High Performance Step-Down DC/DC Controller with DC and PWM dimming up to 78V

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1 Description

The iW380-4X 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 78V input voltage and up to 98% of output voltage/input voltage ratio.

The iW380-4X supports high resolution DC dimming and high resolution, high frequency PWM dimming. The PWM dimming is achieved by only turning on the buck converter during PWM dimming signal ON time. To support highest dimming resolution, the iW380 also embeds the shunt MOSFET driver to short LED string during PWM dimming signal OFF time. This provides in most accurate LED current control.

A dedicated light-off mode in the iW380-4X turns off the output current when the dimming signal input is less than the light-off threshold. In the light-off mode, the iW380-4X consumes minimum power while still monitoring the dimming inputs. If the dimming signal input becomes higher than the light-on threshold, the iW380-4X can immediately wake up and resume output current regulation.

2 Features

- Input DC voltage range: 22V ~ 78V
- Output/input voltage ratio: up to 98%
- Output power up to 150W
- Advanced dimming control
  - Supports DC dimming and PWM dimming
  - DC Dimming range: 12.5%-100%
  - PWM dimming range: 0% to 100%
  - PWM dimming mode supports high frequency PWM dimming
  - Embedded shunt MOSFET driver enables highest resolution in PWM dimming mode
- Constant-current (CC) line and load regulation < ±3%
- Light-off current consumption < 1mA
- Auto dimming signal type detection on ADJ pin
- Rich protections:
  - V_{VIN} over/under voltage
  - Over current protection (OCP)
  - Over temperature protection (OTP)

3 Applications

- High performance DC/DC LED driver
- Stage Lighting

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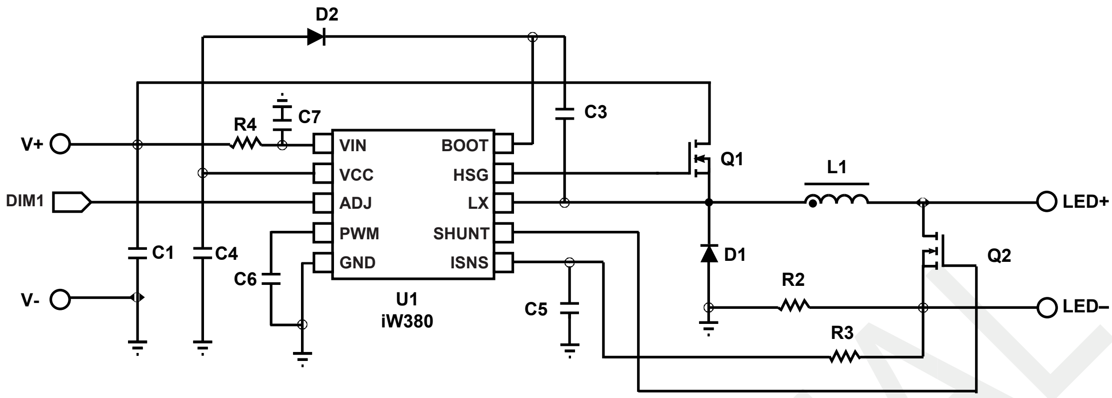

Figure 3.1 : iW380-4X Application Circuit with Shunt MOSFET for Highest Resolution Dimming

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4 Pinout Description

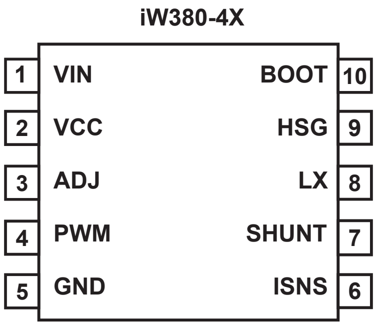

Figure 4.1 : 10-Lead SOIC Package

Pin Number	Pin Name	Type	Pin Description
1	VIN	Power	Power source and input voltage sensing
2	VCC	Power	IC power supply
3	ADJ	Analog Input	DC dimming signal input
4	PWM	Analog Input	PWM dimming signal input
5	GND	Ground	Ground reference
6	ISNS	Analog Input	Buck inductor current sensing
7	SHUNT	Analog Input	LED-short MOSFET driver
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

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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	V_{VCC}	-0.3 to 6.5	V
Continuous DC supply at VCC pin	I_{VCC}	20	mA
VIN pin		-0.3 to 82	V
ADJ and PWM pin		-0.3 to 6.5	V
ISNS pin		-0.3 to 6.5	V
SHUNT pin		-0.3 to 6.5	V
LX pin		-0.7 to 82	V
HSG pin (Note 1)		-0.3 to 87	V
BOOT pin (Note 1)		-0.3 to 87	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}	209	°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 < 5.5V.

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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}				78	V
VIN POR threshold	V_{VIN_POR}		15	16	17.5	V
VIN UVLO threshold	V_{VIN_UVLO}		11	12	13	V
VIN startup-voltage threshold (Note 1)	V_{VIN_ST}			43		V
VIN under-voltage threshold (Note 1)	V_{VIN_UVP}			14		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			2	mA
VCC Section (Pin 2)						
VCC output voltage	V_{VCC}		4.96	5.0	5.04	V
ADJ Section (Pins 3)						
Highest analog DIM voltage	V_{REF_ADIM}			3.3		V
PWM DIM reference voltage (Note 1)	V_{REF_PDIM}			1		V
PWM DIM logic level hysteresis (Note 1)	V_{HYST_PDIM}			0.5		V
PWM signal hysteresis (Note 1)	P_{DIM_HYST}			0.2		%
Analog DIM 0% threshold (Note 1)	V_{ADIM_LO}			362		mV
Analog DIM 100% threshold (Note 1)	V_{ADIM_HI}			2933		mV
Analog signal hysteresis (Note 1)	A_{DIM_HYST}			12.8		mV
Light-off threshold (Note 1)	L_OFF_TH			0.0625		%
Light-on threshold (Note 1)	L_ON_TH			0.5625		%
ISNS Section (Pin 6)						
ISNS upper regulation limit at no DIM (Note 1)	$V_{IPKP(NO\ DIM)}$			445		mV
ISNS lower regulation limit at no DIM (Note 1)	$V_{IPKN(NO\ DIM)}$			355		mV
OCP voltage threshold	V_{OCP_VTH}		567	580	593	mV
Short voltage threshold	V_{SHORT_VTH}		8	18	29	mV
SHUNT Section (Pin 7)						
Pull-up resistance	R_{DSON_P}	V_{VCC} = 5V		5.8		Ω
Pull-down resistance	R_{DSON_N}	V_{VCC} = 5V		3.8		Ω

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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
LX Section (Pin 8)						
LX Low detection threshold	$V_{LX\_LOW\_VTH}$		0.96	1	1.04	V
Bleeder current	I_{BLD}			14.4		mA
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)	$T_{ON(MAX)}$			10		µs
Minimum ON time (Note 1)	$T_{ON(MIN)}$			0.26		µs
Maximum OFF time (Note 1)	$T_{OFF(MAX)}$			20		µs
Minimum OFF time (Note 1)	$T_{OFF(MIN)}$			0.3		µs
Propagation delay from I_{SNS} cross regulation threshold to gate turn on (Note 1)	T_{DELAY}				100	ns
BOOT Section (Pin 10)						
High-side gate driver POR (Note 1)	V_{GPOR}			2.62		V
High-side gate driver UVLO (Note 1)	V_{GUVLO}			1.69		V
Temperature Sensor						
Over temperature 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.

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7 Typical Performance Characteristics

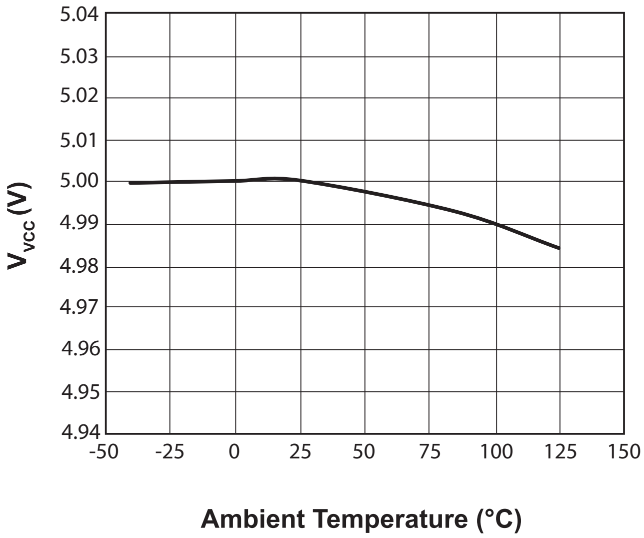

Figure 7.1 : V_{VCC} vs. Temperature

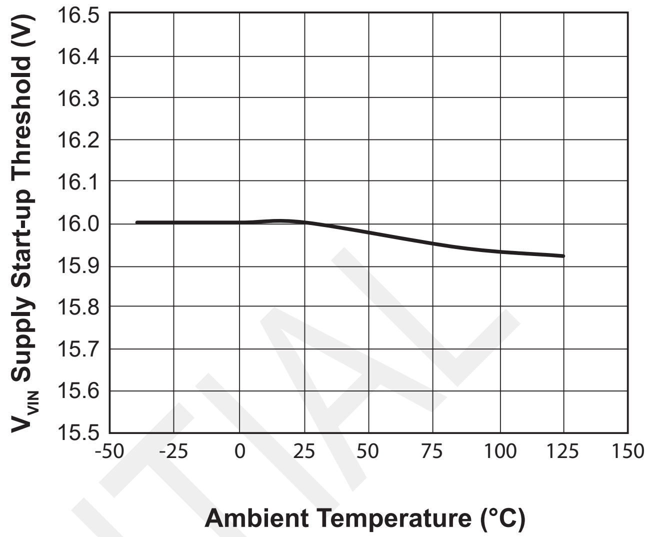

Figure 7.2 : V_{VIN} Start-up Threshold vs. Temperature

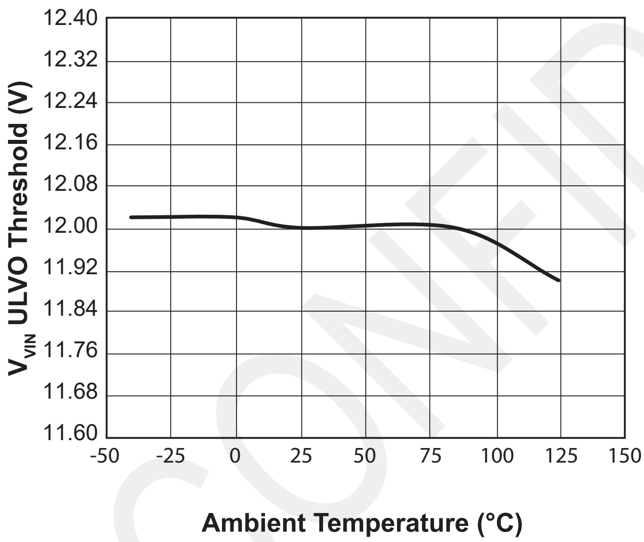

Figure 7.3 : V_{VIN} ULVO Threshold vs Temperature

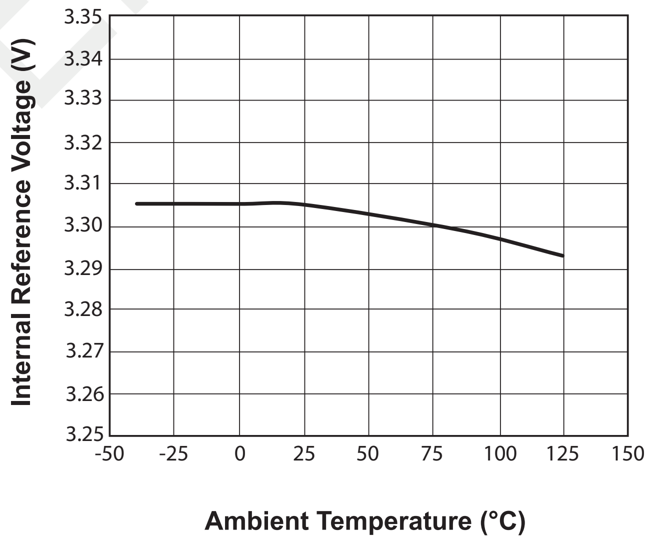

Figure 7.4 : Reference Voltage vs. Temperature

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8 Functional Block Diagram

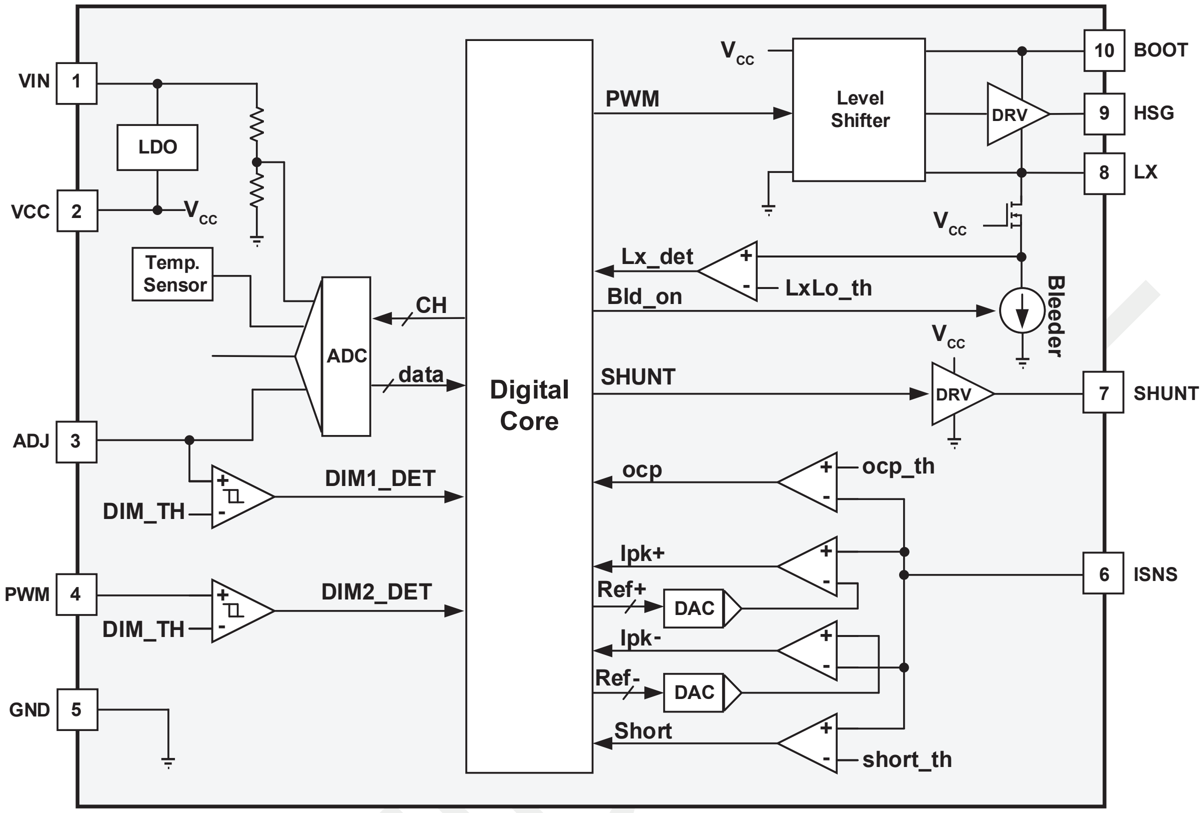

Figure 8.1 : iW380-4X Functional Block Diagram

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9 Theory of Operation

The iW380-4X detects DC dimming signals from the ADJ pin and uses advanced digital processing to determine the DC output current percentage level. This level is mapped to corresponding buck inductor current upper and lower boundaries as well as burst on/off timings. As the buck inductor current is sensed by I_{SNS} pin, it is compared to these boundaries. Power MOSFET is turned on and off when inductor current reaches lower and upper boundary respectively.

As the iW380-4X operates in hysteretic continuous conduction mode (CCM), the output current is the average of upper and lower boundaries of inductor current in the first order. Therefore, the output current of the iW380-4X is tightly regulated regardless of the input voltage, output voltage or buck inductance.

The iW380-4X performs PWM dimming by enabling/disabling the buck converter based on the PWM pin signal logic level. When high, buck converter is running; When low, the buck converter stops. The shunt pin also drives a power MOSFET that shorts the LED when the PWM pin signal is low to ensure zero current to LED when buck converter pulses.

9.1 Pin Details

Pin 1 VIN
The VIN pin is used to power the VCC pin of the iW380-4X 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 normal range. VIN is also used for POR/UVLO of the iW380-4X. The VIN pin should be directly connected to input voltage. The iW380-4X starts operates when V_{VIN} is higher than the V_{VIN} startup voltage, $V_{VIN(ST)}$.

Pin 2 VCC
The VCC pin is the power supply of the iW380-4X and is accurately regulated at 5V. The V_{VCC} voltage is also used as the power of the bootstrap circuit for high side power MOSFET driver. The current draw from the VCC pin other than the IC itself should be limited < 2mA. In the application, connect a 2.2μF to 22μF low ESR capacitor from the VCC pin to ground.

Pin 3 ADJ
ADJ pin is used to set the DC output current percentage of the iW380-4X. The ADJ pin can accept the PWM duty signal or analog voltage level signal.

For the PWM duty signal, it is required to be 3.3V (±5%) or 5V (±5%) logic and frequency within 500Hz to 5kHz for optimized performance. PWM duty percentage maps directly to dim percentage with a DC dimming minimum clamp of 12.5%. For analog signal levels, 683mV or below maps to 12.5% output; 2933mV or above maps to 100% output; 683mV to 2933mV maps linearly to 12.5~100% dimming percentage. When the dim percentage is less than the light off threshold (L_OFF_TH), the iW380-4X will enter light off mode.

The iW380-4X has comprehensive logic to automatically determine whether it is PWM duty signal type or analog level signal type at startup if the PWM duty signal is within the spec mentioned above.

To avoid jittering or noise on the ADJ pin causing an unstable DC output, the ADJ pin input signal is processed with a hysteresis of $P_{DIM(HYST)}$ for PWM type signal and $A_{DIM(HYST)}$ for analog type signal.

Pin 4 PWM
PWM pin is used to perform high frequency PWM dimming. For the PWM duty signal, it is required to be 3.3V (±5%) or 5V(±%) logic and frequency within 15kHz to 35kHz for optimized performance.

When input logic is high, the iW380-4X operates the buck converter. When input logic is low, the iW380-4X immediately pulse the buck converter with high side driver keeps power MOSFET off.

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Pin 5 GND
Ground reference.

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

$$100\%\ I_{OUT}\ (mA) = \left(\frac{400mV}{R_S}\right) \qquad (9.1)$$

Where R_S is the current sense resistor value. An RC filter of 1-5ns time constant is recommended for very high frequency noise filtering.

Pin 7 SHUNT
The SHUNT pin is the power MOSFET driver output for the LED shunt MOSFET. When the PWM pin input signal logic is low, the SHUNT pin turns on the shunt MOSFET to short the LED load. The buck inductor current is then freewheeling between buck inductor, rectifier diode, I_{SNS} resistor and shunt MOSFET. When the PWM pin input signal logic is high, the SHUNT pin turns off the shunt MOSFET and allows the buck converter to deliver current to LED load. In application, the SHUNT pin should directly connect to the gate of the shunt MOSFET.

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 iW380-4X, the LX pin also has a bleeder built-in to bleed off LX node and the output voltage (via buck inductor) at light off mode or fault conditions. In this way, the high-side driver can be permanently sustained by V_{VCC} via bootstrap diode. An LX pin voltage sensor is used to determine whether LX pin is discharged to GND the bleeder circuit.

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 the 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 iW380-4X 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 iW380-4X internal circuit. During any time of the operation, if V_{VIN} drops below UVLO or V_{VCC} drops below V_{VCC_UVLO}, the iW380-4X will be shut down until V_{VIN} or V_{VCC} recovers.

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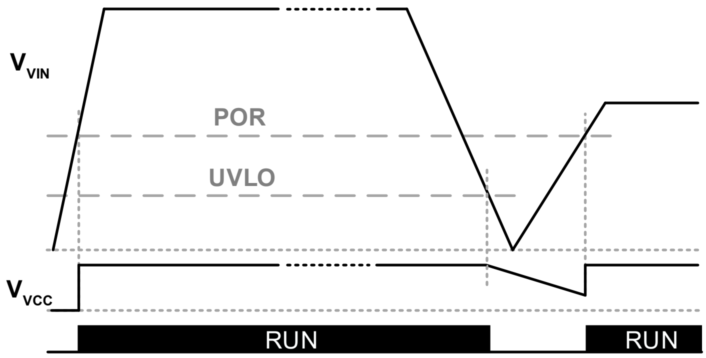

Figure 9.1 : V_{VIN} and V_{VCC} POR/UVLO

After POR, the iW380-4X enters the qualification state. The qualification state checks if V_{VIN} > startup voltage, $V_{VIN(ST)}$ and if IC junction temperature is below the startup temperature ($T_{(ST)}$). If both pass, the iW380-4X exits qualification state. If either qualification fails, the iW380-4X will stay in qualification state until it passes.

The iW380-4X enters Run or Pulse state after exiting qualification and detects the ADJ pin signals and determine the DC dimming percentage. Based on the PWM dimming duty, the iW380-4X operates/pulse the buck converter in the same duty. As a result, a further PWM style dimming is applied on top of the DC dimming level. The final LED current percentage = DC dim % x PWM dim %.

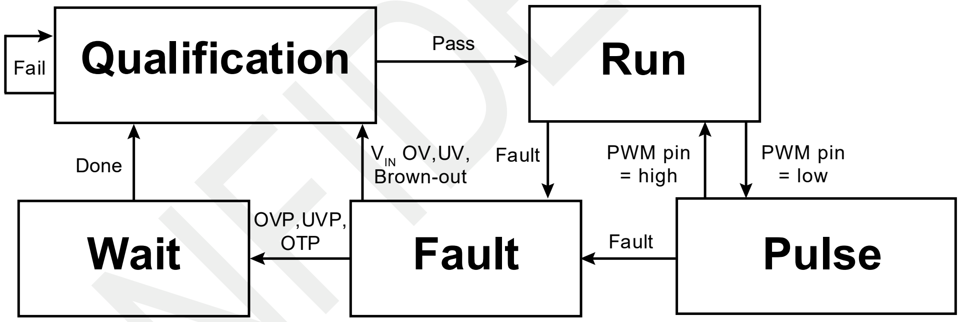

Figure 9.2 : States of iW380-4X Operation

As long as the input and output conditions are ok, the iW380-4X will stay in Run or Pulse state and deliver I_{OUT}% following supplied ADJ pin PWM pin inputs in real time. When the input, output or thermal condition does not meet the operating criteria, the iW380-4X will enter fault state and bleed off V_{OUT} and reset. An over-temperature protection event will incur a wait time before next restart attempt. Detail information can be found in section 9.7.

9.3 ADJ Signal Processing

The iW380-4X ADJ pin can accept both a PWM signal and an analog voltage level signal as command to control the DC I_{OUT}%. At startup, the iW380-4X will detect which signal type it is and respond accordingly. By default, the iW380-4X 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 ADJ pins.

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’s 100% and 0% respectively.

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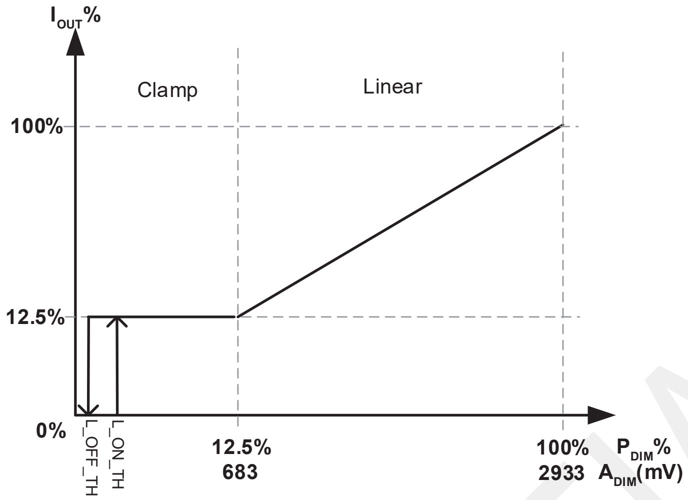

Figure 9.3 : DC Dimming% vs. ADJ Pin Input and Light Off

A special light-off mode is included in the iW380-4X to completely turn off I_{OUT} and achieve remote turn-off function while the iW380-4X stays powered by V_{VIN}. In order to enter light-off mode, the set dimming percentage needs to be lower than the light-off threshold (L_OFF_TH). Once entered, V_{OUT} will be discharged to 0 by the bleeder and there is no power MOSFET switching. The iW380-4X also enters low power mode for minimum power consumption. The dim pins are continuously monitored. As soon as dimming % ≥ light-on threshold (L_ON_TH), the operation will resume.

9.4 DC Dimming Current Regulation

The DC dimming current regulation of the iW380-4X is achieved by adjusting the upper and lower boundary of the buck inductor current, which is called linear dimming.

The operation of linear dimming 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

When ADJ pin input maps to lower than 12.5% dimming, the iW380-4X enters clamp mode which limits further DC dimming.

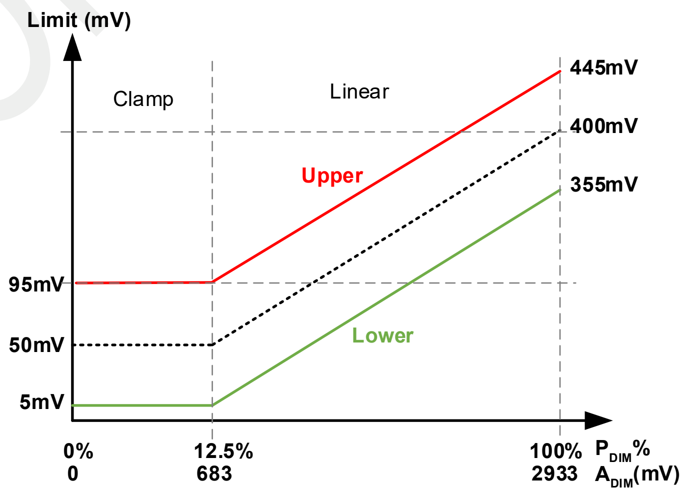

Figure 9.4 : Upper Limit and Lower Limit of Buck Inductor Current vs. I_{OUT} %

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9.5 PWM Dimming Current Regulation

PWM dimming can be used over the full dimming range to achieve very high resolution dimming, or it can be used with the DC Dimming to provide high resolution dimming at low LED light levels while maintaining the high efficiency of DC Dimming mode.

The PWM dimming current regulation of the iW380-4X is achieved by modulating the time percentage that the buck converter is enabled. The LED current % is roughly the PWM pin input signal %. The very first and last buck switching pulse may create some discrepancy between wanted LED current vs. real LED current due to ramp up/down of the LED current from/to zero.

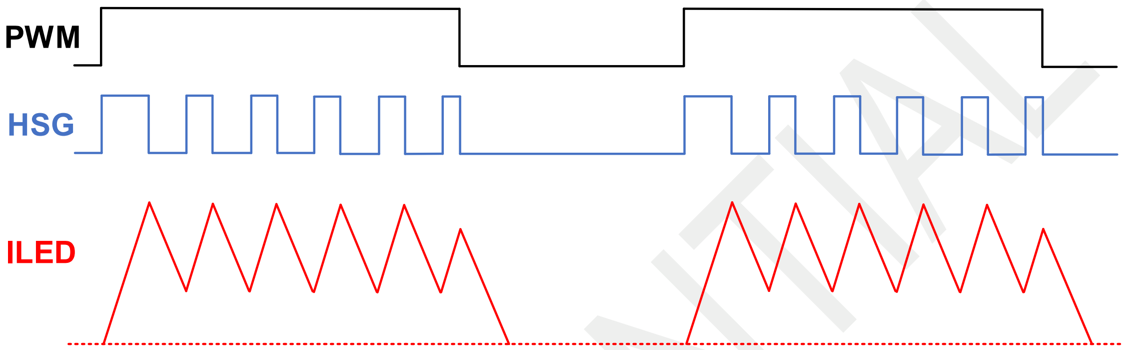

Figure 9.5 : PWM Dimming without Shunt MOSFET

To achieve an even higher LED current dimming accuracy, a shunt MOSFET to short the LED load can be used to precisely control the LED current and remove the ramp up/down effect of the LED current. With the shunt MOSFET, LED current is clamped to zero when buck converter is off. In this way, the LED current % is exactly the PWM pin input signal %.

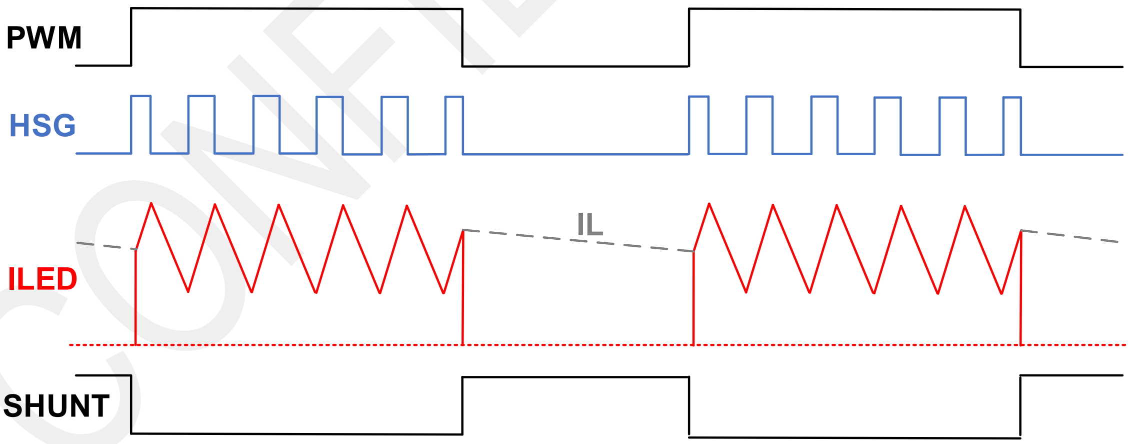

Figure 9.6 : PWM Dimming with Shunt MOSFET

9.6 Protections and Limits

The iW380-4X has a comprehensive set of the protection features to protect the application circuit and LED load from damage under abnormal conditions.

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9.6.1 Brown-out (Power Shutdown)

When power is shutdown, the power source is cut off and V_{VIN} starts to decay as the iW380-4X 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 iW380-4X 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 iW380-4X will reset itself immediately to go through a fresh startup cycle. Otherwise, the iW380-4X 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 iW380-4X will startup again.

This brown-out mechanism makes sure that the iW380-4X 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.

9.6.2 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 iW380-4X will have a fresh restart without any delay.

9.6.3 Over-Temperature Protection (OTP)

A junction temperature sensor is built-in to the iW380-4X. The iW380-4X 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 iW380-4X 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 iW380-4X will stay in the qualification state until this condition is met.

9.6.4 Cycle-by-cycle Limits

The iW380-4X 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 $T_{OFF(MAX)}$. 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.

9.7 Buck Inductor and Power Device Selection

9.7.1 Buck inductor Consideration

The main consideration behind buck inductor parameter is the operating frequency. For any buck converter, the maximum operating frequency happen at V_{OUT} = 50% V_{VIN}.

$$F_{SW\_MAX} = \frac{1}{\dfrac{360mV \times \left(\dfrac{L_M}{R_S}\right)}{V_{VIN}} + 0.1\mu s} \quad (9.2)$$

Where 0.1μs is the estimation of turn on and off delay. It is recommended that F_{SW_MAX} within 400kHz to 600kHz for best regulation and efficiency performance. When the L_M is selected, the number of turns in the inductor can be

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calculated by

$$Turns = \left(\frac{445mV}{R_S}\right) \times \frac{L_M}{(A_E \times B_{MAX})} \tag{9.3}$$

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.

9.7.2 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:

$$\frac{V_{OUT}}{V_{VIN}} \times (I_{OUT})^2 \times R_{DS(ON)} \tag{9.4}$$

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:

$$\frac{(V_{VIN} - V_{OUT})}{V_{VIN}} \times I_{OUT} \times V_F \tag{9.5}$$

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.

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10 Physical Dimensions

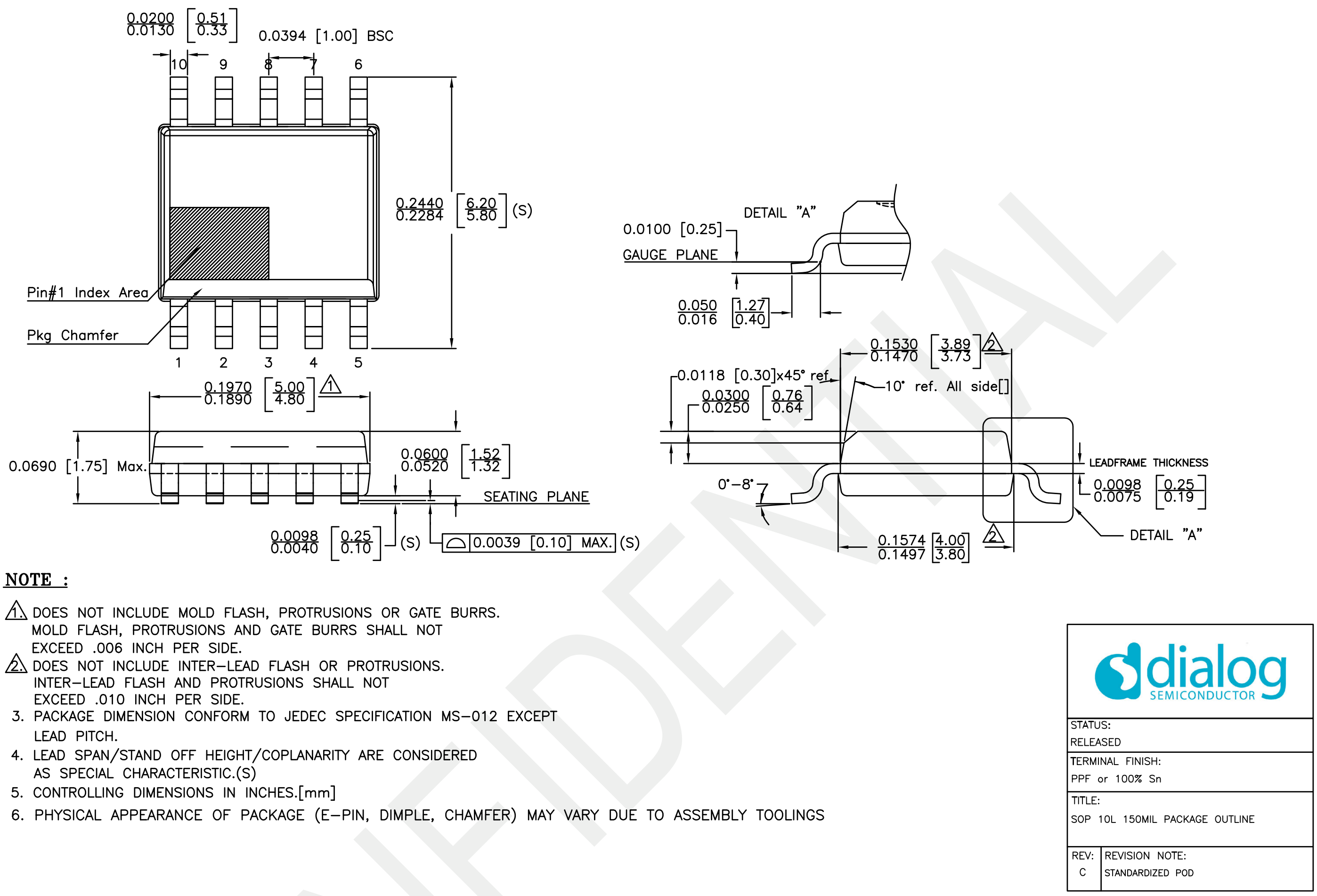

Figure 10.1 : 10-Lead SOIC Package Outline Drawing

11 Ordering Information

Part Number	Options	Package	Description
iW380-40	V_{VIN} startup = 43V, ADJ hysteresis = 0.2% for PWM signal, 0.5% for analog signal	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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(Rev.1.0 Mar 2020)

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