Description

The AL1665 is a high-performance single-stage flyback 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.

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.

Notes:
1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS), 2011/55/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.

Applications

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

Flyback Application Circuit

Buck-Boost Application Circuit

Pin Descriptions

<table>
<thead>
<tr>
<th>Pin Number</th>
<th>Pin Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ADIM</td>
<td>Analog Dimming Input Pin</td>
</tr>
<tr>
<td>2</td>
<td>NTC/PWM</td>
<td>NTC Input Pin for Thermal Foldback/PWM Dimming Input Pin</td>
</tr>
<tr>
<td>3</td>
<td>COMP</td>
<td>Loop Compensation Pin</td>
</tr>
<tr>
<td>4</td>
<td>CS</td>
<td>Current Sense Pin, Connect This Pin to the Source of the Primary Switch</td>
</tr>
<tr>
<td>5</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>6</td>
<td>OUT</td>
<td>Gate Driver Output</td>
</tr>
<tr>
<td>7</td>
<td>VCC</td>
<td>Supply Voltage of Gate Driver and Control Circuits of the IC</td>
</tr>
<tr>
<td>8</td>
<td>FB</td>
<td>The Feedback Voltage Sensing from the Auxiliary Winding</td>
</tr>
</tbody>
</table>
Functional Block Diagram

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCC</td>
<td>Power Supply Voltage</td>
<td>-0.3 to 30</td>
<td>V</td>
</tr>
<tr>
<td>VCS</td>
<td>Voltage at CS to GND</td>
<td>-0.3 to 7</td>
<td>V</td>
</tr>
<tr>
<td>VFB</td>
<td>FB Input Voltage</td>
<td>-0.3 to 7</td>
<td>V</td>
</tr>
<tr>
<td>VCOMP</td>
<td>Voltage at Loop Compensation Pin</td>
<td>-0.3 to 7</td>
<td>V</td>
</tr>
<tr>
<td>VOUT</td>
<td>Driver Output Voltage</td>
<td>-0.3 to 20</td>
<td>V</td>
</tr>
<tr>
<td>VNTC/PWM</td>
<td>Voltage at NTC/PWM to GND</td>
<td>-0.3 to 7</td>
<td>V</td>
</tr>
<tr>
<td>VADIM</td>
<td>Voltage at ADIM to GND</td>
<td>-0.3 to 7</td>
<td>V</td>
</tr>
<tr>
<td>TJ</td>
<td>Operating Junction Temperature</td>
<td>-40 to +150</td>
<td>°C</td>
</tr>
<tr>
<td>TSTG</td>
<td>Storage Temperature</td>
<td>-65 to +150</td>
<td>°C</td>
</tr>
<tr>
<td>TLEAD</td>
<td>Lead Temperature (Soldering, 10s)</td>
<td>+300</td>
<td>°C</td>
</tr>
<tr>
<td>PD</td>
<td>Power Dissipation at (T_A = +50°C)</td>
<td>0.65</td>
<td>W</td>
</tr>
<tr>
<td>θJA</td>
<td>Thermal Resistance (Junction to Ambient)</td>
<td>136</td>
<td>°C/W</td>
</tr>
<tr>
<td>θJC</td>
<td>Thermal Resistance (Junction to Case)</td>
<td>30</td>
<td>°C/W</td>
</tr>
<tr>
<td>—</td>
<td>ESD (Human Body Model)</td>
<td>2000</td>
<td>V</td>
</tr>
<tr>
<td>—</td>
<td>ESD (Charged-Device Model)</td>
<td>1000</td>
<td>V</td>
</tr>
</tbody>
</table>

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.)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_A</td>
<td>Ambient Temperature (Note 5)</td>
<td>-40</td>
<td>+105</td>
<td>°C</td>
</tr>
<tr>
<td>V_CCC</td>
<td>Operating VCC Voltage (Note 6)</td>
<td>8.5</td>
<td>V_CCC_OVP (Min)</td>
<td>V</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_CCC_TH</td>
<td>Startup Threshold Voltage</td>
<td>V_CCC = V_CCC_TH -0.5V, Before Start Up</td>
<td>15.8</td>
<td>18.5</td>
<td>19.5</td>
<td>V</td>
</tr>
<tr>
<td>V_OPR_MIN</td>
<td>Minimal Operating Voltage</td>
<td>After Turn On</td>
<td>5.8</td>
<td>7.8</td>
<td>9</td>
<td>V</td>
</tr>
<tr>
<td>V_CCC_OVP</td>
<td>V_CCC OVP Voltage</td>
<td></td>
<td>21.8</td>
<td>25</td>
<td>29.5</td>
<td>V</td>
</tr>
</tbody>
</table>

#### Standby Current Section

| IST               | Startup Current                                  | —                                          | 120 | 300 | μA  |
| I_CCC             | Operating Current @ 4KHz                        | V_CCC=20V, VDIM=3V, V_HF=V_CSP=V_COMP=1V, C_OUT=1nF | —   | 1   | 2   | mA   |
| I_CCC_OVP       | Shunt Current in OVP Mode                      | V_CCC > V_CCC_OVP                          | 3.1 | —   | —   | mA   |

#### Drive Output Section

| T_R               | Output Voltage Rise Time (Note 7)               | Cl = 1nF                                   | —   | 100 | —   | ns   |
| T_F               | Output Voltage Fall Time (Note 7)              | Cl = 1nF                                   | —   | 100 | —   | ns   |
| V_OUT.Clamp       | Output Clamp Voltage                            | V_CCC = 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  |
| T_MAX             | Maximum Frequency                              | —                                          | 150 | —   | —   | kHz  |

#### Internal CS Reference

| V_REF             | Internal Reference Voltage                     | —                                          | 0.394| 0.4  | 0.406| V    |
| V_CCS_Clamp      | Primary Current Clamp Voltage                  | —                                          |  —   | 2   | —   | V    |
| V_CCS_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 \( @T_A = +25^\circ C, \text{ unless otherwise specified.} \) (continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{NTC/PWM} )</td>
<td>Pullup Voltage when NTC/PWM Open</td>
<td>NTC/PWM Pin Open</td>
<td>—</td>
<td>2.5</td>
<td>—</td>
<td>V</td>
</tr>
<tr>
<td>( I_{OTP(REF)} )</td>
<td>Reference Current for Direct Connection of NTC/PWM (Note 9)</td>
<td>—</td>
<td>70.5</td>
<td>85</td>
<td>91</td>
<td>µA</td>
</tr>
<tr>
<td>( V_{OTP(OFF)} )</td>
<td>Fault Detection Level for OTP (Note 8)</td>
<td>( V_{NTC/PWM} ) Falling</td>
<td>—</td>
<td>0.50</td>
<td>—</td>
<td>V</td>
</tr>
<tr>
<td>( V_{OTP(ON)} )</td>
<td>NTC/PWM Pin Level for Operation Recovery after an OTP Detection</td>
<td>( V_{NTC/PWM} ) Rising</td>
<td>—</td>
<td>0.70</td>
<td>—</td>
<td>V</td>
</tr>
<tr>
<td>( I_{OTP(START)} )</td>
<td>OTP Blankning Time when Circuit Starts Operating (Note 9)</td>
<td>—</td>
<td>250</td>
<td>—</td>
<td>370</td>
<td>µs</td>
</tr>
<tr>
<td>( V_{TF(START)} )</td>
<td>NTC/PWM Pin Voltage at which Thermal Foldback Starts (( V_{REF} ) is Decreased)</td>
<td>—</td>
<td>0.94</td>
<td>1.00</td>
<td>1.06</td>
<td>V</td>
</tr>
<tr>
<td>( V_{TF(STOP)} )</td>
<td>NTC/PWM Pin Voltage at which Thermal Foldback Stops (( V_{REF} ) is Clamped to ( V_{REF(50)} ))</td>
<td>—</td>
<td>0.64</td>
<td>0.69</td>
<td>0.74</td>
<td>V</td>
</tr>
<tr>
<td>( V_{REF(50)} )</td>
<td>( V_{REF} ) at ( V_{NTC/PWM} = 600\text{mV} ) (Percent of ( V_{REF} ))</td>
<td>—</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>%</td>
</tr>
</tbody>
</table>

### Thermal Foldback Section

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{REG} )</td>
<td>Overheating Temperature Regulation (Note 7)</td>
<td>—</td>
<td>—</td>
<td>+150</td>
<td>—</td>
<td>°C</td>
</tr>
</tbody>
</table>

### Overtemperature Protection Section

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>Shutdown Temperature (Notes 7, 8)</td>
<td>—</td>
<td>—</td>
<td>+180</td>
<td>—</td>
<td>°C</td>
</tr>
</tbody>
</table>

**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)

Start-up Threshold Voltage vs. Ambient Temperature

Minimum Operating Voltage vs. Ambient Temperature

Vcc OVP Voltage vs. Ambient Temperature

Startup Current vs. Ambient Temperature

Operating Current vs. Ambient Temperature

CS Reference Voltage vs. Ambient Temperature

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**
  - Graph showing the relationship between CS Clamp Reference Voltage ($V_{CS\_CLAMP}$) and Ambient Temperature ($T_a$) from -40°C to 120°C.

- **FB CV Threshold vs. Ambient Temperature**
  - Graph showing the relationship between FB CV Threshold ($V_{FB\_CV}$) and Ambient Temperature ($T_a$) from -40°C to 120°C.

- **FB CV Threshold vs. $V_{CC}$ Voltage**
  - Graph showing the relationship between FB CV Threshold ($V_{FB\_CV}$) and $V_{CC}$ Voltage from 7V to 23V.

- **CS Reference Voltage vs. $V_{CC}$ Voltage**
  - Graph showing the relationship between CS Reference Voltage ($V_{CS\_REF}$) and $V_{CC}$ Voltage from 7V to 23V.

- **PWM Dimming Curve**
  - Graph showing the relationship between Dimming Percentage (%) and PWM Duty (%) with PWM Frequency = 1kHz.

- **Analog Dimming Curve**
  - Graph showing the relationship between Dimming Percentage (%) and $V_{ADIM}$ (V) from 0V to 2.6V.
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, Vcc overvoltage protection, output open-voltage protection, overcurrent protection, thermal foldback protection, and overtemperature protection. The AL1665 can support analog and PWM dimming modes.

![Flyback Application Circuit](image1)

**Figure 1. Flyback Application Circuit**

![Buck-Boost Application Circuit](image2)

**Figure 2. Buck-Boost Application Circuit**

**Start Up**

After AC supply is powered on, the capacitor CVCC across VCC and GND pin charges up by BUS voltage through a start-up resistor RTH. Once Vcc reaches VCC_TH, the internal blocks start to work. VCC is supplied by VBUS until the auxiliary winding of flyback transformer could supply enough energy to maintain VCC above VOPR_MIN. If VCC voltage is lower than VOPR_MIN, the switch turns off.

After VCC exceeds VCC_TH, the drive blocks do not start to switch on/off signals until VCOMP is higher than the initial voltage VCOMP_ST, which can be programmed by RCOMP. 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 VCOMP_ST is the pre-charged voltage of COMP pin. Figure 1 shows RCOMP.

Generally, a big capacitance of CCOMP 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 RCOMP.
Application Information (continued)

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 VCC exceeds VCC_OVP, the VCC overvoltage protection triggers, the switch turns off, and the VCC discharges. Once VCC is lower than VCC_MIN, the IC shuts down and powers on again by BUS voltage through the startup resistor. If VFB exceeds VFB_MIN, the FB overvoltage protection triggers, the switch turns off, and VCC latches for 16s then VCC discharges. Once VCC is below VCC_MIN, the IC shuts down and powers on again by BUS voltage through the startup 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.

\[
V_{OVP} = \text{Min} \left( \frac{N_S}{N_{AUX}} \cdot V_{CC-OVP}, \frac{N_S}{N_{AUX}} \cdot \frac{R5 + R6}{R6} \cdot V_{FB-CV} \right)
\]

Where:
- \(V_{OVP}\) is the output 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 the turns of secondary wind
- VCC_OVP is the OVP voltage of VCC

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 VFB drops below 0.4V, the output short protection will be triggered, the device cannot detect the tOFF 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 VCC latches for 16s then VCC discharges. Once VCC is below VCC_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 VCC latches for 16s then VCC discharges. Once VCC is below VCC_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 VNTC_PWM drops below VTTF_START), the circuit gradually reduces the LED current down 50% of its nominal value when VNTC_PWM reaches VTTF_STOP, in accordance with the characteristic of Figure 3. If this thermal foldback cannot prevent the temperature from rising (testified by VNTC_PWM dropping below VOTP), the circuit latches off or enters the auto-recovery mode and cannot be reoperated until VNTC_PWM exceeds VOTP to provide some temperature hysteresis (around +10°C typically).
The OTP thresholds nearly correspond to the following resistances of the NTC:
- Thermal foldback starts when \( R_{\text{NTC}} = R_{\text{TF\{START\}}} (11.7k\Omega \text{ typically}) \)
- Thermal foldback stops when \( R_{\text{NTC}} = R_{\text{TF\{STOP\}}} (8.0k\Omega \text{ typically}) \)
- OTP triggers when \( R_{\text{NTC}} = R_{\text{OTP\{OFF\}}} (5.9k\Omega \text{ typically}) \)
- OTP is removed when \( R_{\text{NTC}} = R_{\text{OTP\{ON\}}} (8.0k\Omega \text{ typically}) \)

At startup, when \( V_{\text{CC}} \) reaches \( V_{\text{CC\{ON\}}} \), the OTP comparator blanks for at least 250\( \mu \)s 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.

7. Overtemperature Protection (OTP)
The AL1665 has built-in overtemperature protection (OTP) function. When the temperature goes up to +180\(^\circ\)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:

\[
I_{O\_\text{MEAN}} = \frac{1}{\pi} \int_{0}^{\pi} \frac{1}{2} \cdot I_{SP} \cdot \frac{t_{\text{ONS}}}{t_{\text{SW}}} \, dt
\]

Where:
- \( I_{O\_\text{MEAN}} \) is the mean output current
- \( I_{SP} \) is the secondary peak current of transformer
- \( t_{\text{ONS}} \) is the discharge time of secondary side of transformer
- \( t_{\text{SW}} \) is the switch period

According to the principle of AL1665 closed-loop control, the voltage of \( R_{\text{CS}} \) is sampled when the switch turns off, and the value is held until the discharge time \( t_{\text{ONS}} \) is over. It can be described by following formula:

\[
V_{\text{REF}} = \frac{1}{\pi} \int_{0}^{\pi} I_{P} \cdot R_{\text{CS}} \cdot \frac{t_{\text{ONS}}}{t_{SW}} \, dt
\]

Where:
- \( I_{P} \) is the primary peak current of transformer
- \( R_{\text{CS}} \) is the current sense resister, which is shown in Figure 1
- \( t_{\text{ONS}} \) is the discharge time of secondary side of transformer
- \( t_{\text{SW}} \) is the switch period
- \( V_{\text{REF}} \) 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 \( R_{12} \) is from 800kΩ to 1.5MΩ, and the range of resistor value \( R_{13} \) is from 500Ω to 5.1kΩ. The range of capacitance \( C_{11} \) is 1µF to 2µF. The PF and THD circuit can be improved by fine-tuning these components.

![PF and THD Compensation Circuit](image)

**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:

\[ V_{FB} = \sqrt{2} \cdot V_{IN\_RMS} \cdot N_{AP} \cdot R_{FB3} \]

And the \( V_{CS\_OFFSET} \) can be got:

\[ V_{CS\_OFFSET} = K \cdot \sqrt{2} \cdot V_{IN\_RMS} \cdot N_{AP} \cdot R_{FB3} \cdot (R_{FB1} + R_{FB3}) \]

Where:
- \( K \) is conversion coefficient of \( I_{FB3} \) that is equal to 0.013*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:

\[
I_{O,MEAN} = \frac{N_{PS}}{2 \cdot R_{CS}} \cdot (V_{REF} - V_{CS\_OFFSET}) = \frac{N_{PS}}{2 \cdot R_{CS}} \cdot \left[V_{REF} \cdot \frac{K \cdot \sqrt{2} \cdot V_{IN\_RMS} \cdot N_{AP} \cdot R_{FB3}}{R_{FB1} + R_{FB3}} \cdot (R_{CS1} + R_{CS2})\right]
\]

Where:
- \(V_{REF}\) is the internal reference voltage that is equal to 0.4V

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%.
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.

![PWM Dimming Signal](image1)

![Figure 8. PWM Dimming Setting Circuit](image2)

![Figure 9. PWM Dimming Curve](image3)

**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 resistor, 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:

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

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

\[
I_P = \frac{2 \cdot \pi \cdot I_{O, \text{MEAN}}}{N_{PS} \cdot \int_{0}^{\pi} \frac{\sin(\theta)}{\sqrt{\frac{2}{V_{IN,\text{RMS}}} \cdot \sin(\theta) + N_{PS} \cdot V_O}} d\theta}
\]

Where

- \(V_{IN,\text{RMS}}\) 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)
- \(I_{O, \text{MEAN}}\) 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 \(f_{\text{MIN}}\) at the crest of the minimum AC input, primary inductance can be obtained by the following formula:

\[
L_P = \frac{\sqrt{2} \cdot V_{IN,\text{RMS}} \cdot N_{PS} \cdot V_O}{I_P \cdot (\sqrt{2} V_{IN,\text{RMS}} + N_{PS} V_O) \cdot f_{\text{MIN}}}
\]

Where

- \(V_{IN,\text{RMS}}\) 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
- \(f_{\text{MIN}}\) 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      Package      Packing
AL1665            S : SO-8 (Standard)  13 : 13" Tape & Reel

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Part Number Suffix: -13

Marking Information

(Top View)

AL1665

YY WW XX

YY : Year : 19, 20, 21~
WW : Week : 01~52; 52
represents 52 and 53 week
XX : 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)**

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All Dimensions in mm

Suggested Pad Layout

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

**SO-8 (Standard)**

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