

## Description

The AL1697 is a high performance, high power factor, high efficiency and high precision buck-boost LED driver for mains dimmable LED lamp applications. The AL1697 topology provides an accurate output current over wide line and load regulation. The wide switching frequency operates at boundary conduction mode (BCM) to ease EMI/EMC design, and testing to meet the latest regulatory standards.

The AL1697 with built in MOSFET solution reduces the bill of material (BOM) cost by eliminating the need of auxiliary winding and an external high voltage MOSFET. The AL1697 has extensive protection features to enhance system safety and reliability. The AL1697 starts reducing output current when the driver's temperature is higher than the built-in thermal foldback protection trigger point.

The AL1697 applies to a wide range of dimmers including leading edge and trailing edge dimmer. Some can achieve deep dimming down to 1%. The AL1697 dimming curve is compliant with the NEMA SSL6 standard.

The AL1697 is available in SO-7 package, which provides an extra pin spacing between the high voltage MOSFET's drain and low voltage pins to increase electricity isolation.

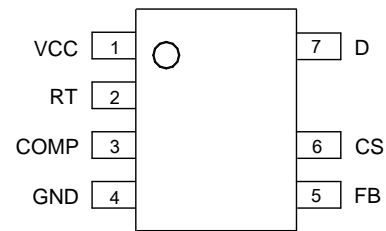
## Features

- Two Internal High-Voltage MOSFET Options:
  - $R_{DS(on)}$  4Ω and 1.8Ω for Super-Junction
- Tight Current Sense Tolerance :  $\pm 3\%$
- Low Startup Current: 130μA
- Low Operation Current: 170μA (Switching Frequency at 4kHz)
- Single Winding Inductor
- Wide Range of Dimmer Compatibility
- NEMA SSL6 Dimming Curve Compliant
- Internal Protections
  - Under Voltage Lockout (UVLO)
  - Leading-Edge Blanking (LEB)
  - Cycle-by-cycle Over Current Protection (OCP)
  - Output Open/Short Protection (OVP/OSP)
  - Thermal Foldback Protection (TFP)
  - Over-Temperature Protection (OTP)
- SO-7 Package
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**

Notes: 1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS) & 2011/65/EU (RoHS 2) compliant.  
 2. See [http://www.diodes.com/quality/lead\\_free.html](http://www.diodes.com/quality/lead_free.html) 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

(Top View)

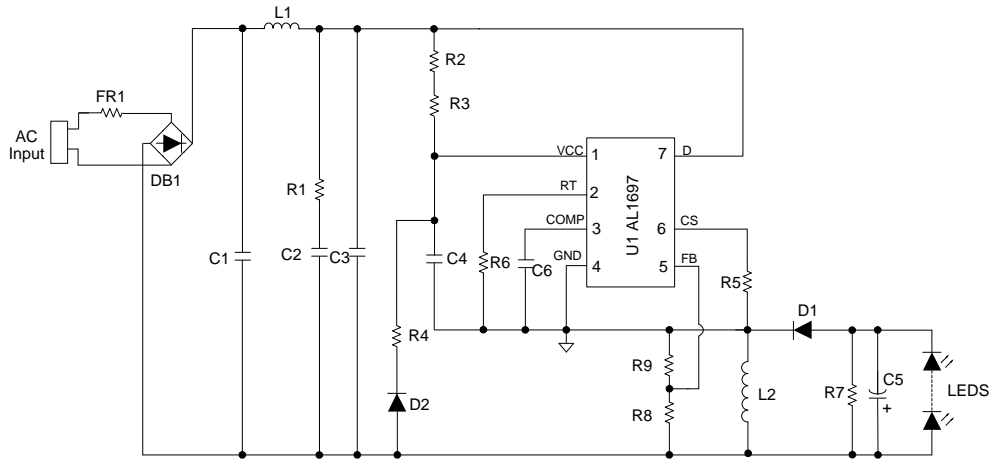


SO-7

## Applications

- Mains Dimmable LED Lamps
- Offline LED Power Supply Driver

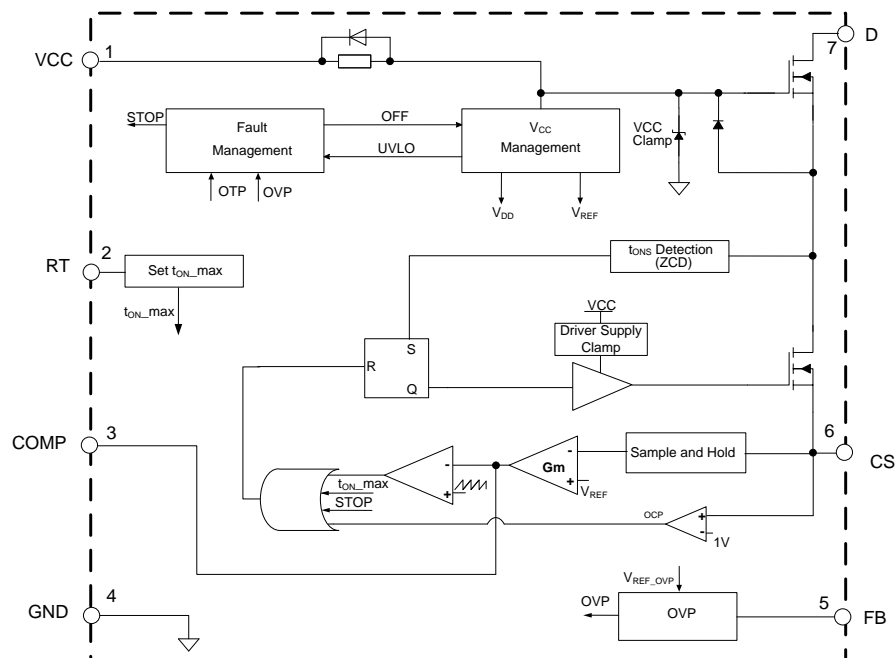
**Typical Applications Circuit**



**Pin Descriptions**

| Pin Number | Pin Name | Function                                   |
|------------|----------|--|
| 1          | VCC      | Power supply voltage                       |
| 2          | RT       | Resistor set the system's maximum $t_{ON}$ |
| 3          | COMP     | Compensation for current control           |
| 4          | GND      | Ground                                     |
| 5          | FB       | Feedback for LED open protection voltage   |
| 6          | CS       | Current sensing                            |
| 7          | D        | Drain of the internal high voltage MOSFET  |

**Functional Block Diagram**



### Absolute Maximum Ratings (@T<sub>A</sub> = +25°C, unless otherwise specified.) (Note 4)

| Symbol            | Parameter  | Rating      | Unit |
|-------------------|--|-------------|------|
| V <sub>CC</sub>   | Power Supply Voltage   | 18          | V    |
| V <sub>D</sub>    | Voltage on Drain Pin (AL1697-20CS7-13)                             | 600         | V    |
|                   | Voltage on Drain Pin (AL1697-40DS7-13)                             | 670         | V    |
| I <sub>DS</sub>   | Continuous Drain Current T <sub>C</sub> = +25°C (AL1697-20CS7-13)  | 2           | A    |
|                   | Continuous Drain Current T <sub>C</sub> = +25°C, (AL1697-40DS7-13) | 4           | A    |
| V <sub>CS</sub>   | Voltage on CS Pin  | -0.3 to 7   | V    |
| V <sub>RT</sub>   | Voltage on RT Pin  | -0.3 to 7   | V    |
| V <sub>FB</sub>   | Voltage on FB Pin  | -0.3 to 7   | V    |
| T <sub>J</sub>    | Operating Junction Temperature                                     | -40 to +150 | °C   |
| T <sub>STG</sub>  | Storage Temperature  | -65 to +150 | °C   |
| T <sub>LEAD</sub> | Lead Temperature (Soldering, 10 seconds)                           | +260        | °C   |
| P <sub>D</sub>    | Power Dissipation (T <sub>A</sub> = +50°C) (Note 5)                | 0.8         | W    |
| θ <sub>JA</sub>   | Thermal Resistance (Junction to Ambient) (Note 5)                  | 123         | °C/W |
| θ <sub>JC</sub>   | Thermal Resistance (Junction to Case) (Note 5)                     | 19          | °C/W |
| -                 | ESD (Human Body Model)   | 2,000       | V    |
|                   | ESD (Machine Model)  | 200         | V    |

- Note:
- Stresses greater than those listed under "Absolute Maximum Ratings" may 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 may affect device reliability. All voltages unless otherwise stated and measured with respect to GND.
  - Device mounted on 1"x1" FR-4 substrate PCB, 2oz copper, with minimum recommended pad layout.

### Recommended Operating Conditions (@T<sub>A</sub> = +25°C, unless otherwise specified.)

| Symbol         | Parameter                    | Min | Max  | Unit |
|----------------|------------------------------|-----|------|------|
| T <sub>A</sub> | Ambient Temperature (Note 6) | -40 | +105 | °C   |

- Note:
- The device may operate normally at +125°C ambient temperature under the condition not trigger temperature protection.

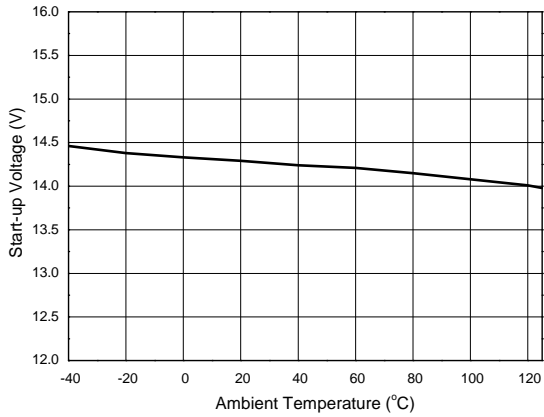
**Electrical Characteristics** (@T<sub>A</sub> = +25°C, unless otherwise specified.)

| Symbol  | Parameter                                       | Conditions  | Min   | Typ  | Max   | Unit |
|---|---|---|-------|------|-------|------|
| <b>UVLO</b>   |   |   |       |      |       |      |
| V <sub>TH (ST)</sub>  | Startup Voltage                                 | –   | –     | 14.5 | –     | V    |
| V <sub>OPR(Min)</sub>   | Minimal Operating Voltage                       | After Turn On   | –     | 8.5  | –     | V    |
| V <sub>CC,CLAMP</sub>   | V <sub>CC</sub> Clamp Voltage                   | I <sub>CC</sub> =1mA  | –     | 15.5 | –     | V    |
| <b>Standby Current</b>  |   |   |       |      |       |      |
| I <sub>ST</sub>   | Start-Up Current                                | V <sub>CC</sub> = V <sub>TH (ST)</sub> -0.5V, Before Start Up | –     | 130  | –     | μA   |
| I <sub>CC (OPR)</sub>   | Operating Current                               | Switching Frequency at 4kHz                                   | –     | 170  | –     | μA   |
| <b>Source Driver</b>  |   |   |       |      |       |      |
| R <sub>DS(ON)LV</sub>   | Low Voltage MOSFET On-State Resistance (Note 7) | –   | –     | 1    | –     | Ω    |
| <b>High Voltage and Super-Junction MOSFET</b>                 |   |   |       |      |       |      |
| R <sub>DS(ON)HV</sub>   | Drain-Source On-State Resistance                | AL1697-20CS7-13   | –     | 4    | 5.5   | Ω    |
|   |   | AL1697-40DS7-13   | –     | 1.8  | 2.5   |      |
| V <sub>DS</sub>   | Drain-Source Breakdown Voltage                  | AL1697-20CS7-13   | 600   | –    | –     | V    |
|   |   | AL1697-40DS7-13   | 670   | 700  | –     |      |
| I <sub>DSS</sub>  | Drain-Source Leakage Current                    | AL1697-20CS7-13   | –     | –    | 1     | μA   |
|   |   | AL1697-40DS7-13   | –     | –    | 1     |      |
| <b>RT</b>   |   |   |       |      |       |      |
| V <sub>RT_REF</sub>   | Reference Voltage of RT pin                     | –   | –     | 0.5  | –     | V    |
| <b>Current Sense</b>  |   |   |       |      |       |      |
| V <sub>CS,CLAMP</sub>   | CS Clamp Voltage                                | –   | –     | 1    | –     | V    |
| V <sub>REF</sub>  | Internal Current Loop Control Reference         | –   | 0.388 | 0.4  | 0.412 | V    |
| t <sub>ON_MIN</sub>   | Minimum t <sub>ON</sub>                         | –   | –     | 550  | –     | ns   |
| t <sub>ON_MAX</sub>   | Maximum t <sub>ON</sub>                         | R <sub>T</sub> =51kΩ, V <sub>COMP</sub> =4V                   | –     | 3.6  | –     | μs   |
| t <sub>OFF_MIN</sub>  | Minimum t <sub>OFF</sub> (Note 7)               | –   | –     | 4    | –     | μs   |
| t <sub>OFF_MAX</sub>  | Maximum t <sub>OFF</sub>                        | –   | –     | 260  | –     | μs   |
| <b>FB</b>   |   |   |       |      |       |      |
| V <sub>FB</sub>   | Feedback Voltage                                | –   | 3.76  | 4.0  | 4.24  | V    |
| I <sub>FB</sub>   | Feedback Pin Input Leakage Current              | V <sub>FB</sub> = 2V  | –     | 4    | –     | μA   |
| <b>Error Amplifier</b>  |   |   |       |      |       |      |
| G <sub>m</sub>  | G <sub>m</sub> Trans-Conductance                | –   | –     | 25   | –     | μA/V |
| I <sub>SOURCE</sub>   | Amplifier Source Current                        | –   | –     | 10   | –     | μA   |
| I <sub>SINK</sub>   | Amplifier Sink Current                          | –   | –     | 9    | –     | μA   |
| <b>Thermal Foldback and Over Temperature Protection (OTP)</b> |   |   |       |      |       |      |
| T <sub>FOLD</sub>   | Foldback Temperature (Note 7)                   | –   | –     | +145 | –     | °C   |
| –   | Shutdown Temperature (Notes 7 & 8)              | –   | –     | +160 | –     | °C   |

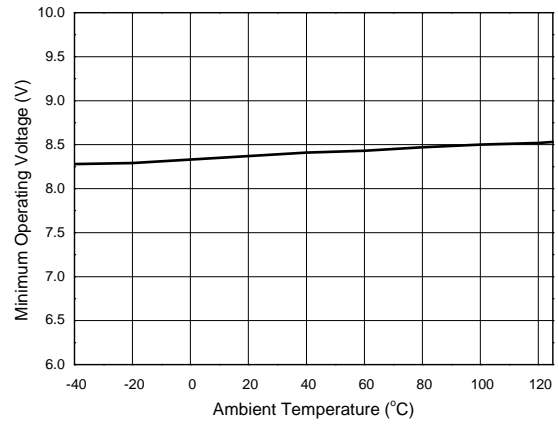
Notes: 7. These parameters, although guaranteed by design, are not tested in production.  
8. The device will latch off when OTP happens, recovered after power cycle and the device won't operate normally at this temperature.

**Performance Characteristics** (Note 9)

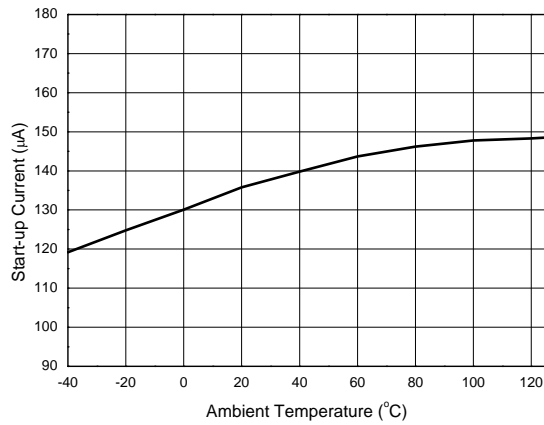
**Start-up Voltage vs. Ambient Temperature**



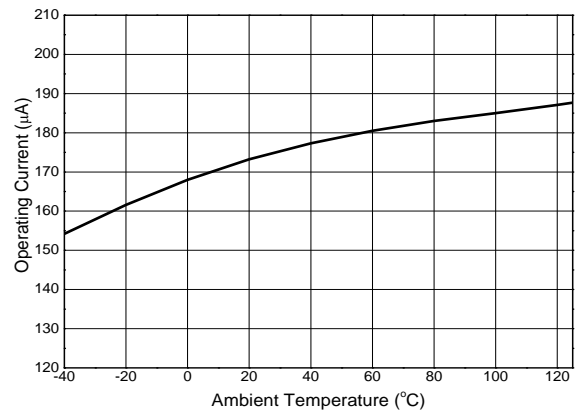
**Minimum Operating Voltage vs. Ambient Temperature**



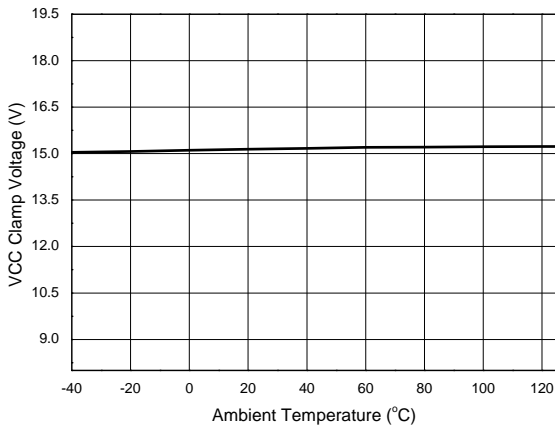
**Start-up Current vs. Ambient Temperature**



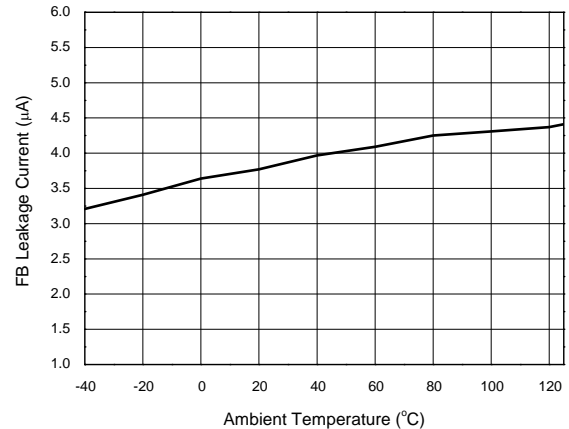
**Operating Current vs. Ambient Temperature**



**VCC Clamp Voltage vs. Ambient Temperature**



**FB Leakage Current vs. Ambient Temperature**



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

## Functional Description and Application Information

### Convertor Operation

The AL1697 is a single stage, single winding, high efficiency, and high power factor LED driver converter for dimmable LED lamp applications. It is available in two internal High-Voltage MOSFET options for 4Ω and 1.8Ω with Super-Junction which reduce the overall LED driver solution size of the LED lamp. Two different MOSFET options are targeted at optimizing the solutions of different LED chain lengths and powers.

High power factor (PF) is achieved using constant on-time mode; coupled with simple closed loop of constant current control the AL1697 achieves good line and load regulation. The AL1697 adopts source-driver technique to decrease the system operating current. It uses a novel method to detect the  $t_{OFF}$  time which results in the removal for the need of an auxiliary winding for ( $V_{CC}$  supply and) detecting the  $t_{OFF}$  time, which enables the AL1697 to have an extremely low bill material (BOM) solution. The AL1697 operates at boundary conduction mode (BCM) which can ease EMI design.

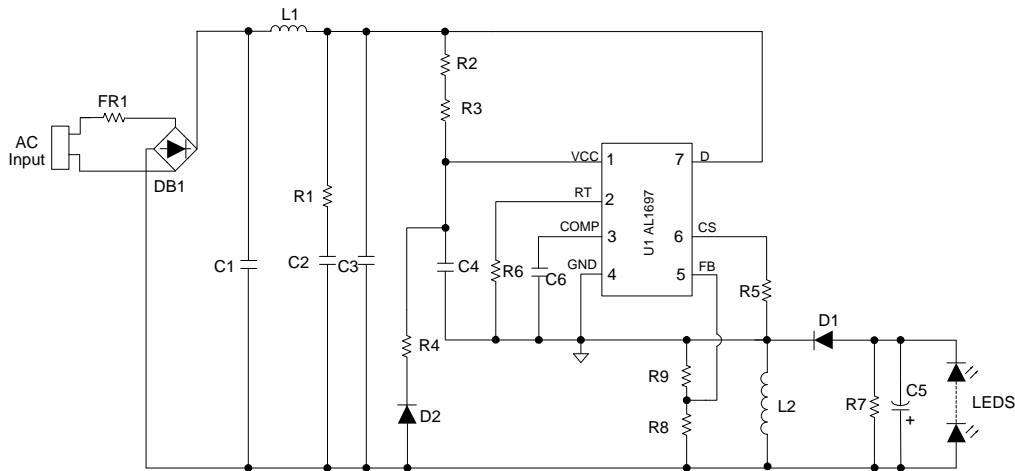


Figure 1. Typical Application Circuit

### Start-up and Supply Voltage

Before start-up, the VCC capacitor C4 is charged by the startup resistors (R2, R3) from the high voltage mains. When the start-up voltage is reached, the AL1697 starts switching. During normal operation, the VCC supply is provided by start-up resistors (R2, R3) and the output voltage ( $V_{OUT}$ ) rectified by one diode (D2). In this way the system can provide VCC supply at low dimming angle.

The AL1697 has an internal VCC clamp voltage (typical 15.5V), which is limited by one internal active Zener diode.

When VCC voltage drops to below the  $V_{OPR(MIN)}$ , switching is stop. So the device can operate normally when the voltage on VCC pin is between  $V_{OPR(MIN)}$  and VCC clamp voltage.

### Protections

#### Under Voltage Lockout (UVLO)

When the voltage on the VCC pin drops to below  $V_{OPR(MIN)}$ , the IC stops switching. The IC can restart when the voltage on VCC exceeds the startup voltage ( $V_{TH(ST)}$ ).

#### Leading-Edge Blanking (LEB)

To prevent false detection of the peak current of the inductor, a blanking time following switch-on is designed. When the internal switch turns on, a short current spike can occur because of the capacitive discharge of the voltage over the drain and source. It is disregarded during the LEB time ( $t_{ON\_MIN}$ ).

#### Cycle-by-cycle Over Current Protection (OCP)

The AL1697 has a built-in peak current detector. It triggers when the voltage on CS pin reaches the peak level  $V_{CS\_CLAMP}$ . The R5 is connected to the CS pin to sense the current of the inductor. The maximum peak current ( $I_{PEAK(MAX)}$ ) of the inductor can be calculated as below:

**Functional Description and Application Information (Cont.)**

$$I_{PEAK(MAX)} = \frac{V_{CS\_CLAMP}}{R5} \dots\dots\dots (1)$$

The detection circuit is activated after the LEB time. When the detection circuit sense the CS voltage is higher than 1V, the IC will turn off the switching to limit the output current. It automatically provides protection for the maximum LED current during operation. A propagation delay exists between over current detection and actual source-switch off, so the actual peak current is a little higher than the OCP level set by the R5.

**Over-Voltage Protection and Output-Open Protection (OVP)**

The output voltage is sensed by the FB pin, which provides an over-voltage protection (OVP) function. When the output is open or large transient happens, the output voltage will exceed the rated value (R8, R9). When the voltage exceeds  $V_{FB}$ , the over-voltage is triggered and the IC will discharge  $V_{CC}$ . When the  $V_{CC}$  is below the UVLO threshold voltage, IC will restart and the  $V_{CC}$  capacitor is charged again by start-up resistance. If the over voltage condition still exists, the system will work in hiccup mode.

**Output-Short Protection (OSP)**

When LED is shorted, the device cannot detect the  $t_{OFF}$  time, and the device controls the system operation at 4kHz low frequency.

**Thermal Foldback Protection (TFP)**

AL1697 has a thermal foldback function and adopts self-adaptive control method, which can prevent the system breaking down caused by high temperature. The overheating temperature is set at +145°C typical, when the junction temperature of the IC is higher than +145°C typical, the device will linearly decrease the internal reference voltage to decrease the output current. As a result of this feature, the device can control the system's output power at high ambient temperature, to control the quantity of heat of the system. This enhances the safety of the system at high temperature.

The thermal foldback waveform is shown below:

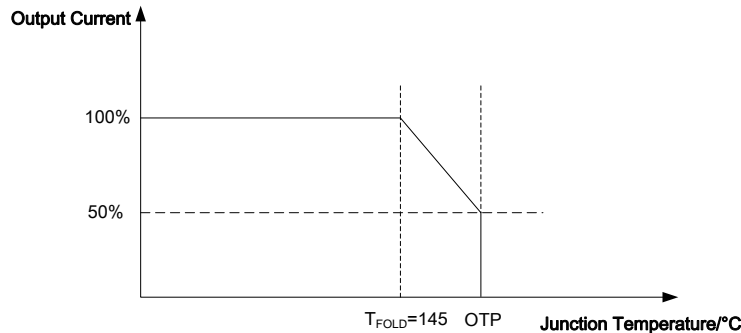


Figure 2. Thermal Foldback Waveform

**Over-Temperature Protection (OTP)**

The AL1697 has OTP protection function. When the junction temperature reach to +160°C typical, the IC will trigger an over-temperature protection condition which causes the device to shut down and latched. Once OTP has triggered, the system will resume after the system's AC source supply has been reset and power up.

**Design Parameters**

**Setting the Current Sense Resistor R5**

The AL1697 adopts boundary conduction mode, the output current is calculated as below,

$$I_{O\_MEAN} = \frac{1}{\pi} \cdot \int_0^{\pi} \frac{1}{2} \cdot I_{PEAK} \cdot \sin(\theta) \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} d\theta \dots\dots\dots (2)$$

Where,

$I_{PEAK}$  is the peak current of the inductance

$t_{ON}$  is the internal MOSFET on time

$t_{OFF}$  is the freewheel diode D1 conduction time

$t_{DELAY}$  is typical 0.15µs

## Functional Description and Application Information (Cont.)

The AL1697 is a closed loop constant current control with the relationship between output current and current sense voltage follows this equation

$$V_{REF} = \frac{1}{\pi} \cdot \int_0^{\pi} I_{PEAK} \cdot \sin(\theta) \cdot R5 \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} d\theta \quad \dots\dots\dots (3)$$

Where,

$V_{REF}$  is the internal reference, typical 0.4V.

R5 is the current sense resistor

So we can get the output current equation as below,

$$I_{O\_MEAN} = \frac{1}{2} \cdot \frac{V_{REF}}{R5} \quad \dots\dots\dots (4)$$

### Inductance Selection (L2)

In buck-boost structure, the peak current of the inductance can be calculated as below

$$I_{PEAK} = \frac{\pi \cdot V_{REF}}{R5 \cdot \int_0^{\pi} \sin(\theta) \cdot \frac{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta)}{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta) + V_O} d\theta} \quad \dots\dots\dots (5)$$

Where,

$V_{IN\_RMS}$  is the input voltage's RMS value

$V_O$  is the system output voltage

The AL1697 controls the system operating at boundary conduction mode which results in its operating frequency not being constant. To set the minimum switching frequency  $f_{MIN}$  at the crest of the minimum AC input.

$$L2 = \frac{\sqrt{2} V_{IN\_RMS} \cdot V_O}{I_{PEAK} \cdot (\sqrt{2} V_{IN\_RMS} + V_O) \cdot f_{MIN}} \quad \dots\dots\dots (6)$$

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

$$N_{L2} = \frac{L2 \cdot I_{PEAK}}{A_e \cdot B_m} \quad \dots\dots\dots (7)$$

Where,

$A_e$  is the core effective area.

$B_m$  is the maximum magnetic flux density.

### $t_{ON\_MAX}$ Setting

In order to get a good dimmer compatibility and a good dimming depth, the device sets a  $t_{ON\_MAX}$  by one external resistor  $R_T$  (R6).

And the  $t_{ON\_MAX}$  time has the below equation:

$$t_{ON\_MAX} = \frac{3.3 \cdot C_{REF}}{\frac{V_{RT\_REF}}{10 \cdot R6} + 0.5\mu A} \quad \dots\dots\dots (8)$$

Where

$V_{RT\_REF}$  is the internal RT pin 0.5V's reference.

$C_{REF}$  is the internal 1.5pF capacitor.



**Functional Description and Application Information (Cont.)**

**Dimming Control**

AL1697 is a closed loop control device, the dimming function is realized by  $t_{ON\_MAX}$  limited when dimmer is connected in. When the dimmer is at the largest conduction angle, the device still has the adjustability to control the output current constant before COMP voltage is adjusted to the maximum 4V, so for most of the dimmer, the output current is almost the same with the no dimmer condition at the largest conduction angle. If the conduction angle is decreased, the COMP pin voltage will continue to increase quickly till to the maximum level (typical 4V), the device will output  $t_{ON\_MAX}$  to limit system's output current. The  $t_{ON\_MAX}$  is set by RT pin connected with one resistor, so the dimming depth can be adjusted by RT resistor (R6).

Before the AL1697 enters  $t_{ON\_MAX}$  mode, the AL1697 keep the output current constant the same as no dimmer condition. When enter  $t_{ON\_MAX}$  mode, we can get the following equation:

$$I_{PEAK\_DIM} = \frac{V_{IN\_RMS} \cdot \sin(\theta) \cdot t_{ON\_MAX}}{L2} \dots \dots \dots (9)$$

From the buck-boost output current equation, we can get the output current when dimming:

$$I_o(\theta) = \begin{cases} \frac{1}{2} \cdot \frac{V_{REF}}{R5} & \text{if } t_{ON} < t_{ON\_MAX} \\ \frac{1}{\pi} \int_0^\alpha \frac{1}{2} \cdot I_{PEAK\_DIM} \cdot \frac{\sqrt{2}V_{IN\_RMS} \cdot \sin(\theta)}{\sqrt{2}V_{IN\_RMS} \cdot \sin(\theta) + V_o} d\theta & \text{else} \end{cases} \dots \dots \dots (10)$$

Where,  
 $\alpha$  is the dimmer conduction angle.

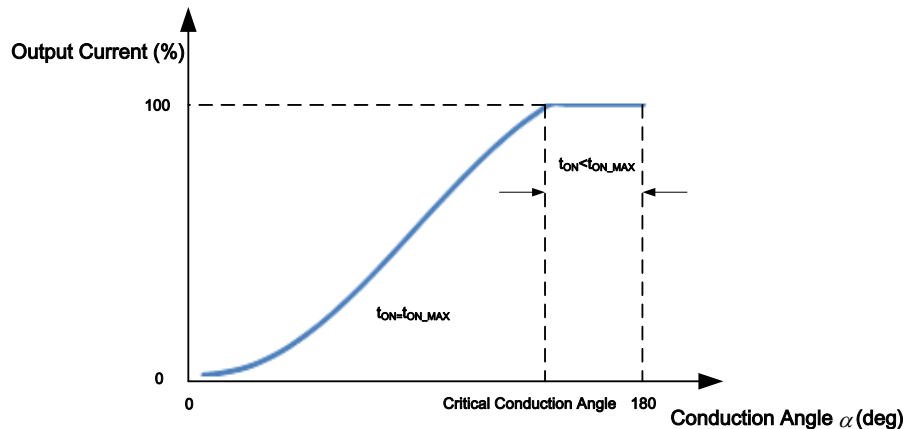


Figure 3. Dimming Curve

**Dimmer Compatibility**

**Passive Bleeder Design**

The passive bleeder is designed to supply latching and holding current to eliminate dimmer misfire and flicker.

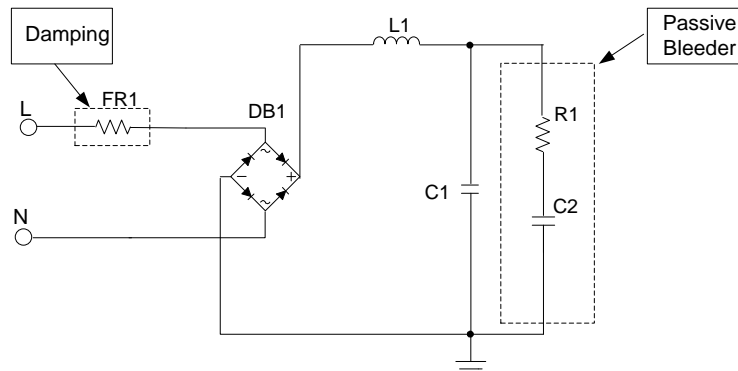


Figure 4. LED Driver Schematic with Passive Bleeder

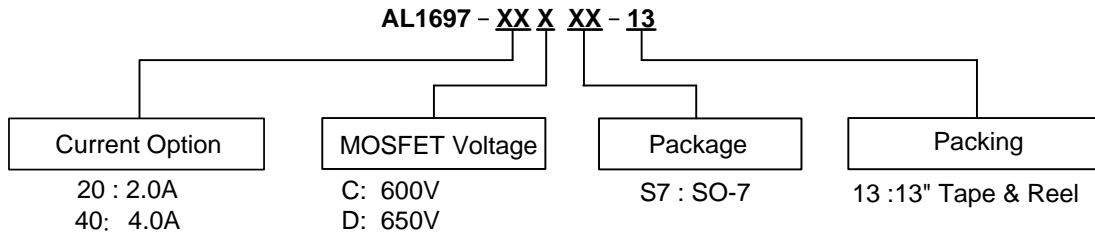
**Functional Description and Application information (Cont.)**

The passive bleeder includes a capacitor (C2, in hundreds of nF) to provide latching current. A resistor (R1) is necessary to dampen the current spike. Because a large C2 will affect the PF, THD and efficiency, the value of the capacitor (C2) should be selected accordingly. Generally, 100nF/400V to 330nF/400V is recommended. R1 is used to limit the latching current, If R1 is too large, the latching current is not enough and the TRIAC dimmer will misfire causing LED flicker. If R1 is too small, it will result in greater power dissipation. Generally speaking, a 200Ω to 2KΩ resistor is selected for R1.

**Passive Damping Design**

FR1 is the damper for reducing the spike current caused by quick charging of C2 at firing. In General, FR1 is selected from 20Ω to 100Ω for low line like 120V<sub>AC</sub> application, and 51Ω to 200Ω for high line like 230V<sub>AC</sub> application.

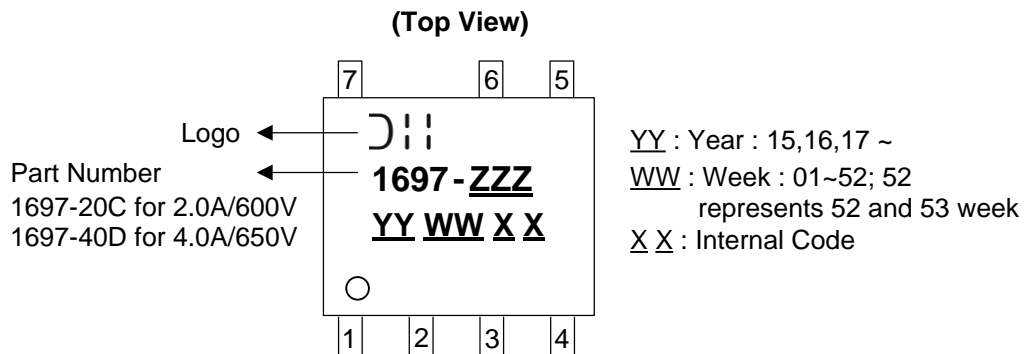
**Ordering Information**



| Part Number     | Package Code | Package | 13" Tape and Reel |                    |
|-----------------|--------------|---------|-------------------|--------------------|
|                 |              |         | Quantity          | Part Number Suffix |
| AL1697-20CS7-13 | S7           | SO-7    | 4000/Tape & Reel  | -13                |
| AL1697-40DS7-13 | S7           | SO-7    | 4000/Tape & Reel  | -13                |

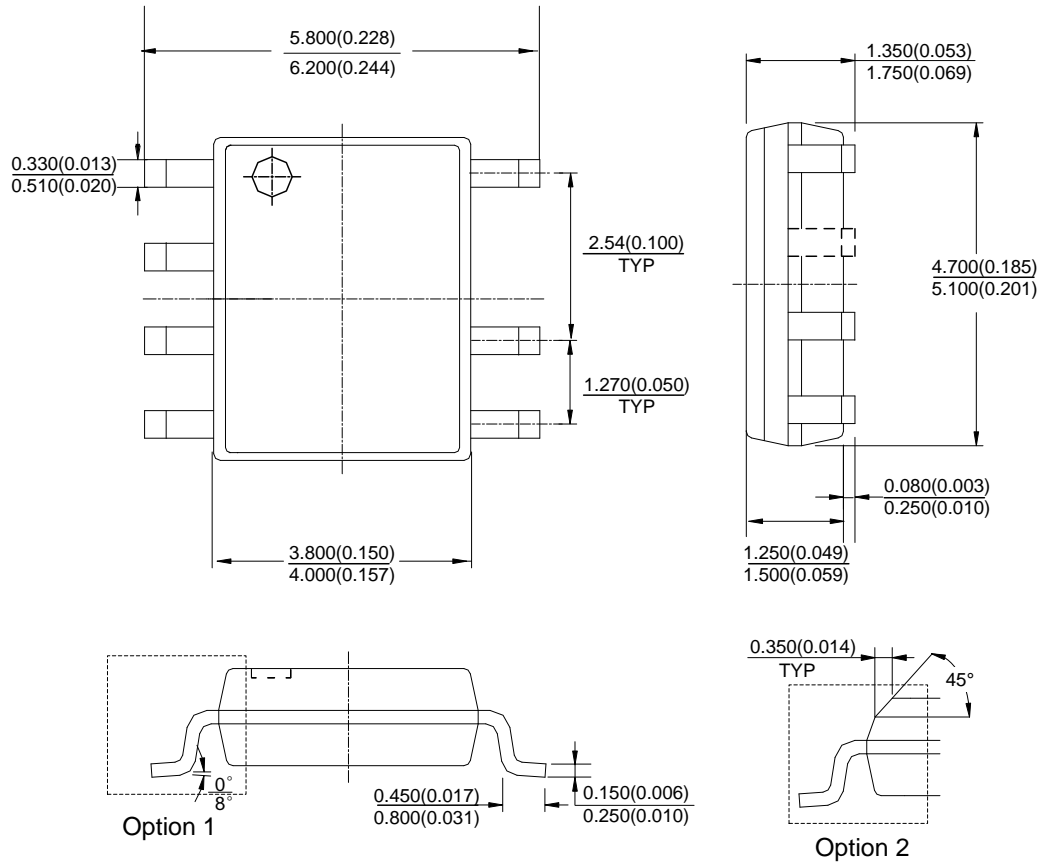
**Marking Information**

(1) SO-7



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

(1) Package Type: SO-7

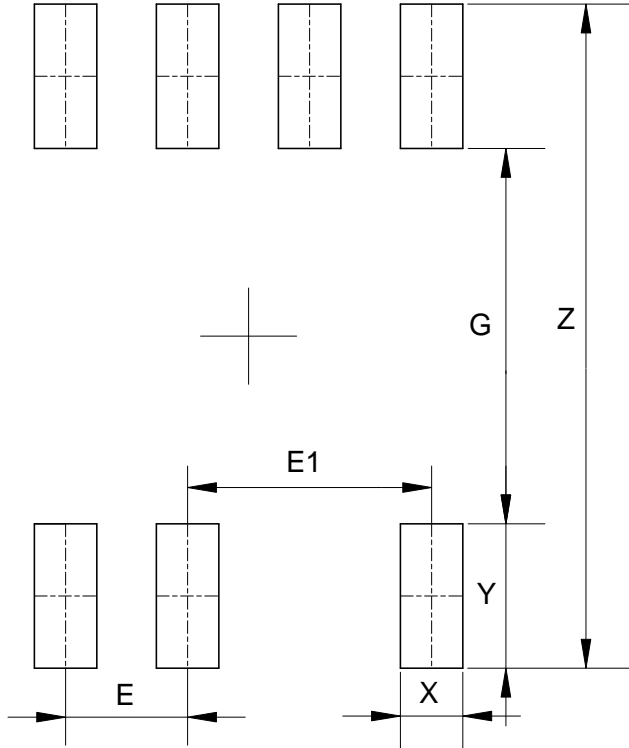


Note: Eject hole, oriented hole and mold mark is optional.

NEW PRODUCT

**Suggested Pad Layout**

(1) Package Type: SO-7



| Dimensions | Z<br>(mm)/(inch) | G<br>(mm)/(inch) | X<br>(mm)/(inch) | Y<br>(mm)/(inch) | E<br>(mm)/(inch) | E1<br>(mm)/(inch) |
|------------|------------------|------------------|------------------|------------------|------------------|-------------------|
| Value      | 6.900/0.272      | 3.900/0.154      | 0.650/0.026      | 1.500/0.059      | 1.270/0.050      | 2.540/0.100       |

**IMPORTANT NOTICE**

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