

Description

The AL1666 is a high performance single stage Flyback and Buck-boost controller, targeting dimmable LED lighting application. It is a primary side regulation (PSR) controller which can provide accurate Constant Current (CC) regulation without opto-coupler and secondary control circuitry. It is operating at BCM mode which results in good EMI and efficiency, and keeps high PF and low THD under universal input voltage.

The AL1666 can support analog/PWM dimming modes. When a 0 to 2.4V DC signal is applied on ADIM pin, the device will operate in analog dimming mode; when a digital signal is applied on PWMD pin and the ADIM pin is connected with hundreds of nF capacitors, the device will work at PWM-to-DC dimming mode. The dimming range is 1% to 100%.

The AL1666 has rich protection features. It integrates multiple protections including Under Voltage Lock Out (UVLO), Output Over Voltage Protection (OVP), Output Short Circuit Protection (OSP), Over Current Protection (OCP), Winding Short Circuit, Secondary Diode Short, Internal Thermal Fold-Back Protection (TFP) and Over Temperature Protection (OTP).

The AL1666 is available in SO-8 (Standard) package.

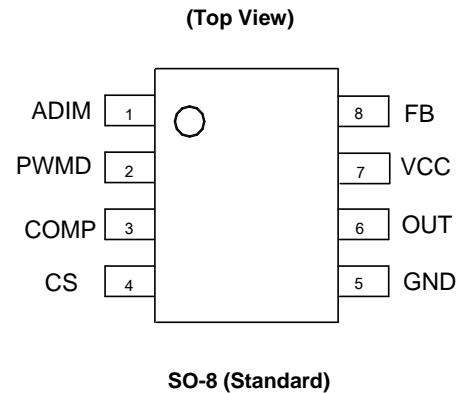
Features

- Primary Side Regulation without Opto-Coupler
- Valley Switching for Low Switching Loss
- Support Analog and PWM-to-DC Dimming
- Analog/PWM-to-DC Dimming Range: 1% to 100%
- Tight CS Reference Voltage $0.4V \pm 1.5\%$
- High PF > 0.9 and Low THD < 20%
- High Efficiency
- Internal Protections
 - Under Voltage Lock Out (UVLO)
 - Output Over Voltage Protection (OVP)
 - Output Short Protection (OSP)
 - Over Current Protection (OCP)
 - Winding Short Circuit Protection
 - Secondary Diode Short Protection
 - Internal Thermal Fold-back Protection (TFP)
 - Over Temperature Protection (OTP)
- Tight LED Current Variation Range
 - LED Current Line Regulation: $\pm 2\%$ (90V_{AC} to 305V_{AC})
 - LED Current Load Regulation: $\pm 2\%$ Full Load to Half Load
- Package: SO-8 (Standard)
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**
- **For automotive applications requiring specific change control (i.e. parts qualified to AEC-Q100/101/200, PPAP capable, and manufactured in IATF 16949 certified facilities), please [contact us](mailto:contact@diodes.com) or your local Diodes representative. <https://www.diodes.com/quality/product-definitions/>**

Notes:

1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS), 2011/65/EU (RoHS 2) & 2015/863/EU (RoHS 3) compliant.
2. See <https://www.diodes.com/quality/lead-free/> for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
3. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

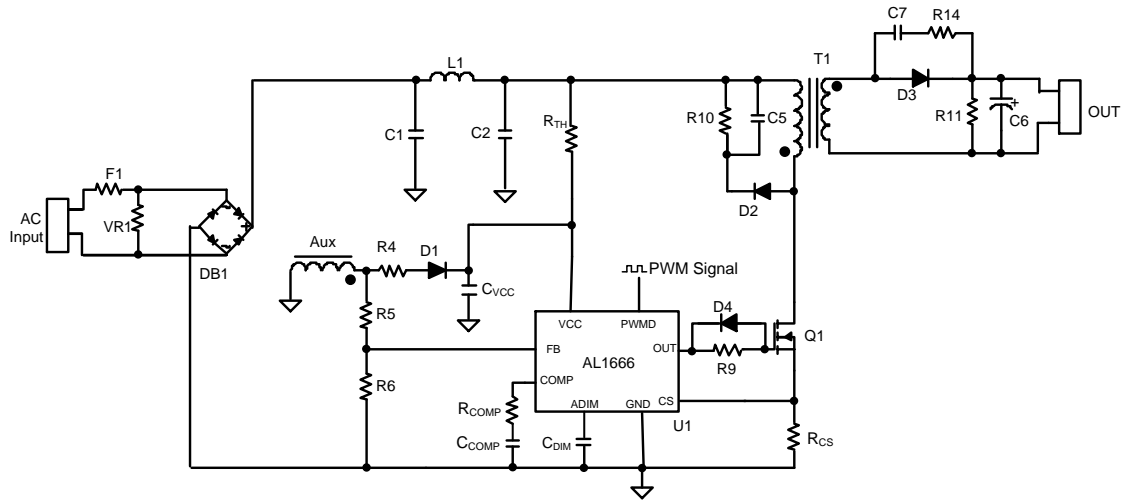
Pin Assignments



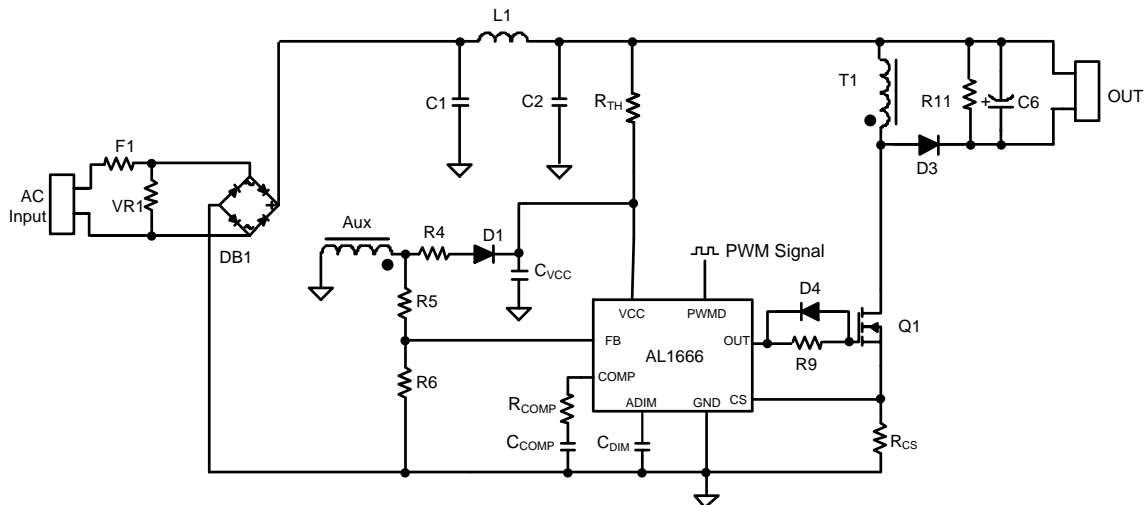
Applications

- General LED Lighting Driver with Dimming Function
- 0 to 10V Dimming Luminaires
- General Purpose Constant Current Source
- Smart LED Lighting

Typical Applications Circuit



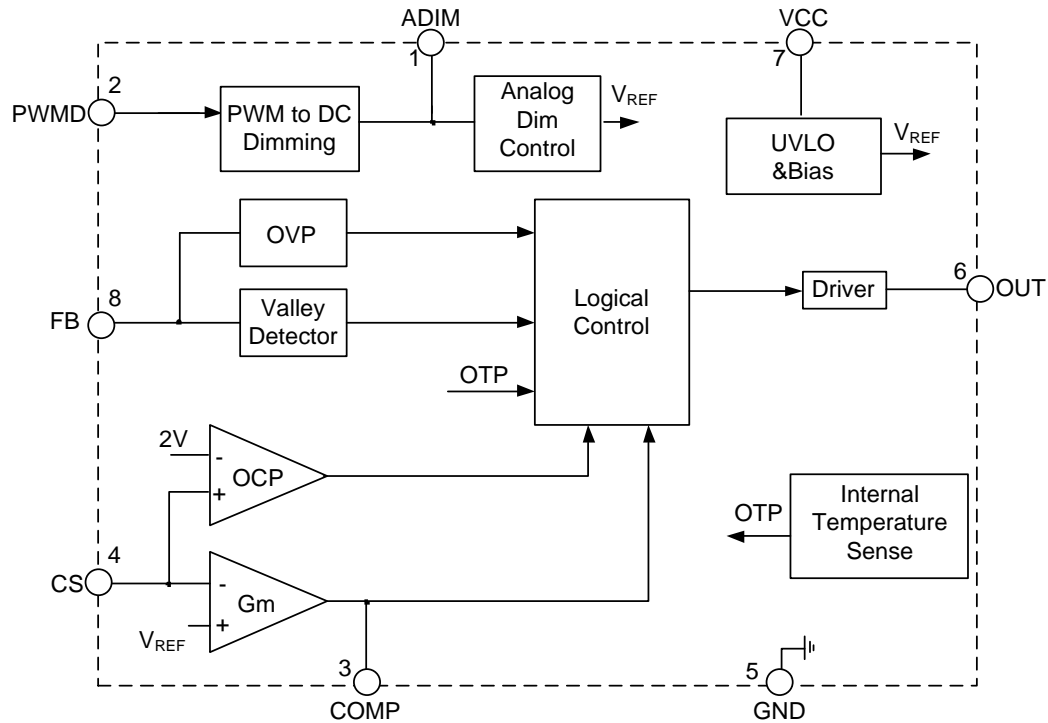
Flyback Application Circuit



Buck-Boost Application Circuit

Pin Descriptions

Pin Number	Pin Name	Function
1	ADIM	Analog dimming input pin
2	PWMD	PWM signal input pin
3	COMP	Loop compensation pin
4	CS	Current sense pin, connect this pin to the source of the primary switch
5	GND	Ground
6	OUT	Gate driver output
7	VCC	Supply voltage of gate driver and control circuits of the IC
8	FB	The feedback voltage sensing from the auxiliary winding

Functional Block Diagram

Absolute Maximum Ratings (@T_A = +25°C, unless otherwise specified.) (Note 4)

Symbol	Parameter	Rating	Unit
V _{CC}	Power Supply Voltage	-0.3 to 30	V
V _{CS}	Voltage at CS to GND	-0.3 to 7	V
V _{FB}	FB Input	-0.3 to 7	V
V _{COMP}	Loop Compensation Pin	-0.3 to 7	V
V _{OUT}	Driver Output Voltage	-0.3 to 20	V
V _{PWMD}	Voltage at PWMD to GND	-0.3 to 7	V
V _{ADIM}	Voltage at ADIM to GND	-0.3 to 7	V
T _J	Operating Junction Temperature	-40 to +150	°C
T _{STG}	Storage Temperature	-65 to +150	°C
T _{LEAD}	Lead Temperature (Soldering, 10s)	+300	°C
P _D	Power Dissipation at T _A = +50°C	0.65	W
θ _{JA}	Thermal Resistance (Junction to Ambient)	136	°C/W
θ _{JC}	Thermal Resistance (Junction to Case)	30	°C/W
—	ESD (Human Body Model)	2000	V
	ESD (Charged-Device Model)	1000	V

Note: 4. Stresses greater than those listed under *Absolute Maximum Ratings* can cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to *Absolute Maximum Ratings* for extended periods can affect device reliability. All voltages unless otherwise stated and measured with respect to GND.

Recommended Operating Conditions (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Min	Max	Unit
T _A	Ambient Temperature (Note 5)	-40	+105	°C
V _{CC}	Operating VCC Voltage (Note 6)	8.5	V _{CC_OVP} (Min)	V

Notes: 5. The device may operate normally at +125°C ambient temperature under the condition not triggers temperature protection.
 6. I_{CC} should be limited less than 5mA.

Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
UVLO Section						
V _{CC_TH}	Startup Threshold Voltage	—	15.8	18.5	19.5	V
V _{OPR_MIN}	Minimal Operating Voltage	After Turn On	5.8	7.8	9	V
V _{CC_OVP}	V _{CC} OVP Voltage	—	21.8	25	29.5	V
Standby Current Section						
I _{ST}	Startup Current	V _{CC} =V _{CC_TH} -0.5V, before start up	—	120	300	μA
I _{CC}	Operating Current @4kHz	V _{CC} =20V, V _{DIM} =3V, V _{FB} =V _{CS} =V _{COMP} =1V, C _{OUT} =1nF	—	2	4	mA
I _{CC_OVP}	Shunt Current in OVP Mode	V _{CC} > V _{CC_OVP}	3.1	—	—	mA
Drive Output Section						
t _R	Output Voltage Rise Time (Note 7)	C _L = 1nF	—	100	—	ns
t _F	Output Voltage Fall Time (Note 7)	C _L = 1nF	—	100	—	ns
V _{OUT_CLAMP}	Output Clamp Voltage	V _{CC} = 20V	9.8	12	15.5	V
t _{ON_MIN}	Minimum On Time (Note 7)	—	—	1000	2010	ns
t _{ON_MAX}	Maximum On Time	—	—	15	—	μs
t _{OFF_MAX}	Maximum Off Time	—	—	290	405	μs
f _{MAX}	Maximum Frequency	—	—	150	—	kHz
Internal CS Reference						
V _{REF}	Internal Reference Voltage	—	0.394	0.4	0.406	V
V _{CS_CLAMP}	Primary Current Clamp Voltage	—	—	2	—	V
V _{CS_OCP}	Primary Over Current Voltage	—	—	3	—	V
Error Amplifier						
G _m	Trans-Conductance	—	—	27	—	μA/V
I _{SOURCE}	Amplifier Source Current	—	—	7.2	—	μA
Feedback Input Section						
V _{FB_CV}	FB CV Threshold	—	2.86	3.0	3.26	V
PWMD Section						
V _{PWM_L}	PWM Signal Low Threshold Voltage	—	—	—	0.4	V
V _{PWM_H}	PWM Signal High Threshold Voltage	—	2.0	—	—	V
f _{PWM}	PWM Frequency for PWM to DC Dimming	—	0.5	—	20	kHz

Note: 7. These parameters, although guaranteed by design, are not 100% tested in production.

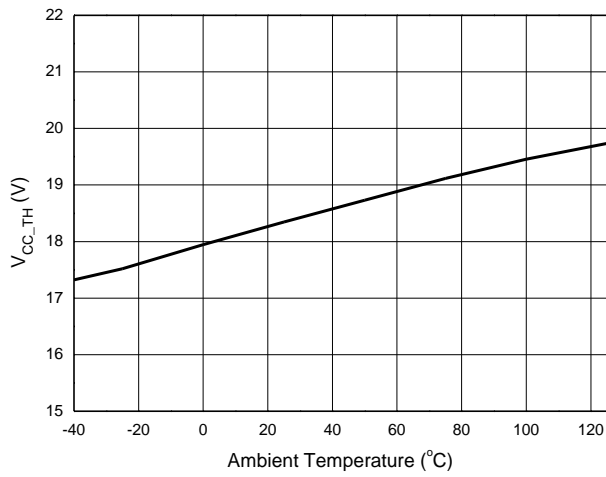
Electrical Characteristics (@T_A = +25°C, unless otherwise specified.) (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
ADIM Section						
—	Analog Dimming Range on ADIM	—	0.05	—	2.4	V
—	Analog Dimming High Level	—	2.35	2.4	2.45	V
—	Analog Dimming Range Ratio	—	1	—	100	%
Thermal Fold-Back Section						
T _{REG}	Overheating Temperature Regulation (Note 7)	—	—	+150	—	°C
Over Temperature Protection Section						
—	Shutdown Temperature (Notes 7, 8)	—	—	+180	—	°C

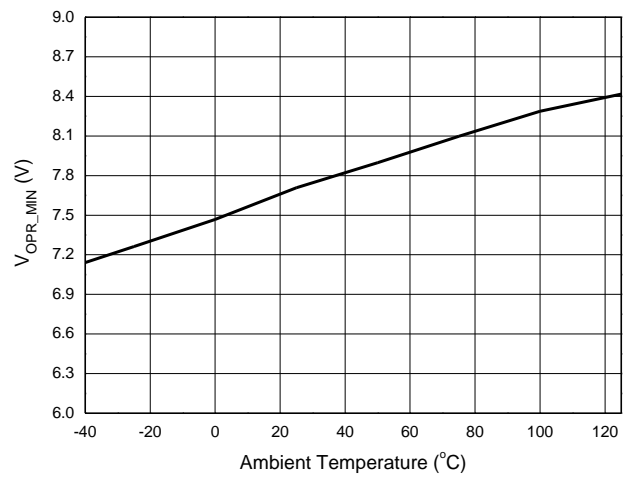
Notes: 7. These parameters, although guaranteed by design, are not 100% tested in production.
8. At startup, when V_{CC} reaches V_{CC,TH}, the controller blanks OTP for more than 250μs to avoid detecting an OTP fault by allowing the PWMD pin voltage to reach its nominal value if a filtering capacitor is connected to the PWMD pin.

Performance Characteristics (Note 9)

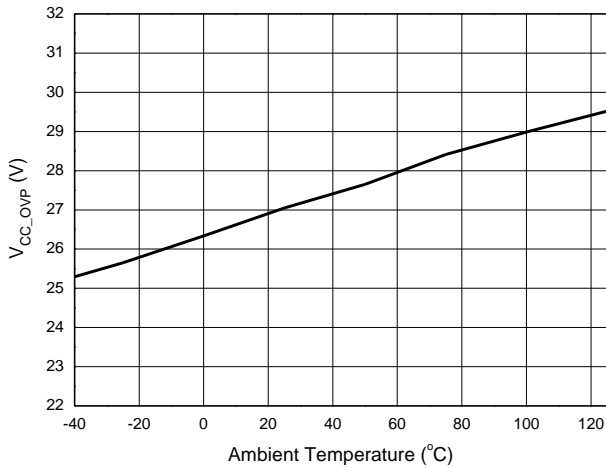
Startup Threshold Voltage vs. Ambient Temperature



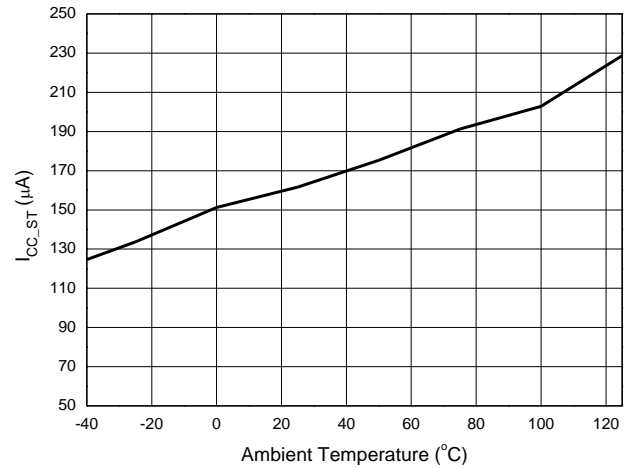
Minimum Operating Voltage vs. Ambient Temperature



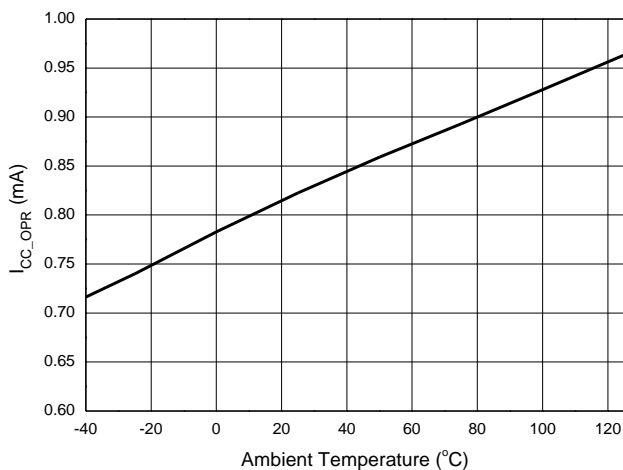
V_{CC} OVP Voltage vs. Ambient Temperature



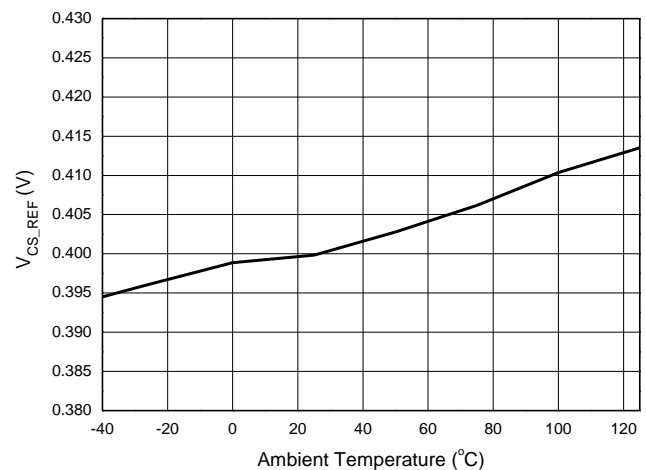
Startup Current vs. Ambient Temperature



Operating Current vs. Ambient Temperature



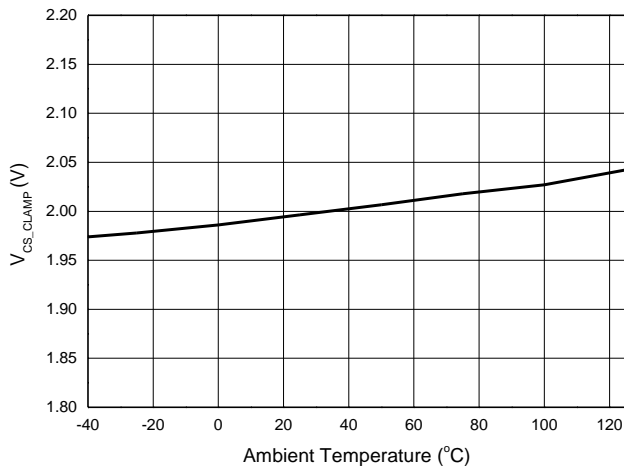
CS Reference Voltage vs. Ambient Temperature



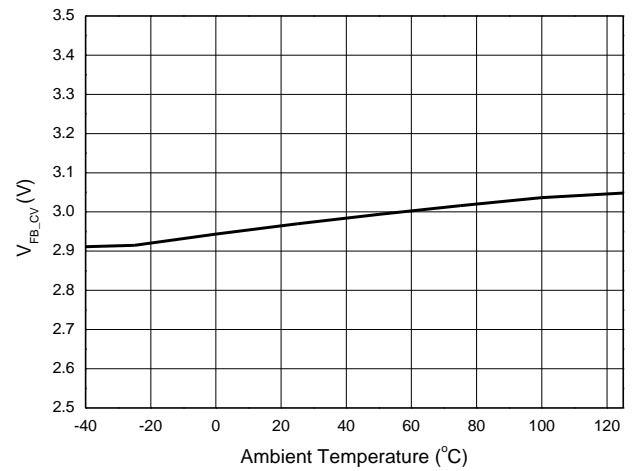
Note: 9. These electrical characteristics are tested under DC condition. The ambient temperature is equal to the junction temperature of the device.

Performance Characteristics (continued)

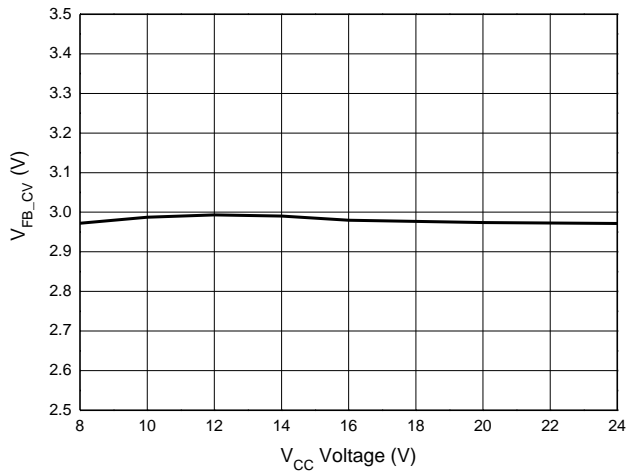
CS Clamp Reference Voltage vs. Ambient Temperature



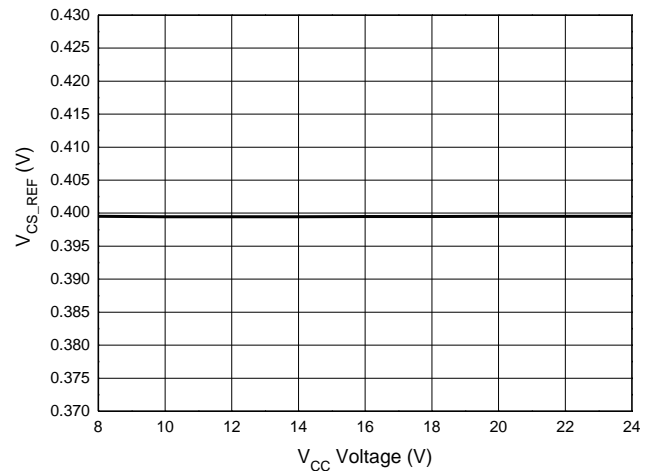
FB CV Threshold vs. Ambient Temperature



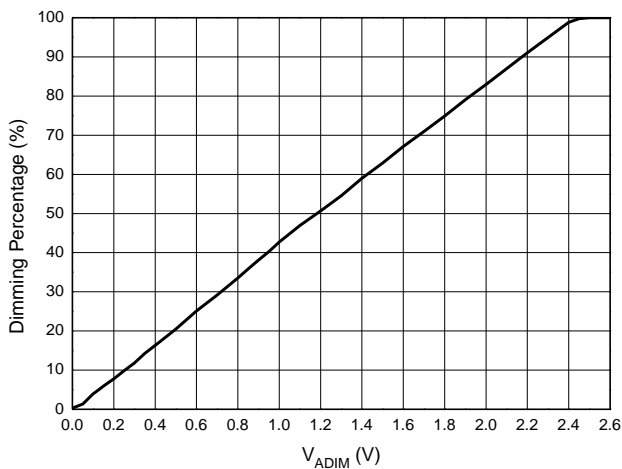
FB CV Threshold vs. V_{CC} Voltage



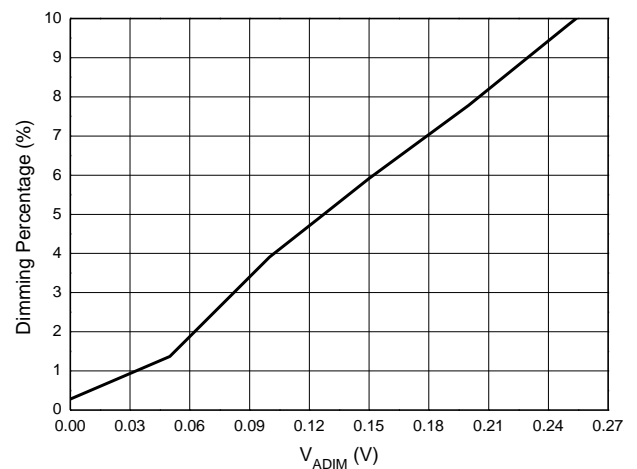
CS Reference Voltage vs. V_{CC} Voltage



Analog Dimming Curve



Analog Dimming Curve (Zoomed in 0 to 10%)



NEW PRODUCT

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Application Information (continued)

Protections

1. Output Open Protection (OVP)

The output voltage is reflected by the voltage on transformer's auxiliary winding. Both FB pin and VCC pin of IC integrate over voltage protection function. When there is a rapid line and load transient, the output voltage may exceed the regulated value. If V_{CC} exceeds V_{CC_OVP} , the V_{CC} over voltage protection will be triggered, switch will be turned off and V_{CC} will be discharged. Once V_{CC} is below V_{OPR_MIN} , the IC will shut down and be powered on again by BUS voltage through start up resistor. If V_{FB} exceeds V_{FB_CV} , the FB over voltage protection will be triggered, switch will be turned off and V_{CC} will be latched for 16s, then V_{CC} will be discharged. Once V_{CC} is below V_{OPR_MIN} , the IC will shut down and be powered on again by BUS voltage through start up resistor. Power dissipation is low when FB over voltage protection happens.

Thus, output over voltage depends on the minimum voltage between both OVP protections' limitation. It can be gotten by below formula.

$$V_{OVP} = \text{Min} \left(\frac{N_S}{N_{AUX}} \cdot V_{CC_OVP}, \frac{N_S}{N_{AUX}} \cdot \frac{R5 + R6}{R6} \cdot V_{FB_CV} \right)$$

Where V_{OVP} is the output over voltage setting; R5 and R6, shown as Figure 1, divide reflected voltage.

N_{AUX} is the turns of auxiliary wind; N_S is turns of the secondary wind. V_{CC_OVP} is OVP Voltage of V_{CC} .

2. Output Short Protection (OSP)

When the output is shorted, the output voltage is clamped to zero. The output voltage of the auxiliary winding, which is proportional to the output winding, will drop down too. If V_{FB} drops below 0.4V, the output short protection will be triggered, the device cannot detect the t_{OFF} time, and the device controls the system operation at 4kHz low frequency.

3. Over Current Protection (OCP)

The AL1666 has a built-in cycle by cycle over current protection of primary inductor current. When CS pin voltage reaches the voltage V_{CS_CLAMP} , switch will be turned off until next switch period. The maximum peak current (I_{PEAK_MAX}) of the inductor can be calculated as below:

$$I_{PEAK_MAX} = \frac{V_{CS_CLAMP}}{R_{CS}}$$

Where V_{CS_CLAMP} means primary current clamp voltage that is 2V.

R_{CS} is current sense resistor which is shown as Figure 1.

4. Secondary Diode/Primary Windings/Secondary Windings Short Protection

The CS voltage will be high when Secondary Diodes/Primary windings/Secondary windings are Shorted. If CS is higher than V_{CS_OCP} , the protection will be triggered, switch will be turned off and V_{CC} will be latched for 16s, then V_{CC} will be discharged. Once V_{CC} is below V_{OPR_MIN} , the IC will shut down and power on again by the BUS voltage through the startup resistor. Power dissipation is low when output short protection happens.

5. Thermal Fold-Back Protection (TFP)

The AL1666 has thermal fold-back function: it adopts self-adaptive control method which can prevent the system from breaking down caused by over temperature. The overheating temperature is set at +150°C. When the temperature of the IC is higher than this point; the device will decrease the voltage reference of the CS linearly till OTP happens. By this way, the device can limit system's input power at high ambient temperature, preventing system's temperature increases further.

6. Over Temperature Protection (OTP)

The AL1666 has built-in Over Temperature Protection (OTP) function. When the temperature goes up to +180°C, the over temperature protection is triggered, which leads to V_{CC} UVLO. When OTP recovers, the system can be restarted.

Application Information (continued)

Output Constant-Current Control

According to the definition of mean output current, the mean output current can be obtained as below.

$$I_{O_MEAN} = \frac{1}{\pi} \cdot \int_0^{\pi} \frac{1}{2} \cdot I_{SP} \cdot \frac{t_{ONS}}{t_{SW}} dt$$

Where I_{O_MEAN} is the mean output current; I_{SP} is secondary peak current of transformer; t_{ONS} is discharge time of secondary side of transformer; t_{SW} is the switch period.

According to the principle of AL1666 close loop control, the voltage of R_{CS} will be sampled when switch is turned off and the value will be held until discharge time t_{ONS} is over. It can be described by following formula:

$$V_{REF} = \frac{1}{\pi} \int_0^{\pi} I_P \cdot R_{CS} \cdot \frac{t_{ONS}}{t_{SW}} dt$$

Where I_P is primary peak current of transformer; R_{CS} is current sense resistor which is shown as Figure 1.

t_{ONS} is discharge time of secondary side of transformer; t_{SW} is the switch period. V_{REF} is internal reference voltage that is equal to 0.4V.

The peak current at secondary side has following relationship with primary side peak current, if the effect of the leakage inductor is neglected.

$$I_{SP} = N_{PS} \cdot I_P$$

Where N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost); I_P is the primary peak current of the transformer.

According to these above formulas, the mean output current can be induced finally by below expressions.

$$I_{O_MEAN} = \frac{N_{PS} \cdot V_{REF}}{2 \cdot R_{CS}}$$

Where I_{O_MEAN} is the mean output current; R_{CS} is current sense resistor which is shown as Figure 1 and Figure 2;

V_{REF} is internal reference voltage that is equal to 0.4V; N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost); Therefore, the constant output current control can be realized with appropriate parameter design.

PF and THD Compensation Circuit

In typical application, the AL1666 can provide PF>0.9 and THD <20%. It can improve PF>0.95 and THD<10% by adding the below compensation circuit. V_{BUS} is connected to bus line which is after rectifier bridge. COMP pin voltage will add an offset that almost follows with bus line voltage in the circuit. Due to COMP voltage controls switch-on time, thus phase difference between input voltage and input current will be reduced that can optimize PF and THD. In the circuit, range of resistor value R_{12} is from 800kΩ to 1.5MΩ, range of resistor value R_{13} is from 500Ω resistor to 5.1kΩ. Range of capacitance C_{11} is 1μF to 2μF. PF and THD can be improved by fine tuning these components.

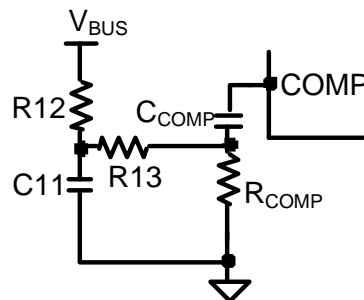


Figure 3. PF and THD Optimization Circuit

Application Information (continued)

Line Regulation Compensation Function

The AL1666 can achieve good line regulation by adjusting the FB pull-up resistor R_{FB1} and the CS external horizontal resistor R_{CS1} . R_{FB2} is the FB pull-down resistor. Figure 4 shows this circuit. As R_{FB2} is far larger than R_{FB3} , during t_{ONP} , the V_{FB} can be calculated approximately as:

$$V_{FB} = \frac{\sqrt{2} \cdot V_{IN_RMS} \cdot N_{AP} \cdot R_{FB3}}{R_{FB1} + R_{FB3}}$$

And the V_{CS_OFFSET} can be got:

$$V_{CS_OFFSET} = \frac{K \cdot \sqrt{2} \cdot V_{IN_RMS} \cdot N_{AP} \cdot R_{FB3}}{R_{FB1} + R_{FB3}} \cdot (R_{CS1} + R_{CS2})$$

Where:

- K is conversion coefficient of I_{FB3} that is equal to $0.013 \cdot 10^{-3}$
- V_{IN_RMS} is the input RMS voltage
- N_{AP} is the turns' ratio of auxiliary winding and primary winding
- R_{FB3} is the internal FB pulldown resistor that is connected to the system during t_{ONP} time and equals to 184Ω
- R_{CS2} is the internal horizontal resistor that is $6k\Omega$

The output current can be calculated as:

$$I_{O_MEAN} = \frac{N_{PS}}{2 \cdot R_{CS}} \cdot (V_{REF} - V_{CS_OFFSET}) = \frac{N_{PS}}{2 \cdot R_{CS}} \cdot \left[V_{REF} - \frac{K \cdot \sqrt{2} \cdot V_{IN_RMS} \cdot N_{AP} \cdot R_{FB3}}{R_{FB1} + R_{FB3}} \cdot (R_{CS1} + R_{CS2}) \right]$$

Where:

- V_{REF} is the internal reference voltage that is equal to $0.4V$

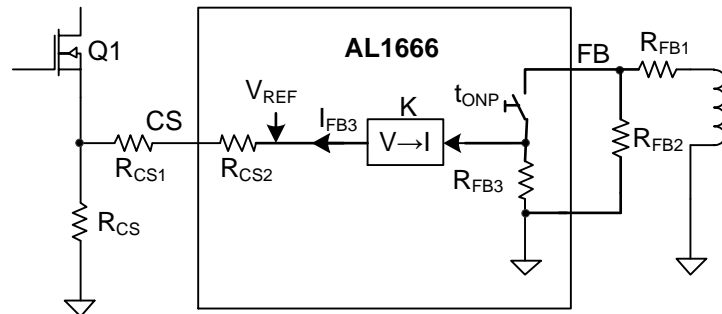


Figure 4. Line Regulation Compensation Circuit

Application Information (continued)

Dimming Mode

The AL1666 can support two dimming modes: analog dimming and PWM-to-DC dimming.

1. Analog Dimming Mode

In analog dimming mode, the dimming signal is added to ADIM pin directly to realize dimming function. The setting circuit is shown as Figure 5. When V_{ADIM} is higher than 2.4V, the driver will output 100% of rated current; when the voltage V_{ADIM} is in the range from 0mv to 2.4V, the output current will change linearly with the voltage V_{ADIM} . The dimming curve is shown as Figure 6 and the dimming range is from 1% to 100%.

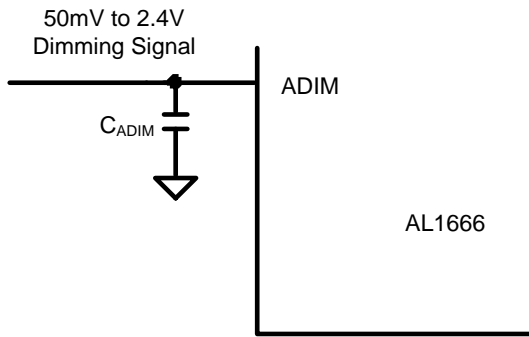


Figure 5. Analog Dimming Setting Circuit

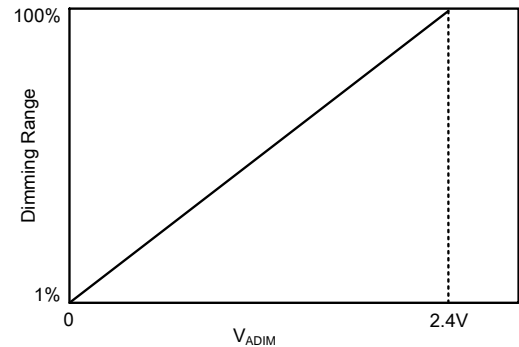


Figure 6. Analog Dimming Curve

2. PWM-to-DC Dimming Mode

In PWM-to-DC dimming mode, PWM dimming signal is added to PWMD pin. The setting circuit is shown as below. A capacitance of hundreds nF is recommended for C_{ADIM} . The duty cycle of the dimming signal D_{DIM} is reflected by the voltage on ADIM pin V_{ADIM} .

$$V_{ADIM} = D_{DIM} \times 2.4V$$

Where D_{DIM} is duty of PWM signal; V_{ADIM} is the voltage of ADIM pin.

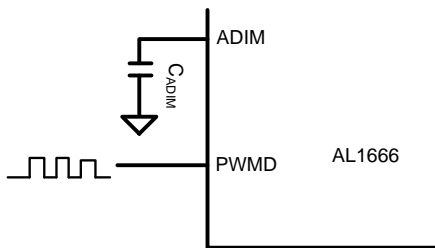


Figure 7. PWM Dimming Setting Circuit

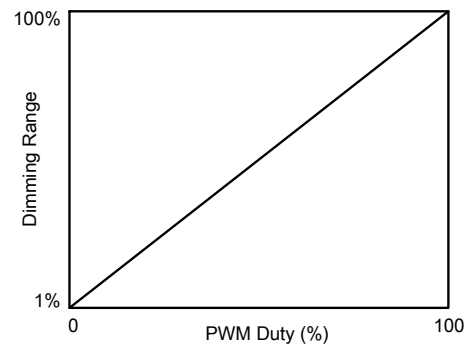


Figure 8. PWM Dimming Curve (PWM Frequency is 1kHz)

Application Information (continued)

Operation Parameters Design

Setting the Current Sense Resistor Rcs

The current sense resistance can be calculated as following:

$$R_{CS} = \frac{N_{PS} \cdot V_{REF}}{2 \cdot I_{O_MEAN}}$$

Where I_{O_MEAN} is the mean output current; R_{CS} is current sense resistor which is shown as Figure 1;

V_{REF} is internal reference voltage that is equal to 0.4V; N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost).

Setting Transformer Selection (T1)

N_{PS} is limited by the electrical stress of the switch MOSFET, can be calculated by below formula.

$$N_{PS} \leq \frac{V_{MOS_ (BR)DS} \cdot 90\% - \sqrt{2} \cdot V_{IN_MAX} - \Delta V_S}{V_O + V_{D_F}}$$

Where $V_{MOS_ (BR)DS}$ is the breakdown voltage of the switch MOSFET. V_{IN_MAX} is the max rated input voltage. ΔV_S is the overshoot voltage clamped by RCD snobbier during OFF time. V_O is the output voltage. V_{D_F} is the forward voltage of secondary diode. N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost).

For boundary conduction mode and constant on time method, the peak current of primary inductance can be calculated as below.

$$I_P = \frac{2 \cdot \pi \cdot I_{O_MEAN}}{N_{PS} \cdot \int_0^\pi \sin(\theta) \cdot \frac{\sqrt{2} \cdot V_{IN_RMS} \cdot \sin(\theta)}{\sqrt{2} \cdot V_{IN_RMS} \cdot \sin(\theta) + N_{PS} \cdot V_O} d\theta}$$

Where V_{IN_RMS} is the rate input voltage; I_P is the primary inductance current. N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost); I_{O_MEAN} is the mean output current; V_O is the output voltage.

The switching frequency is not constant for AL1666 due to boundary conduction mode. To set the minimum switching frequency f_{MIN} at the crest of the minimum AC input, primary inductance can be obtained by below formula.

$$L_P = \frac{\sqrt{2} \cdot V_{IN_RMS} \cdot N_{PS} \cdot V_O}{I_P \cdot (\sqrt{2} V_{IN_RMS} + N_{PS} V_O) \cdot f_{MIN}}$$

Where V_{IN_RMS} is the rate input voltage; I_P is the primary inductance current. N_{PS} is the turns ratio of Flyback transformer ($N_{PS}=1$ for Buck-boost);

I_{O_MEAN} is the mean output current; V_O is the output voltage; f_{MIN} is the minimum switching frequency at the crest of the minimum AC input.

According to the Faraday's Law, the winding number of the inductance can be calculated by:

$$N_P = \frac{L_P \cdot I_P}{A_e \cdot B_m}$$

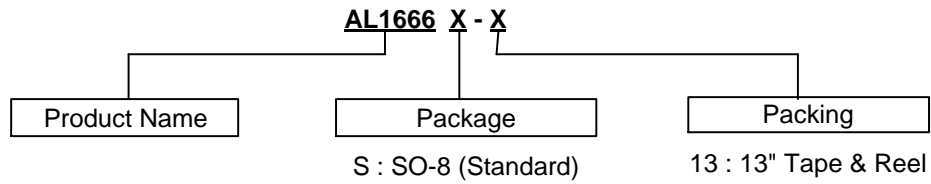
$$N_S = \frac{N_P}{N_{PS}}$$

Where,

A_e is the core effective area.

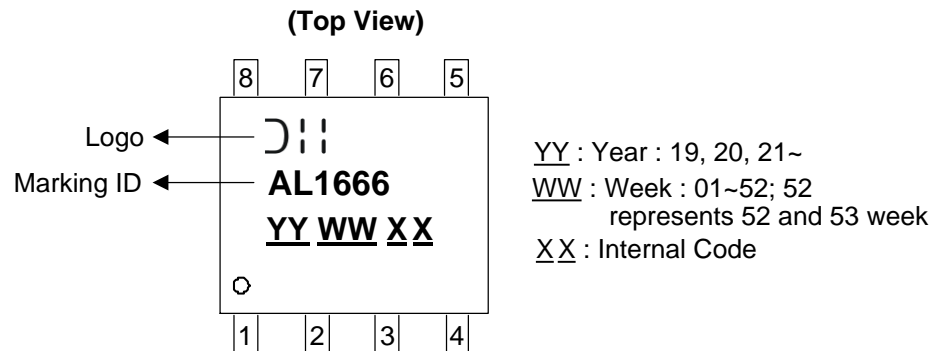
B_m is the maximum magnetic flux density.

Ordering Information



Part Number	Package Code	Package	13" Tape and Reel	
			Quantity	Part Number Suffix
AL1666S-13	S	SO-8 (Standard)	4000/Tape & Reel	-13

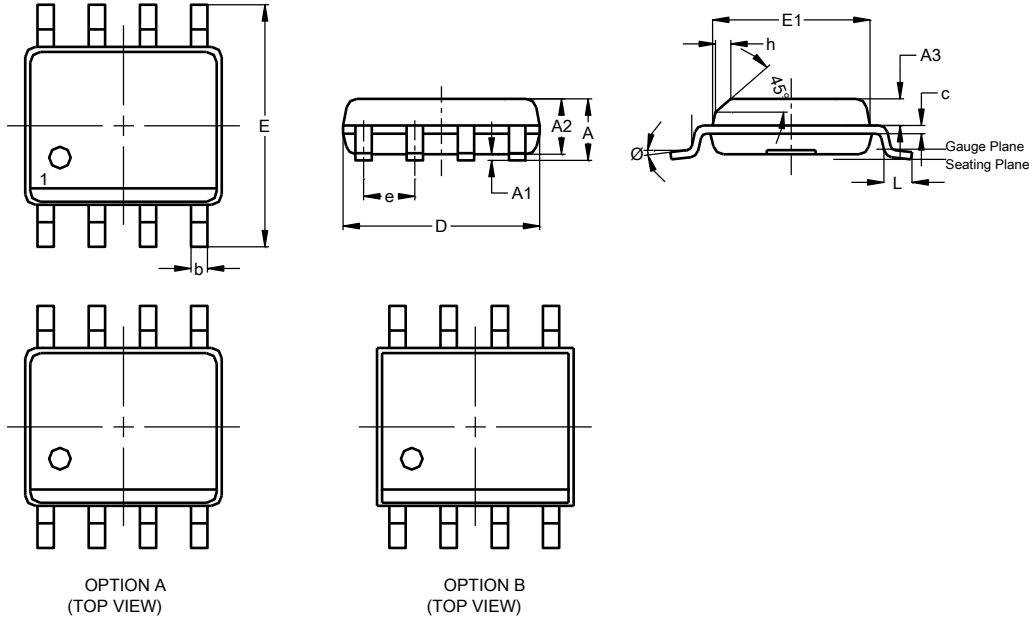
Marking Information



Package Outline Dimensions

Please see <http://www.diodes.com/package-outlines.html> for the latest version.

SO-8 (Standard)

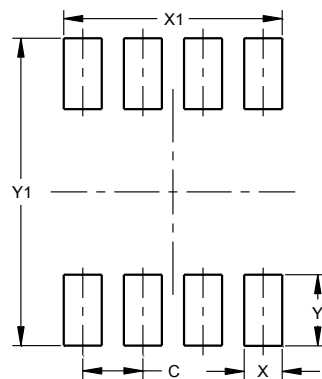


SO-8 (Standard)			
Dim	Min	Max	Typ
A	--	1.75	--
A1	0.10	0.25	--
A2	1.25	1.65	--
A3	0.50	0.70	--
b	0.30	0.51	--
c	0.15	0.25	--
D	4.80	5.00	--
E	5.80	6.20	6.00
E1	3.80	4.00	--
e	--	--	1.27
h	0.25	0.50	--
L	0.45	0.82	--
Ø	0°	8°	--
All Dimensions in mm			

Suggested Pad Layout

Please see <http://www.diodes.com/package-outlines.html> for the latest version.

SO-8 (Standard)



Dimensions	Value (in mm)
C	1.27
X	0.802
X1	4.612
Y	1.505
Y1	6.50

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