and LX pins to hold the power for the high-side driver when not switching (and V_{OUT} is not 0) or during on-time of the MOSFET. The differential voltage between the BOOT and LX pins is always around 5V. The absolute voltage of the BOOT pin to GND is LX + 5V.

9.2 Operational Cycle and States

The iW380 is powered by V_{VIN}. As soon as V_{VIN} reaches the POR level, the internal the V_{VCC} regulator starts to work and generate V_{VCC} for the iW380 internal circuit. If at any time during operation, V_{VIN} drops below UVLO or V_{VCC} drops below 4V, the iW380 will shut down until V_{VIN} or V_{VCC} recovers.

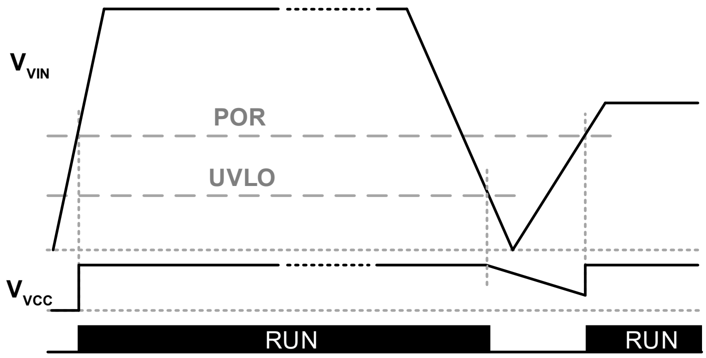


Figure 9.1 : V_{VIN} and V_{VCC} POR/UVLO

After POR, the iW380 enters the qualification state. The qualification state checks if $V_{VIN} > V_{VIN(ST)}$ and if the junction temperature is below the startup temperature threshold ($T_{(ST)}$). If both pass, the iW380 exits qualification state. If either qualification fails, the iW380 will stay in qualification state until it passes.

The iW380 enters constant-current (CC) state after exiting qualification and detects the DIM pin signals and determines the dimming percentage. The device then proceeds to provide the output current percentage as determined by the DIM pins. As long as the input and output conditions are ok, the iW380 remains in CC state and provides the output current required by the DIM signals in real time. For the CV/CC variant, if the scaled output voltage (V_{OUT}) reaches V_{OUT} reference 2.5V, the iW380 enters CV state and the internal control loop will adjust the output current percentage to maintain the scaled V_{OUT} equal to 2.5V. The iW380 can switch between CC and CV state depending on loading conditions.

When the input, output or thermal condition does not meet the operating criteria, the iW380 enters a fault state, discharges the output voltage and resets. OVP, UVP and OTP will incur a wait time before the next restart attempt. Detailed information can be found in section 9.7.

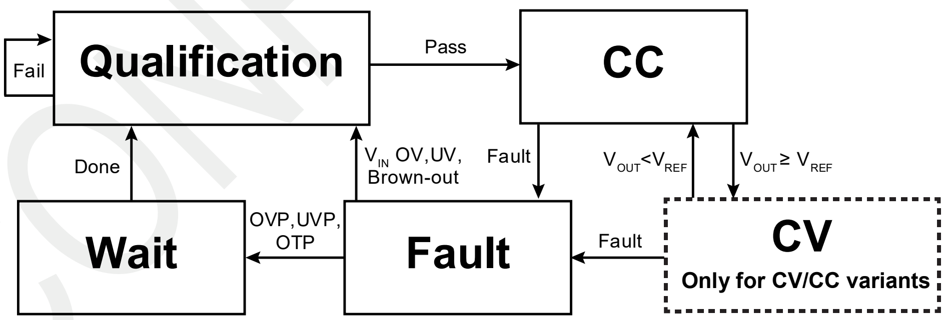


Figure 9.2 : States of iW380 Operation

9.3 Dimming Signal Processing

The iW380 can accept both PWM and analog voltage level signals as commands to control the output current percentage. At startup, the iW380 detects the signal type and responds accordingly. By default, the iW380 assumes the dimming signal input is an analog level until it sees consistent PWM style toggling.

The specification and mapping of accepted analog level signal and PWM duty signal are described in detail in section 9.1 (DIM pin details). The I_{OUT} % = DIM1% x DIM2% then rounded to the closest 0.0625% step.

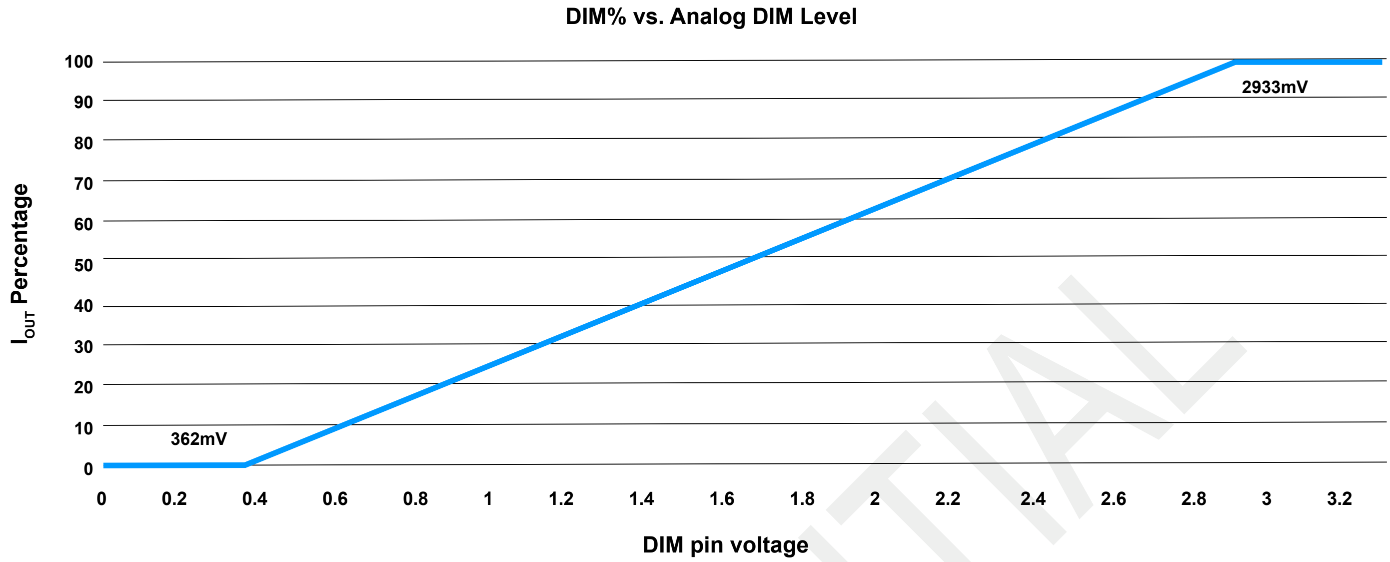


Figure 9.3 : Analog Level Signal vs. DIM% Mapping

For the special case of 100% duty or 0% duty of PWM signal, both are essentially an “analog voltage level”. Therefore, PWM = 1 voltage level must > 3.3V * 95% = 3.13V and PWM = 0 voltage level must < 3.3V * 5% = 165mV. This definition is compatible with analog voltage level signal 100% and 0% respectively.

A configurable hysteresis is built-in to optimize performance for dimming resolution and dimming signal noise immunity. The window size is equal to how much noise or jitter can be tolerated on the PWM duty signal or the analog level signal. Table 9.4 below shows the hysteresis window size vs. noise level and jitter that can be tolerated. Please note the minimum clamp of the analog level signal type’s hysteresis window is 0.5% due to ADC sensor resolution in the iW380.

Hysteresis Window	PWM Jitter Allowance @ 1kHz	PWM Jitter Allowance @ 5kHz	Analog Level Noise Tolerance %
0.05%	±250ns	±50ns	±6.4mV (clamp to 0.5%)
0.20%	±1µs	±200ns	±6.4mV (clamp to 0.5%)
2%	±10µs	±2µs	±25.6mV

Table 9.4 Hysteresis Window Size

9.4 True DC Dimming - Current Regulation and Light-off Mode

To achieve Dialog's True DC dimming, the current regulation in the iW380 has two different modes: continuous mode and burst mode. The continuous mode is used between I_{OUT} = 100% to 10% while the burst mode is used in I_{OUT} = 10% to I_{OUT} = 0.0625%. Although burst mode will cause larger ripple, the relative high burst frequency and low energy output together with a reasonable sized output capacitor can make I_{OUT} appear DC from the user point of view. This enables True DC dimming across the entire dimming range from 100% down to 0.0625%. A 0.5% hysteresis is set between the light-off threshold (L_OFF_TH) and light-on threshold (L_ON_TH) to avoid flickering when entering or exiting light-off mode.

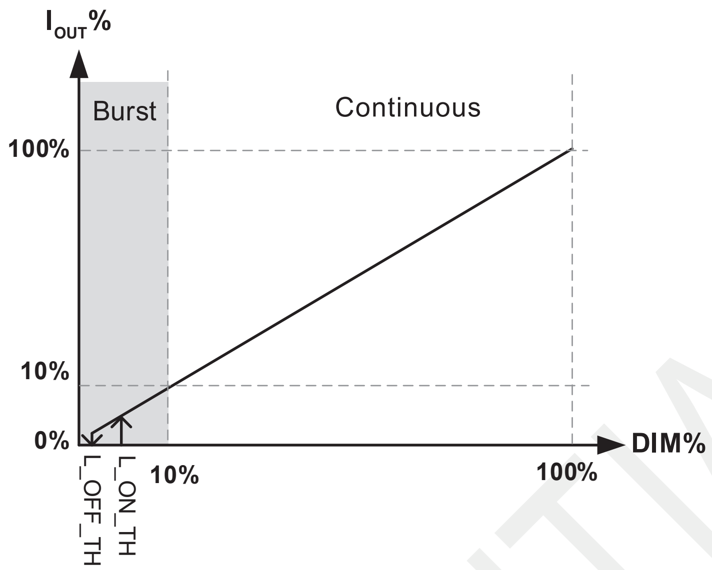


Figure 9.4 : I_{OUT}% vs. Dimming % and Light-off

The operation of continuous mode is straight forward. When the buck inductor current drops below the lower limit, the power MOSFET is turned on and the buck inductor current starts to rise linearly. When the buck inductor current reaches the upper limit, the power MOSFET is turned off and the buck inductor current starts to fall linearly. And this process repeats indefinitely. The regulated I_{OUT} = (upper limit + lower limit) / 2

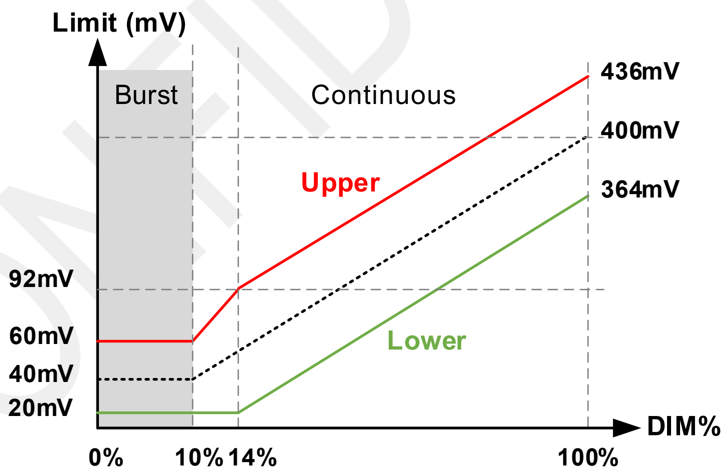


Figure 9.5 : Upper Limit and Lower Limit of Buck Inductor Current vs. I_{OUT} %

When the dimming level is < 10%, the upper and lower limits of the buck inductor current cannot be further dropped due to signal fidelity. The iW380 enters the burst mode to further decrease the output current percentage. Each burst period equals to 40 times of power MOSFET switching periods and is updated in real time. Therefore, the burst frequency is V_{VIN}, V_{OUT} and L_M dependent and can be adjusted by application. The I_{OUT} is regulated by the duty cycle of each burst group. For example, if the iW380 can execute 20 switching pulses and halt 20 switching pulses in one burst group, I_{OUT} = 10% * (20/40) = 5%.

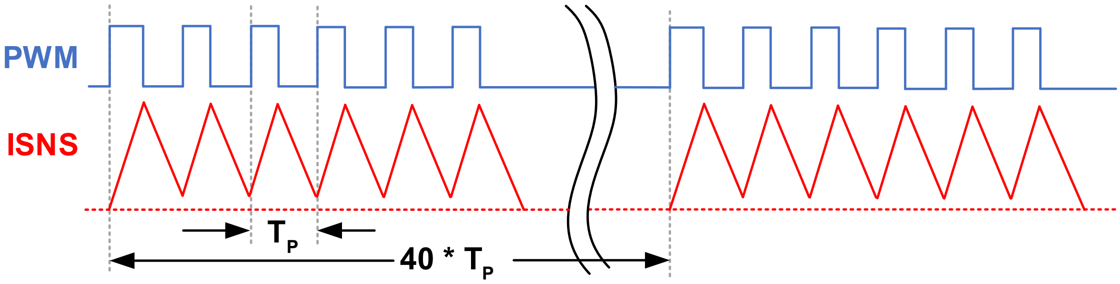


Figure 9.6 : Burst Mode Operation

A special light-off mode is included in the iW380 to completely turn off I_{OUT} and achieve remote turn-off function while the iW380 stays powered by V_{VIN}. In order to enter light-off mode, the set dimming percentage must be lower than the light-off threshold. Once entered, V_{OUT} will be discharged to 0 by the bleeder and the power MOSFET stops switching. The iW380 also enters low power mode for minimum power consumption. The DIM pins are continuously monitored. As soon as the dimming percentage is equal to or greater than the light-on threshold (L_ON_TH), the operation will resume.

9.5 Constant Power Limit for CP/CC Variants

Besides detecting OVP event, the V_{OUT} information in the iW380 is also used to calculate the I_{OUT_MAX} limit the CP/CC variant of the iW380 to limit the output power level when V_{OUT} increases.

The iW380 sets the 100% output voltage level to equal the selected OVP level (see section 9.1 CFG pin). The CP limit can be selected by part number option. At any V_{OUT} %, I_{OUT_MAX} can be calculated by:

$$I_{OUT\_MAX} \text{ (max clamped to 100\%)} = \left(\frac{\text{CP constant}}{V_{OUT}}\right) \% \qquad (9.3)$$

For example, if the C_P constant = 50%, when $V_{OUT} \leq 50\%$, I_{OUT_MAX} = 100%; when V_{OUT} = 100%, I_{OUT_MAX} = 50%. If the CP constant = 70%, when $V_{OUT} \leq 70\%$, I_{OUT_MAX} = 100%; when V_{OUT} = 100%, I_{OUT_MAX} = 70%.

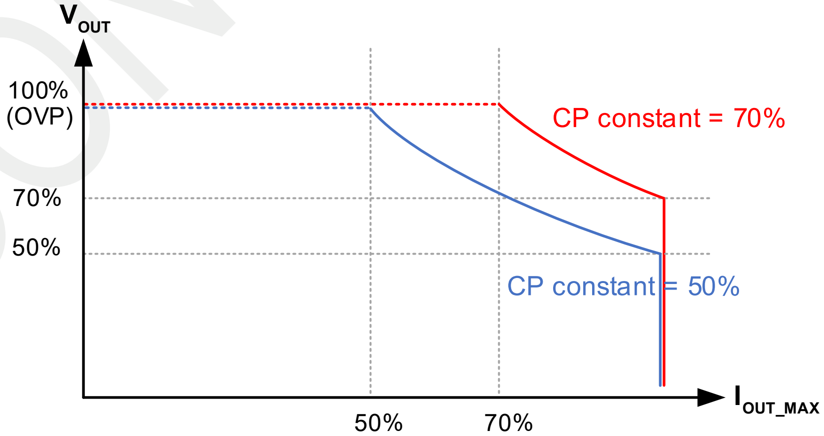


Figure 9.7 : I_{OUT_MAX} vs. V_{OUT} % for Different CP Constants

Note that when I_{OUT_MAX} < 100%, a dead zone in the dimming will occur. For example, if I_{OUT_MAX} = 75% at a given V_{OUT}, dimming signal input between 75% ~ 100% will all result in I_{OUT} = I_{OUT_MAX} = 75%.

9.6 Constant Voltage Regulation for CV/CC variants

Although the absolute V_{OUT} is a known for the iW380, to achieve good CV regulation in both steady state and dynamic load conditions, sensing the output voltage directly is necessary. For CV/CC variants, DIM2 pin is used for V_{OUT} sensing feedback (refer to Figure 3.2). A resistor divider ratio should be selected so that the desired V_{OUT} CV level is 2.5V multiplied by the ratio:

$$V_{OUT}(CV) = 2.5V \times \left(\frac{R1+R5}{R5}\right) \qquad (9.4)$$

When in the CV mode, the scaled V_{OUT} is compared to 2.5V. The difference of the two is fed into a digital error amplifier and generates the desired I_{OUT} % to keep scaled V_{OUT} regulated to 2.5V. The control loop is internally compensated and is guaranteed stable across all input and output conditions.

When the control loop derived I_{OUT} % is higher than the I_{OUT} % set by DIM1 pin (in configurations where DIM1 function is disabled, the limit is I_{OUT} = 100%, refer to 9.1 CFG section), the final I_{OUT} % will be limited by DIM1 pin and the iW380 will enter CC mode in this case.

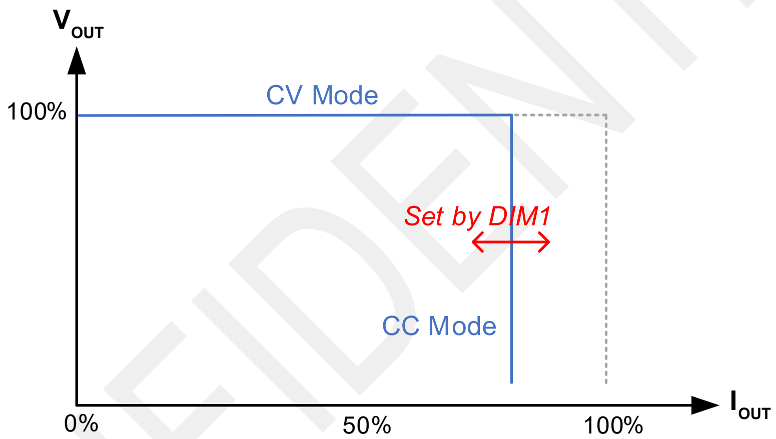


Figure 9.8 : CV/CC Variant Operation

Due to the voltage drop across the ISNS resistor, the sensed V_{OUT} is slightly different than the true V_{OUT}. The percentage difference is anywhere between nearly 0 at no load to 400mV/V_{OUT} depending on the I_{OUT} %. The iW380 compensates this difference in % to achieve tight load regulation.

9.7 Protections, Limits and De-Rating

The iW380 has a comprehensive set of the protection features to protect the application circuit and LED load from damage under abnormal conditions.

9.7.1 Brown-out (Power Shutdown)

When power is shutdown, the power source is cut off and V_{VIN} starts to decay as the iW380 still delivers power to the load. When V_{VIN} approaches V_{OUT}, the on-time (T_{ON}) will become longer to reach the inductor current upper limit. The brown-out protection is triggered when $T_{ON(MAX)}$ is reached 16 consecutive times and at the same time $V_{VIN} < V_{VIN(ST)}$. Reaching $T_{ON(MAX)}$ is an indicator that V_{VIN} is too close to V_{OUT} and the buck converter is no longer able to regulate I_{OUT}.

Once triggered, the iW380 stops switching and discharges V_{OUT} by the bleeder. During this time, V_{VIN} is being monitored.

If at any time $V_{VIN} > V_{VIN(ST)}$, the iW380 will reset itself immediately to go through a fresh startup cycle. Otherwise, the iW380 will reset itself after V_{OUT} is discharged to 0. Once reset, V_{VIN} is being checked continuously at qualification state. At any time if $V_{VIN} > V_{VIN(ST)}$, the iW380 will startup again.

This brown-out mechanism makes sure that the iW380 not only stops operation when the V_{VIN} condition does not meet the requirement, but also restarts without delay at any time when the V_{VIN} condition recovers.

9.7.2 V_{VIN} Over-voltage Protection (V_{VIN} OVP) and V_{VIN} Under-voltage Protection (V_{IN} UVP)

When $V_{VIN} > V_{VIN\_OVP(TH)}$ or $V_{VIN} < V_{VIN\_UVP(TH)}$ for longer than 200μs, V_{VIN} OVP or V_{VIN} UVP will trigger. The action taken after V_{VIN} OVP or UVP is same as for brown-out protection. If V_{VIN} recovers at any moment, the iW380 will have a fresh restart without any delay.

9.7.3 Output Over-voltage Protection (OVP) and Output Short Protection (OSP)

When $V_{OUT} > V_{OVP(TH)}$ for longer than 200μs or 16 consecutive $T_{ON(MAX)}$ while $V_{VIN} > V_{VIN(ST)}$, OVP will be triggered. When $V_{OUT} < V_{OSP(TH)}$ for 200μs or 16 consecutive $T_{OFF(MAX)}$ while $V_{VIN} > V_{VIN(ST)}$, OSP will be triggered.

For CC only and CC/CP variants, the OVP threshold ($V_{OVP(TH)}$) can be found in table 9.2. The OSP threshold ($V_{OSP(TH)}$) is a fixed 3V. For CC/CV variants, $V_{OVP(TH)}$ is 3V and $V_{OSP(TH)}$ is 0.5V.

Once OVP or OSP is triggered, V_{OUT} is discharged to 0. After discharge is done or discharge lasts for 1s, the iW380 resets itself and proceeds with a delayed startup after waiting for 1s. This is to prevent high frequency hiccup if OV or UV condition persists. For example, if the load is kept open, the iW380 will startup and hit OVP, discharge V_{OUT}, wait for 1s then restart and hit OVP again, discharge V_{OUT}, wait for another 1s and restart the 3rd time etc. The 1s per attempt not only lowers the stress of the system, but also saves the average power loss during continuous open or short conditions.

9.7.4 ISNS Resistor Short Protection

The ISNS resistor is critical for the iW380 to regulate the output current. It is important to make sure that the ISNS resistor is not short before starting to deliver power for safety. During the qualification state, the iW380 will send out two small pulses with maximum $T_{ON(ISNS)} = 100V{*}\mu s/V_{IN}$. When T_{ON} is shorter than $T_{ON(ISNS)}$ and $V_{ISNS} > 60mV$, the power MOSFET will be turned off and considered a pass. When T_{ON} is equal to $T_{ON(ISNS)}$, the power MOSFET will also be turned off. If $V_{ISNS} > V_{SHORT\_VTH}$ at the turn off moment, it is also considered a pass. After both pulses pass the iW380 will proceed to startup, otherwise triggers ISNS short protection.

Once the ISNS resistor short protection is triggered, V_{OUT} will be discharged and the iW380 will reset itself, wait 1s and proceed with a fresh startup attempt just like OVP and OSP.

9.7.5 Over-Temperature Protection (OTP) and Temperature De-rating

A junction temperature sensor is built-in to the iW380. The iW380 continuously monitors the junction temperature during operation. If at any time the IC junction temperature > T_{OTP} for more than 80ms, OTP will trigger.

Once OTP is triggered, the iW380 will discharge V_{OUT} and reset itself, wait for 1s and initiate a fresh restart attempt like OVP and OSP. Normally, the IC junction temperature will not cool down fast enough that junction temperature < $T_{(ST)}$. Thus, the iW380 will stay in the qualification state until this condition is met.

Besides the OTP, an I_{OUT_MAX} de-rating mechanism is included in the iW380 to reduce power step-by-step when moderate over temperature events occur. If the temperature recovers, the iW380 will also recover from de-rating step-by-step. In this way, the impact to lighting performance is minimized under temporary and moderate over temperature events. The I_{OUT_MAX} de-rating and recover conditions vs. temperature is depicted in the Figure 9.8. When de-rating occurs, it takes the iW380 about 4s to slowly change the I_{OUT_MAX} from one level to another in order to avoid instability from positive feedback between junction temperature and power.

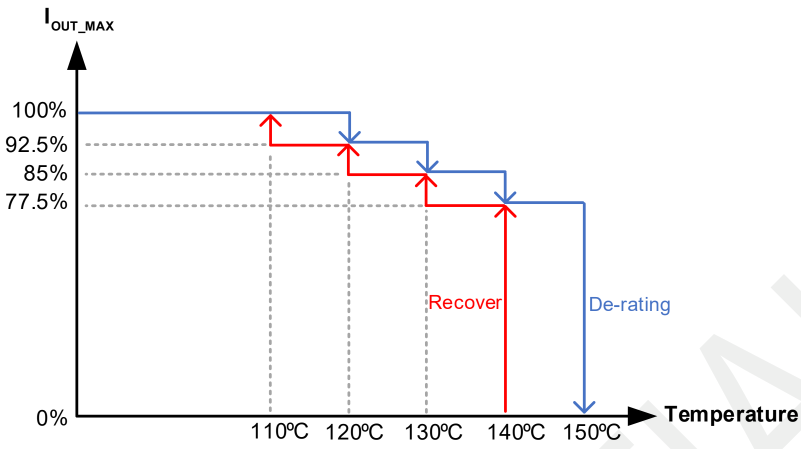


Figure 9.9 : I_{OUT_MAX} vs. Junction Temperature

9.7.6 Cycle-by-cycle Limits

The iW380 has built-in limits for each switching cycle of the power MOSFET. These limits are $T_{ON(MIN)}$, $T_{OFF(MIN)}$, $T_{ON(MAX)}$ and max $T_{OFF(MAX)}$. Also, an independent over-current protection is included. For conditions such as inductor winding short, if V_{ISNS} is higher than the OCP threshold voltage (V_{OCP_VTH}), the power MOSFET will be turned off immediately to prevent damage. OCP only disables power MOSFET switching but does not trigger any protection.

9.8 Buck Inductor and Power Device Selection

9.8.1 Buck inductor Consideration

The main consideration behind the buck inductor determination is the operating frequency. For hysteretic buck converters, the maximum operating frequency occurs at V_{OUT} = 50% * V_{VIN}. With this assumption, "max of the max" frequency is at low dimming where I_{OUT} < 10%. And the "min of the max" frequency is at high dimming where I_{OUT} = 14% ~ 100%. They can be calculated by:

$$F_{SW\_MAX} = \frac{1}{\frac{160mV \times \left(\frac{L_M}{R_S}\right)}{V_{VIN}} + 0.1\mu s} \tag{9.5}$$

$$F_{SW\_MIN} = \frac{1}{\frac{288mV \times \left(\frac{L_M}{R_S}\right)}{V_{VIN}} + 0.1\mu s} \tag{9.6}$$

Where 0.1µs is the estimation of turn on and off delay. It is recommended that F_{SW_MAX} < 400kHz and F_{SW_MIN} < 200kHz for best regulation and efficiency performance. When the L_M is selected, the number of turns in the inductor can be calculated by

$$Turns = \left(\frac{436mV}{R_S}\right) \times \frac{L_M}{(A_E \times B_{MAX})} \tag{9.7}$$

Where A_E is the effective magnetic core cross-sectional area and B_{MAX} is the maximum flux density the core can support. Both of these parameters can be found in the selected core datasheet.

9.8.2 Power MOSFET and Rectifier Diode Consideration

In the DC/DC application, conduction loss is a key factor in thermal consideration. The maximum conduction loss of the power MOSFET happens at I_{OUT} = 100% and highest V_{OUT}; while the maximum conduction loss of the rectifier diode happens at I_{OUT} = 100% and lowest V_{OUT}. For the power MOSFET, conduction loss is:

$$\frac{V_{OUT}}{V_{VIN}} \times (I_{OUT})^2 \times R_{DS(ON)} \tag{9.8}$$

Where $R_{DS(ON)}$ is the on-resistance of the power MOSFET at full power operation temperature, which is typically 1.5 to 2 times of that at 25°C. For the rectifier diode, conduction loss is:

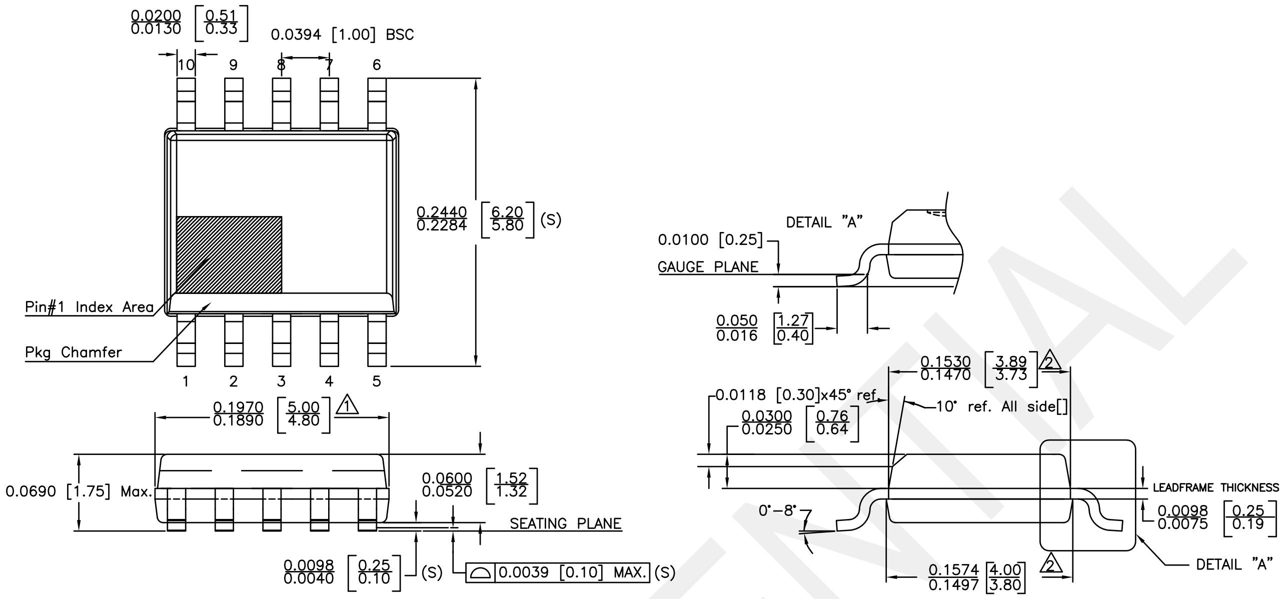
$$\frac{(V_{VIN} - V_{OUT})}{V_{VIN}} \times I_{OUT} \times V_F \tag{9.9}$$

Where V_F is the forward voltage drop of the rectifier diode, which is around 500mV for typical power Schottky.

It is worth noting that with lower $R_{DS(ON)}$ and V_F, the power devices typically also come with a bigger parasitic capacitance, which will slow down LX node swing. Too high of a parasitic capacitance will cause the high-side driver to malfunction. It is necessary to make sure that at lowest dimming, the LX node is still able to swing to negative V_F during inductor discharge. Otherwise, the high-side bootstrap circuit cannot be sustained by V_{VCC} and the high-side driver will lose power.

In addition to thermal considerations, the breakdown voltages are also critical. Both the power MOSFET and rectifier breakdown voltage should be the maximum input voltage of the application plus some margin. For the power MOSFET, make sure that $V_{GS(TH)} \leq 3V$ as the lowest high-side driver turn-on voltage can be as low as 3.5V.

10 Physical Dimensions



NOTE :

1. DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS AND GATE BURRS SHALL NOT EXCEED .006 INCH PER SIDE.
2. DOES NOT INCLUDE INTER–LEAD FLASH OR PROTRUSIONS. INTER–LEAD FLASH AND PROTRUSIONS SHALL NOT EXCEED .010 INCH PER SIDE.
3. PACKAGE DIMENSION CONFORM TO JEDEC SPECIFICATION MS–012 EXCEPT LEAD PITCH.
4. LEAD SPAN/STAND OFF HEIGHT/COPLANARITY ARE CONSIDERED AS SPECIAL CHARACTERISTIC.(S)
5. CONTROLLING DIMENSIONS IN INCHES.[mm]
6. PHYSICAL APPEARANCE OF PACKAGE (E–PIN, DIMPLE, CHAMFER) MAY VARY DUE TO ASSEMBLY TOOLINGS

dialog SEMICONDUCTOR	
STATUS: RELEASED	
TERMINAL FINISH: PPF or 100% Sn	
TITLE: SOP 10L 150MIL PACKAGE OUTLINE	
REV: C	REVISION NOTE: STANDARDIZED POD

Figure 10.1 : 10-Lead SOIC Package Outline Drawing

11 Ordering Information

Part Number	Options	Package	Description
iW380-00	CC only	SOIC-10	Tape & Reel[1]
iW380-01	CC only, 0.3125% lowest dimming startup threshold	SOIC-10	Tape & Reel[1]
iW380-20	CV/CC variant, DIM2 as feedback	SOIC-10	Tape & Reel[1]
iW380-30	CP/CC variant, CP constant = 50%	SOIC-10	Tape & Reel[1]
iW380-31	CP/CC variant, CP constant = 70%	SOIC-10	Tape & Reel[1]

Note 1. Tape and reel packing quantity is 2,500/reel. Minimum packing quantity is 2,500.

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