## Description

The AL1665 is a high-performance single-stage flyback and buck-boost controller, targeting dimmable LED lighting application. It is a primary side regulation (PSR) controller that can provide accurate constant current (CC) regulation without optocoupler and secondary control circuitry. It can be operated at BCM mode, which results in low EMI and high efficiency, and keeps high power factor (PF) and low total harmonic distortion (THD) under universal input voltage.

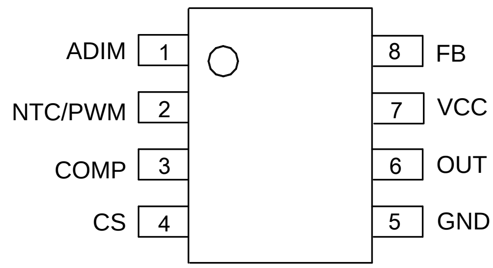
The AL1665 can support analog/PWM dimming modes. When a 50mV to 2.5V DC signal is applied on ADIM pin, the device is operated in analog dimming mode. The analog dimming range is 5% to 100%. When a PWM signal is applied to NTC/PWM pin, the device is operated at PWM dimming mode. The PWM dimming range is 0.5% to 100% (1k PWM dimming frequency).

The AL1665 has full protection features. It integrates multiple protections including undervoltage lockout (UVLO), output overvoltage (OVP), output short circuit (OSP), overcurrent protection (OCP), winding short circuit, secondary diode short, internal thermal foldback (TFP), and overtemperature protection (OTP).

The AL1665 is available in SO-8 (Standard) package.

## Pin Assignments

**(Top View)**




**SO-8 (Standard)**

## Features

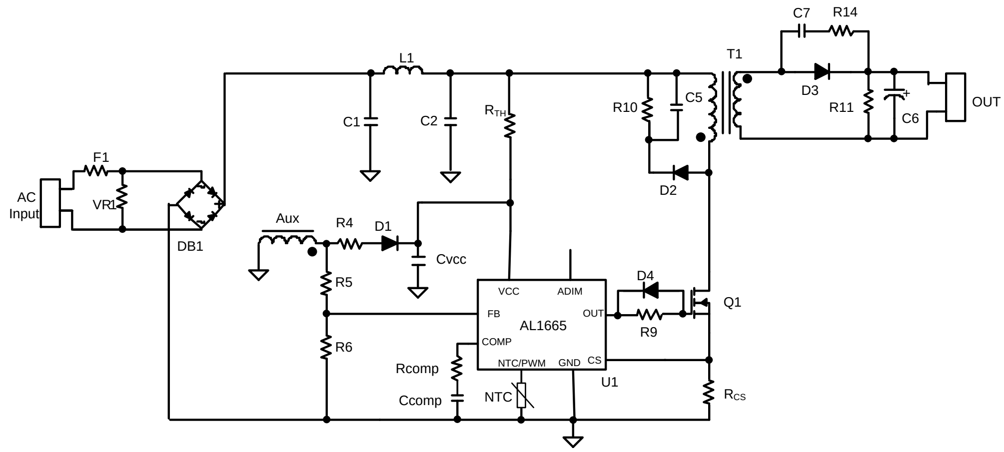
- Primary Side Regulation without Optocoupler
- Valley Switching for Low Switching Loss
- Tight CS Reference Voltage 0.4V±1.5%
- High PF>0.9 and Low THD<20%
- Support Analog and PWM Dimming
  - Analog Dimming Range: 5% to 100%
  - PWM Dimming Range: 0.5% to 100% (1k PWM Frequency)
- Internal Protections
  - Undervoltage Lockout (UVLO)
  - Output Overvoltage Protection (OVP)
  - Output Short Protection (OSP)
  - Overcurrent Protection (OCP)
  - Winding Short-Circuit Protection
  - Secondary Diode Short Protection
  - Shorted Current Sense Protection
  - User Programmable NTC Based Thermal Foldback
  - Internal Thermal Foldback Protection (TFP)
  - Overtemperature Protection (OTP)
- Tight LED Current Variation Range
  - LED Current Line Regulation: ±2%
  - LED Current Load Regulation: ±2% Full Load to Half Load
- Tight Output Open Voltage Variation Range
- 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 or your local Diodes representative.**
  **https://www.diodes.com/quality/product-definitions/**

## Applications

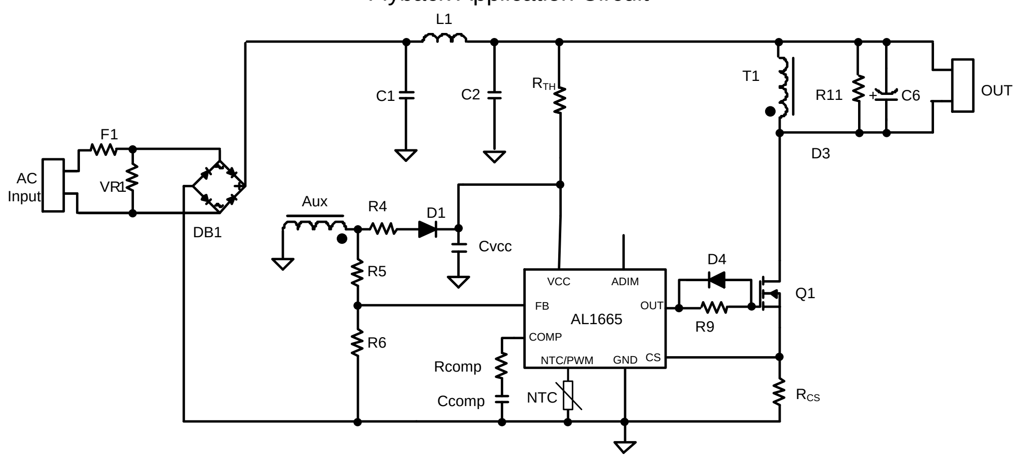
- General LED Lighting Driver with Dimming Function
- General Purpose Constant Current Source
- LED Backlighting Driver
- Smart LED Lighting

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.

## Typical Applications Circuit




Flyback Application Circuit

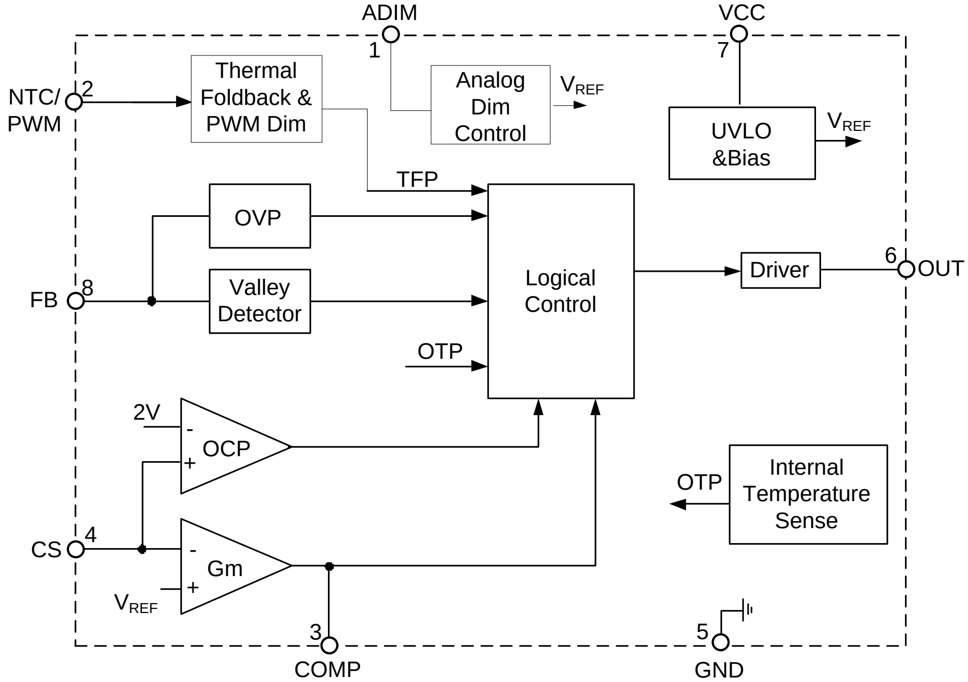



Buck-Boost Application Circuit

## Pin Descriptions

| Pin Number | Pin Name | Function |
|---|---|---|
| 1 | ADIM | Analog Dimming Input Pin |
| 2 | NTC/PWM | NTC Input Pin for Thermal Foldback/PWM Dimming 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 Voltage | -0.3 to 7 | V |
| $V_{COMP}$ | Voltage at Loop Compensation Pin | -0.3 to 7 | V |
| $V_{OUT}$ | Driver Output Voltage | -0.3 to 20 | V |
| $V_{NTC/PWM}$ | Voltage at NTC/PWM 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 |
| $\theta_{JA}$ | Thermal Resistance (Junction to Ambient) | 136 | °C/W |
| $\theta_{JC}$ | 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 are 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, VDIM=3V, $V_{FB}$=$V_{CS}$=$V_{COMP}$=1V, $C_{OUT}$=1nF | — | 1 | 2 | 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 Overcurrent Voltage | — | — | 3 | — | V |
| **Error Amplifier** | | | | | | |
| Gm | 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 |
| **ADIM Section** | | | | | | |
| — | Analog Dimming Range on ADIM | — | 0.05 | — | 2.5 | V |
| — | Analog Dimming High Level | — | 2.45 | 2.5 | 2.55 | V |
| — | Analog Dimming Range Ratio | — | 5% | — | 100% | — |

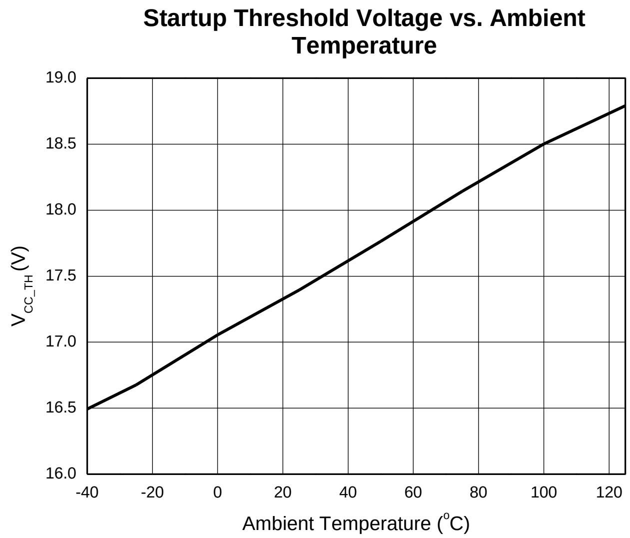
Note: 7. These parameters, although guaranteed by design, are not 100% tested in production.

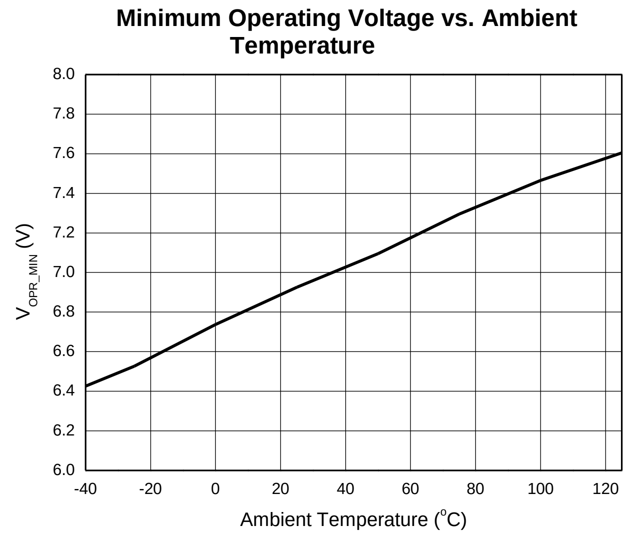
## Electrical Characteristics (@$T_A$ = +25°C, unless otherwise specified.) (continued)

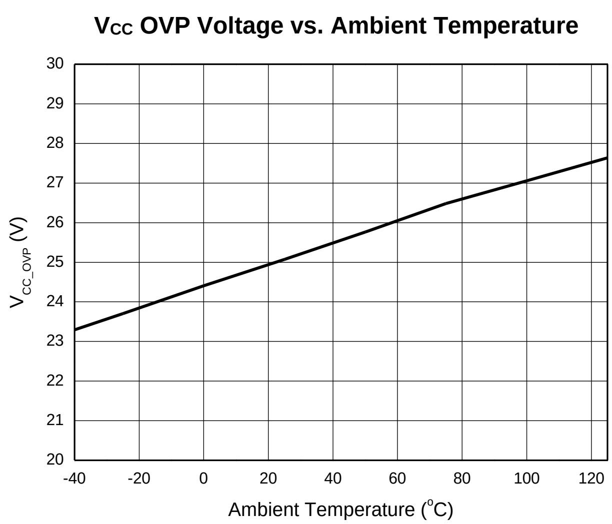
| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **NTC/PWM Section** | | | | | | |
| $V_{NTC/PWM(PULL-UP)}$ | Pullup Voltage when NTC/PWM Open | NTC/PWM Pin Open | — | 2.5 | — | V |
| $I_{OTP(REF)}$ | Reference Current for Direct Connection of NTC/PWM (Note 9) | — | 70.5 | 85 | 91 | µA |
| $V_{OTP(OFF)}$ | Fault Detection Level for OTP (Note 8) | $V_{NTC/PWM}$ Falling | — | 0.50 | — | V |
| $V_{OTP(ON)}$ | NTC/PWM Pin Level for Operation Recovery after an OTP Detection | $V_{NTC/PWM}$ Rising | — | 0.70 | — | V |
| $t_{OTP(START)}$ | OTP Blanking Time when Circuit Starts Operating (Note 9) | — | 250 | — | 370 | µs |
| $V_{TF(START)}$ | NTC/PWM Pin Voltage at which Thermal Foldback Starts ($V_{REF}$ is Decreased) | — | 0.94 | 1.00 | 1.06 | V |
| $V_{TF(STOP)}$ | NTC/PWM Pin Voltage at which Thermal Foldback Stops ($V_{REF}$ is Clamped to $V_{REF50}$) | — | 0.64 | 0.69 | 0.74 | V |
| $V_{REF(50)}$ | $V_{REF}$ @ $V_{NTC/PWM}$ = 600mV (Percent of $V_{REF}$) | — | 40 | 50 | 60 | % |
| **Thermal Foldback Section** | | | | | | |
| $T_{REG}$ | Overheating Temperature Regulation (Note 7) | — | — | +150 | — | °C |
| **Overtemperature Protection Section** | | | | | | |
| — | Shutdown Temperature (Notes 7, 8) | — | — | +180 | — | °C |

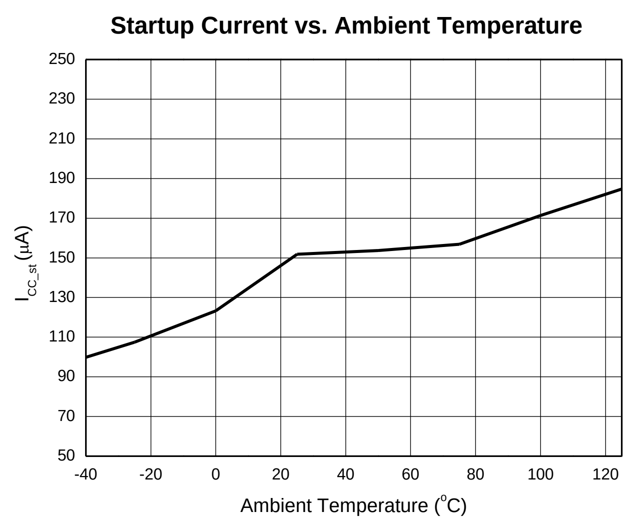
Notes:
7. These parameters, although guaranteed by design, are not 100% tested in production.
8. The device will latch when OTP occurs and will not be operated constantly at this temperature.
9. At startup, when $V_{CC}$ reaches $V_{CC(ON)}$, the controller blanks OTP for more than 250µs to avoid detecting an OTP fault by allowing the NTC/PWM pin voltage to reach its nominal value if a filtering capacitor is connected to the NTC/PWM pin.

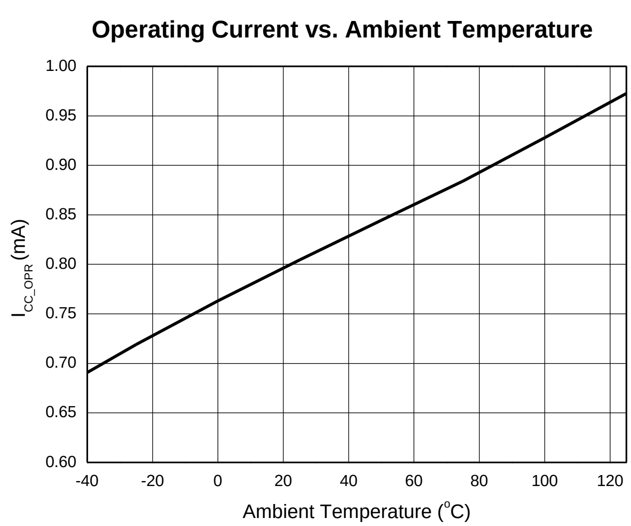
## Performance Characteristics (Note 10)

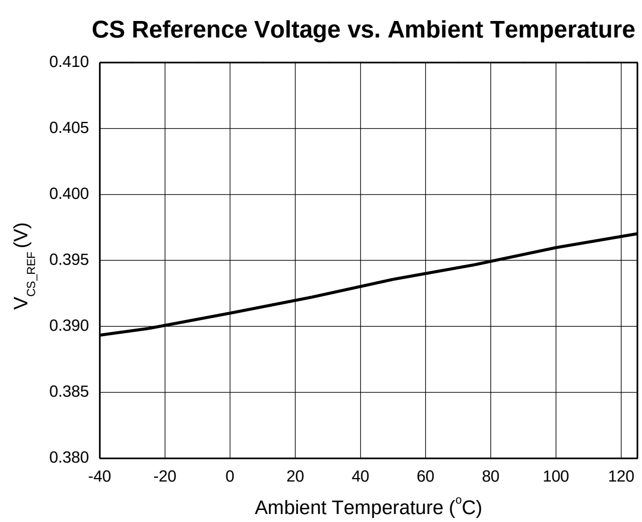


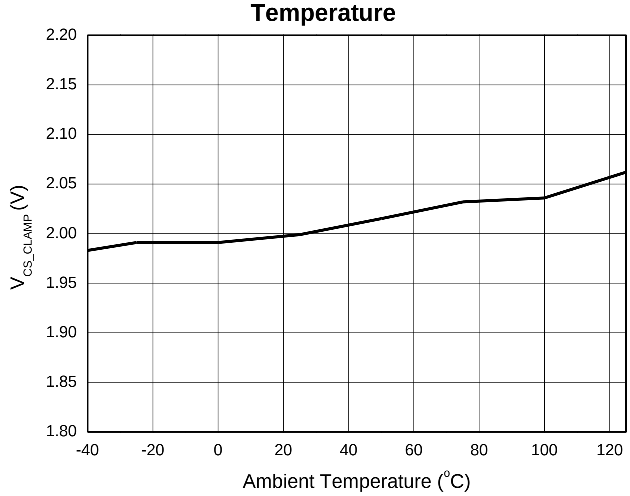



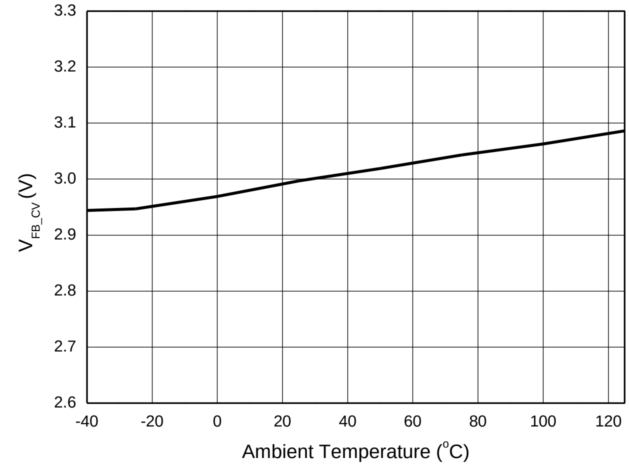

Note: 10. These electrical characteristics are tested under DC condition. The ambient temperature is equal to the junction temperature of the device.

## Performance Characteristics (continued)

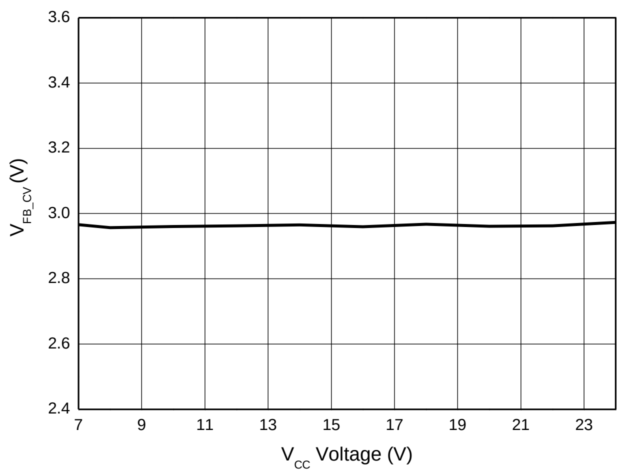
**CS Clamp Reference Voltage vs. Ambient Temperature**



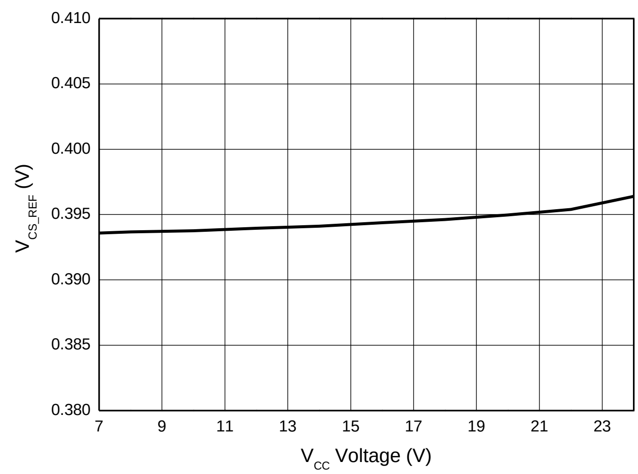

**FB CV Threshold vs. Ambient Temperature**



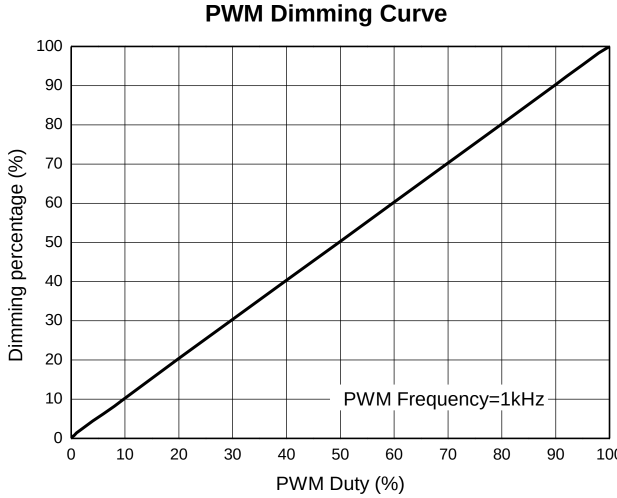

**FB CV Threshold vs. $V_{CC}$ Voltage**



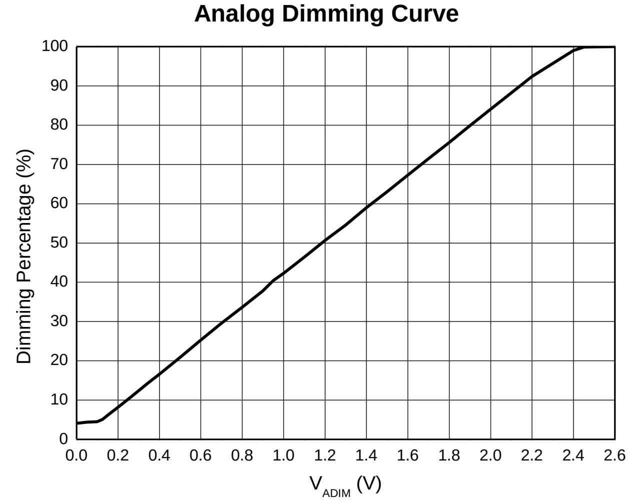

**CS Reference Voltage vs. $V_{CC}$ Voltage**




**PWM Dimming Curve**




**Analog Dimming Curve**



## Application Information

The AL1665 is a constant-current high-PF flyback and buck-boost controller with primary side regulation (PSR), targeting LED lighting applications. The device eliminates the optocouplers or the secondary feedback circuits, which is helpful to minimize the cost of the whole system. High power factor is achieved by constant on-time operation. In order to reduce the switching losses and improve EMI performance, quasi-resonant switching mode is applied. The AL1665 integrates multiple protections including UVLO protection, $V_{CC}$ overvoltage protection, output open-voltage protection, overcurrent protection, thermal foldback protection, and overtemperature protection. The AL1665 can support analog and PWM dimming modes.

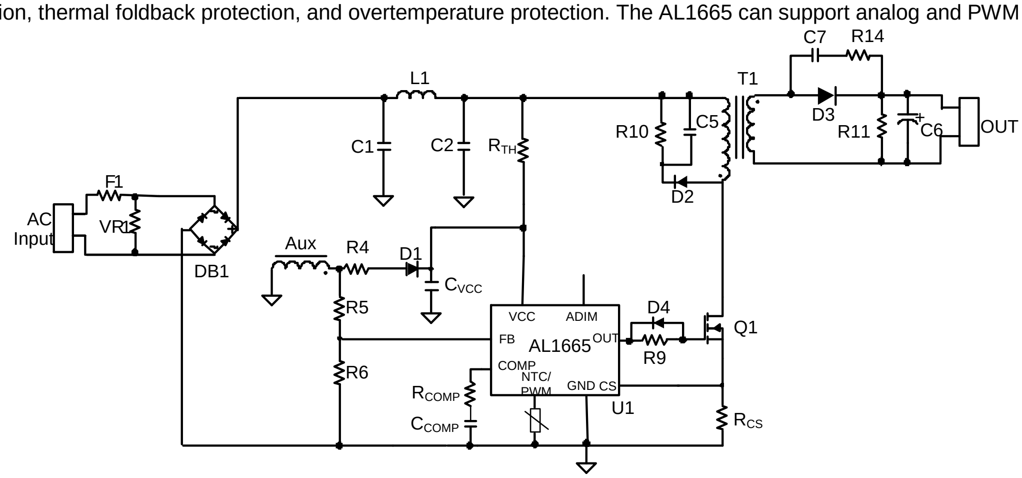



Figure 1. Flyback Application Circuit

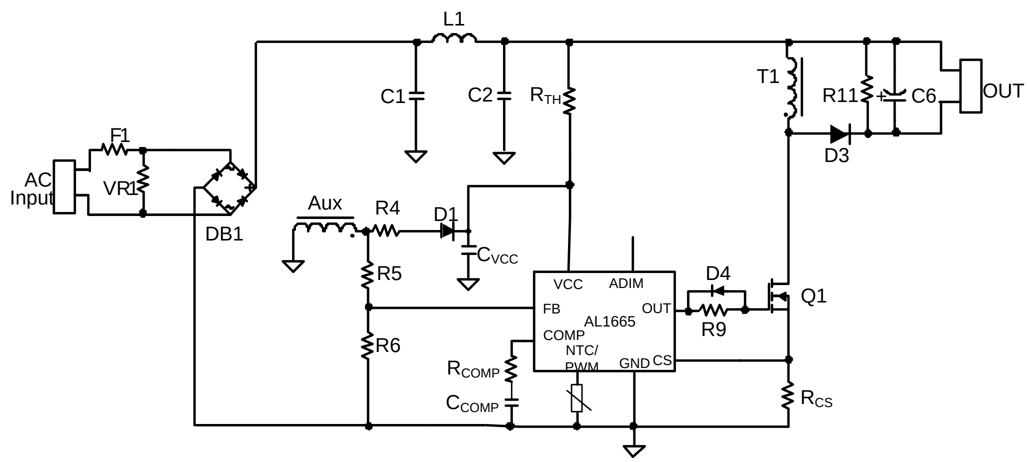



Figure 2. Buck-Boost Application Circuit

**Start Up**

After AC supply is powered on, the capacitor $C_{VCC}$ across VCC and GND pin charges up by BUS voltage through a start-up resistor $R_{TH}$. Once $V_{CC}$ reaches $V_{CC\_TH}$, the internal blocks start to work. $V_{CC}$ is supplied by $V_{BUS}$ until the auxiliary winding of flyback transformer could supply enough energy to maintain $V_{CC}$ above $V_{OPR\_MIN}$. If $V_{CC}$ voltage is lower than $V_{OPR\_MIN}$, the switch turns off.

After $V_{CC}$ exceeds $V_{CC\_TH}$, the drive blocks do not start to switch on/off signals until $V_{COMP}$ is higher than the initial voltage $V_{COMP\_ST}$, which can be programmed by $R_{COMP}$. The formula is shown below. Such design can program startup on time to reduce the startup time or the output overshoot current.

$$V_{COMP\_ST} = 1.4V - 700\mu A \cdot R_{COMP}$$

Where $V_{COMP\_ST}$ is the pre-charged voltage of COMP pin. Figure 1 shows $R_{COMP}$.

Generally, a big capacitance of $C_{COMP}$ is necessary to achieve high power factor and stabilize the system loop (1μF to 2μF is recommended). The pre-charged voltage in start-up procedure can be programmed by $R_{COMP}$.

## Application Information (continued)

**Protections**

**1. Output Open Protection (OVP)**

The output voltage is reflected by the voltage on transformer's auxiliary winding. Both the FB pin and the VCC pin of IC have the overvoltage protection function. When there is a rapid line and load transient, the output voltage can exceed the regulated value. If $V_{CC}$ exceeds $V_{CC\_OVP}$, the $V_{CC}$ overvoltage protection triggers, the switch turns off, and the $V_{CC}$ discharges. Once $V_{CC}$ is lower than $V_{OPR\_MIN}$, the IC shuts down and powers on again by BUS voltage through the start-up resistor. If $V_{FB}$ exceeds $V_{FB\_CV}$, the FB overvoltage protection triggers, the switch turns off, and $V_{CC}$ latches for 16s then $V_{CC}$ discharges. Once $V_{CC}$ is below $V_{OPR\_MIN}$, the IC shuts down and powers on again by BUS voltage through the start-up resistor. Power dissipation is low when FB overvoltage protection occurs.

Thus, output overvoltage depends on the minimum voltage between both OVP protections' limitation, which can be found with the below formula.

$$V_{OVP} = Min\left(\frac{N_S}{N_{AUX}} \cdot V_{CC\_OVP}, \frac{N_S}{N_{AUX}} \cdot \frac{R5+R6}{R6} \cdot V_{FB\_CV}\right)$$

Where:

- $V_{OVP}$ is the output overvoltage setting
- R5 and R6 shown in Figure 1 are divider resistors connected from the auxiliary winding
- $N_{AUX}$ is the turns of auxiliary wind
- $N_S$ is turns of the secondary wind
- $V_{CC\_OVP}$ is the 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. Overcurrent Protection (OCP)**

The AL1665 has a built-in cycle-by-cycle overcurrent protection of primary inductor current. When the CS pin voltage reaches the voltage $V_{CS\_CLAMP}$, the switch turns off until the next switch period. The maximum peak current ($I_{PEAK\ (MAX)}$) of the inductor can be calculated as follows:

$$I_{PEAK\_MAX} = \frac{V_{CS\_CLAMP}}{R_{CS}}$$

Where:

- $V_{CS\_CLAMP}$ means primary current clamp voltage, which is 2V.
- $R_{CS}$ is current sense resister, which is shown as Figure 1

**4. CS Short Protection**

When the CS pin shorts to GND, CS voltage latches to zero. If CS is detected lower than 0.3V for seven pulses, the CS short protection triggers, the switch turns off, and $V_{CC}$ latches for 16s then $V_{CC}$ discharges. Once $V_{CC}$ is below $V_{OPR\_MIN}$, the IC shuts down and powers on again by the BUS voltage through the startup resistor. High rush current appears when CS is shorted to GND, and it may damage the components.

**5. Secondary Diodes/Primary Windings/Secondary Windings Short Protection**

The CS voltage is high when secondary diodes/primary windings/secondary windings short. If the CS voltage is higher than $V_{CS\_OCP}$, the protection triggers, the switch turns off, and $V_{CC}$ latches for 16s then $V_{CC}$ discharges. Once $V_{CC}$ is below $V_{OPR\_MIN}$, the IC shuts down and powers on again by the BUS voltage through the startup resistor. Power dissipation is low when output short protection occurs.

**6. Thermal Foldback Protection (TFP)**

Connect a NTC between the NTC/PWM pin and ground to detect an overtemperature condition. In response to a high temperature (detected if $V_{NTC/PWM}$ drops below $V_{TF(START)}$), the circuit gradually reduces the LED current down 50% of its nominal value when $V_{NTC/PWM}$ reaches $V_{TF(STOP)}$, in accordance with the characteristic of Figure 3. If this thermal foldback cannot prevent the temperature from rising (testified by $V_{NTC/PWM}$ dropping below $V_{OTP}$), the circuit latches off or enters the auto-recovery mode and cannot be reoperated until $V_{NTC/PWM}$ exceeds $V_{OTP(ON)}$ to provide some temperature hysteresis (around +10°C typically).

## Application Information (continued)

The OTP thresholds nearly correspond to the following resistances of the NTC:

- Thermal foldback starts when $R_{NTC}$ <=$R_{TF(START)}$(11.7kΩ typically)
- Thermal foldback stops when $R_{NTC}$ <=$R_{TF(STOP)}$ (8.0kΩ typically)
- OTP triggers when $R_{NTC}$ <= $R_{OTP(OFF)}$ (5.9kΩ typically)
- OTP is removed when $R_{NTC}$ >= $R_{OTP(ON)}$ (8.0kΩ typically)

At startup, when $V_{CC}$ reaches $V_{CC(ON)}$, the OTP comparator blanks for at least 250µs in order to allow the NTC/PWM pin voltage to reach its nominal value if a filtering capacitor is connected to the NTC/PWM pin. This would avoid flickering of the LED light during turn-on.

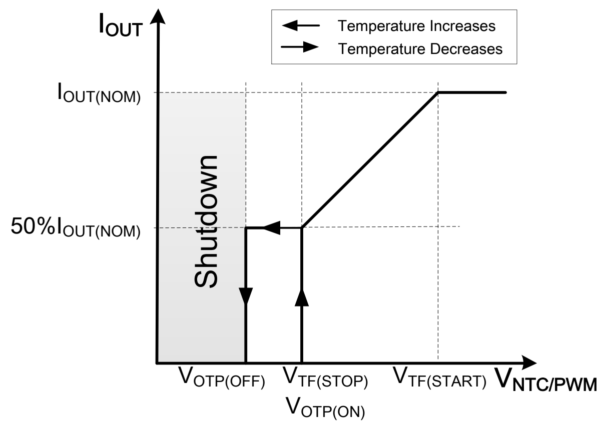



Figure 3. Output Current Reduction vs NTC/PWM Pin Voltage

**7. Overtemperature Protection (OTP)**

The AL1665 has built-in overtemperature protection (OTP) function. When the temperature goes up to +180°C, the overtemperature protection is triggered, which leads to VCC UVLO. When OTP recovers, the system can be restarted.

**Output Constant Current Control**

According to the definition of mean output current, the mean output current can be obtained as following:

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

Where:

- $I_{O\_MEAN}$ is the mean output current
- $I_{SP}$ is the secondary peak current of transformer
- $t_{ONS}$ is the discharge time of secondary side of transformer
- $t_{SW}$ is the switch period

According to the principle of AL1665 closed-loop control, the voltage of $R_{CS}$ is sampled when the switch turns off, and the value is held until the 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 the primary peak current of transformer
- $R_{CS}$ is the current sense resister, which is shown in Figure 1
- $t_{ONS}$ is the 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

## Application Information (continued)

The peak current at secondary side has the 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), and $I_P$ is the primary peak current of the transformer.

According to these above formulas, the mean output current can be induced finally by the following equation:

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

Where:

- $I_{O\_MEAN}$ is the mean output current
- $R_{CS}$ is the current sense resister, which is shown as Figure 1 and Figure 2
- $V_{REF}$ is the 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, AL1665 can provide PF>0.9 and THD <40%. It can improve PF>0.95 and THD<20% by adding the compensation circuit as below. The $V_{BUS}$ is connected to bus line, which is after the rectifier bridge. The COMP pin voltage increases an offset that is almost followed with bus line voltage in the circuit. Due to the COMP voltage controls, the switch-on time, the phase difference between input voltage and input current, is reduced, which can optimize the PF and THD. In the circuit, the range of resister value R12 is from 800kΩ to 1.5MΩ, and the range of resistor value R13 is from 500Ω to 5.1kΩ. The range of capacitance C11 is 1µF to 2µF. The PF and THD circuit can be improved by fine-tuning these components.

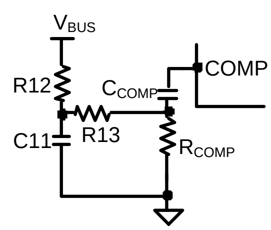



Figure 4. PF and THD Compensation Circuit

**Line Regulation Compensation Function**

The AL1665 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 5 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 6kΩ

## Application Information (continued)

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

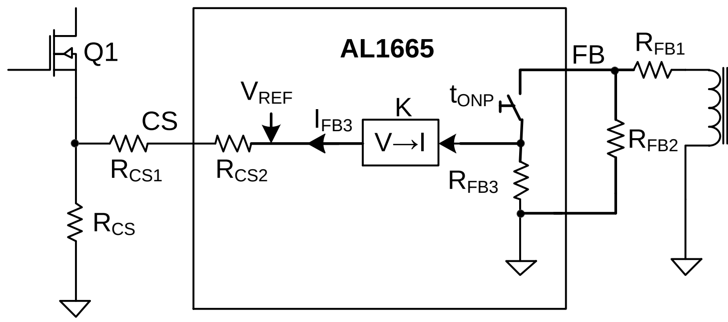



Figure 5. Line Regulation Compensation Circuit

**Dimming Mode**

The AL1665 can support two dimming modes: analog dimming and PWM dimming.

**1. Analog Dimming Mode**

In analog dimming mode, the dimming signal is added to ADIM pin directly to realize dimming function. Figure 6 shows the setting circuit. When $V_{APWM}$ is higher than 2.5V, the driver outputs 100% of rated current, and when the voltage $V_{ADIM}$ is within the 50mV to 2.5V range, the output current changes linearly with the voltage $V_{APWM}$. Figure 7 shows the dimming curve, and the dimming range is from 5% to 100%.

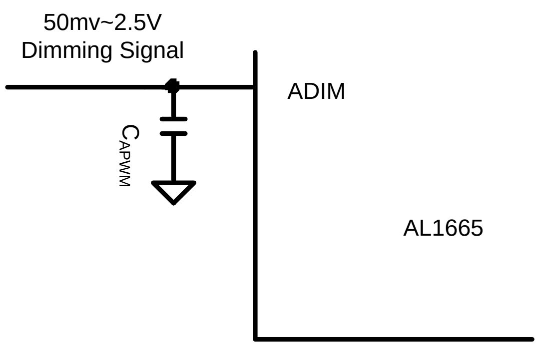



Figure 6. Analog Dimming Setting Circuit

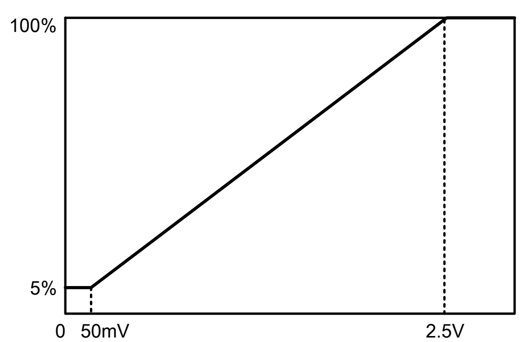



Figure 7. Analog Dimming Curve

## Application Information (continued)

**2. PWM Dimming Mode**

In PWM dimming mode, the dimming signal is added to NTC/PWM pin. Figure 8 shows the setting circuit. The output current is chopped by the dimming signal directly. The logic high level of the dimming signal must be higher than 1V while the logic low level is lower than 0.5V. The switch turns off at logic low level. Figure 9 shows the dimming curve. The dimming range can be 100% to 0.5% with 1KHz frequency of PWM signal.

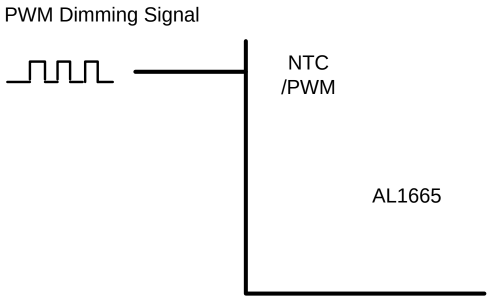



Figure 8. PWM Dimming Setting Circuit

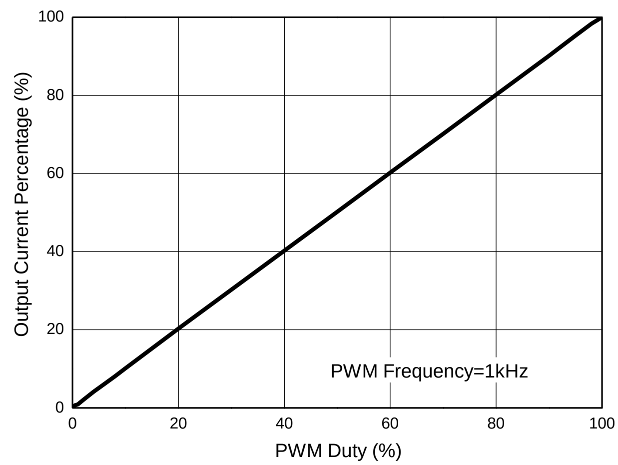



Figure 9. PWM Dimming Curve

**Operation Parameters Design**

**1. Setting the Current Sense Resistor $R_{CS}$**

The current sense resistance is calculated using the following equation:

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

Where:

- $I_{O\_MEAN}$ is the mean output current
- $R_{CS}$ is the current sense resister, which is shown as Figure 1
- $V_{REF}$ is the internal reference voltage that is equal to 0.4V
- $N_{PS}$ is the turns' ratio of flyback transformer ($N_{PS}$=1 for buck-boost)

**2. Setting Transformer Selection (T1)**

$N_{PS}$ is limited by the electrical stress of the switch MOSFET and can be calculated with the following formula:

$$N_{PS} \le \frac{V_{MOS\_(BR)DS} \cdot 90\% - \sqrt{2} \cdot V_{IN\_MAX} - \Delta V_S}{V_O + V_{D\_F}}$$

Where:

- $V_{MOS\_(BR)DS}$ is the breakdown voltage of the switch MOSFET
- $V_{IN\_MAX}$ is the max rated input voltage
- $\Delta V_S$ 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)

## Application Information (continued)

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

$$I_P = \frac{2 \cdot \pi \cdot I_{O\_MEAN}}{N_{PS} \cdot \int_0^{\pi} \sin(\theta) \cdot \frac{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta)}{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta) + N_{PS} \cdot Vo} d\theta}$$

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 AL1665 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 the following 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)
- $V_O$ 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

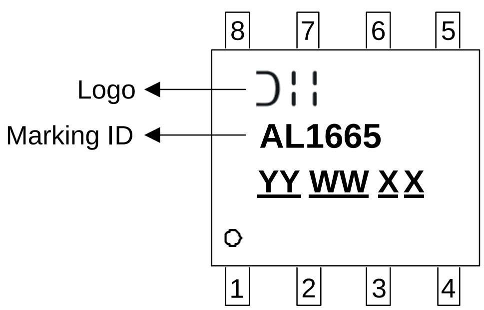
**AL1665 X - X**

- Product Name: AL1665
- Package: S : SO-8 (Standard)
- Packing: 13 : 13" Tape & Reel

| Part Number | Package Code | Package | 13" Tape and Reel | |
|---|---|---|---|---|
| | | | Quantity | Part Number Suffix |
| AL1665S-13 | S | SO-8 (Standard) | 4000/Tape & Reel | -13 |

## Marking Information

**(Top View)**

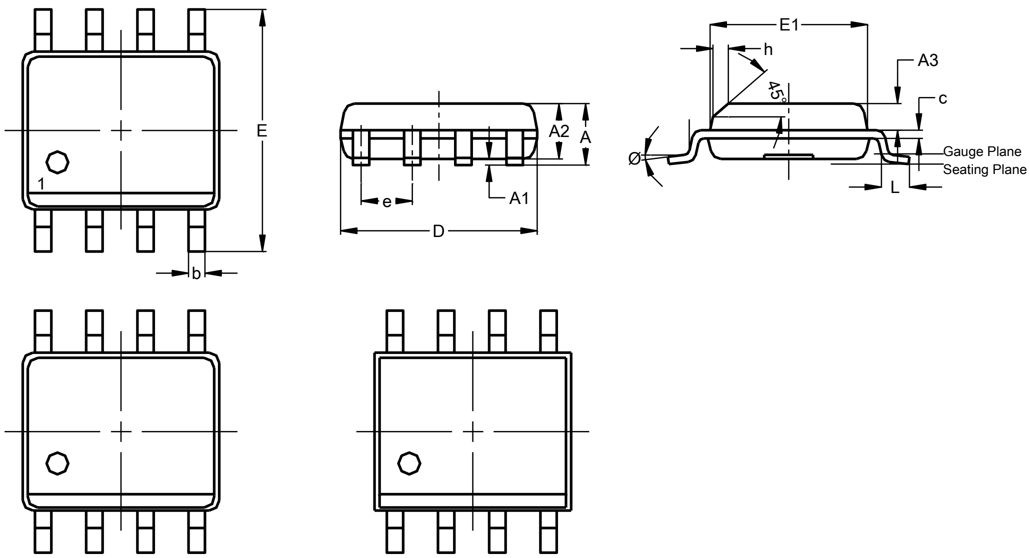



YY : Year : 19, 20, 21~
WW : Week : 01~52; 52 represents 52 and 53 week
X X : Internal Code

## Package Outline Dimensions (All dimensions in mm.)

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

**SO-8 (Standard)**




OPTION A
(TOP VIEW)

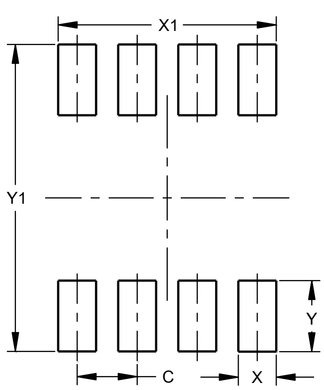
OPTION B
(TOP VIEW)

| 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 |