

Description

The DIODES™ AL1698K is a high efficiency, high performance, high power factor, and high current precision boost, buck-boost, and flyback dimmable LED driver for triac dimmable LED lamp applications. The AL1698K provides an accurate output current over wide line and load regulation. The AL1698K can achieve higher than 90% efficiency by using a boost topology to meet the latest lighting regulatory high efficiency requirements. The wide switching frequency operates at Boundary Conduction Mode (BCM) to ease EMI/EMC design and testing.

The AL1698K LED driver has a built-in high voltage JFET, which provides the system with fast start-up time and enables users an easy and stable VCC supply design. The AL1698K LED driver integrates a 600V/2A high voltage MOSFET. It can cover both 120V_{AC} and 230V_{AC} triac dimmable applications with eliminating the external high voltage MOSFET, which will reduce the system BOM cost. The AL1698K has the built-in thermal fold-back protection trigger point to automatically reduce output current. Other protection features enhance LED lighting system's safety and reliability.

The AL1698K dimming curve is compliant with the NEMA SSL6 standard. The AL1698K applies to a wide range of dimmers, including leading edge and trailing edge dimmer, to achieve deep dimming down to 1%.

The AL1698K is available in SO-7 package.

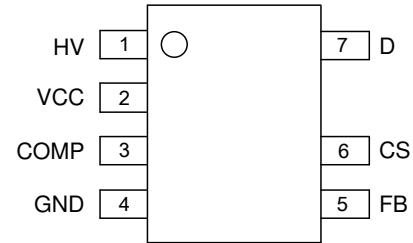
Features

- High Efficiency > 90% (Boost Topology)
- Tight Current Sense Tolerance: ± 3%
- Low Operation Current: 310µA
- Single Winding Inductor
- Wide Range of Dimmer Compatibility
- Integration of 600V/2A MOSFET
- Integration of HV JFET
- NEMA SSL6 Dimming Curve Compliant
- Internal Protections
 - Under Voltage Lockout (UVLO)
 - Leading-Edge Blanking (LEB)
 - Cycle-By-Cycle Over Current Protection (OCP)
 - Over Voltage Protection (OVP)
 - Output Short Protection (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)**
- **For automotive applications requiring specific change control (i.e. parts qualified to AEC-Q100/101/104/200, 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

(Top View)

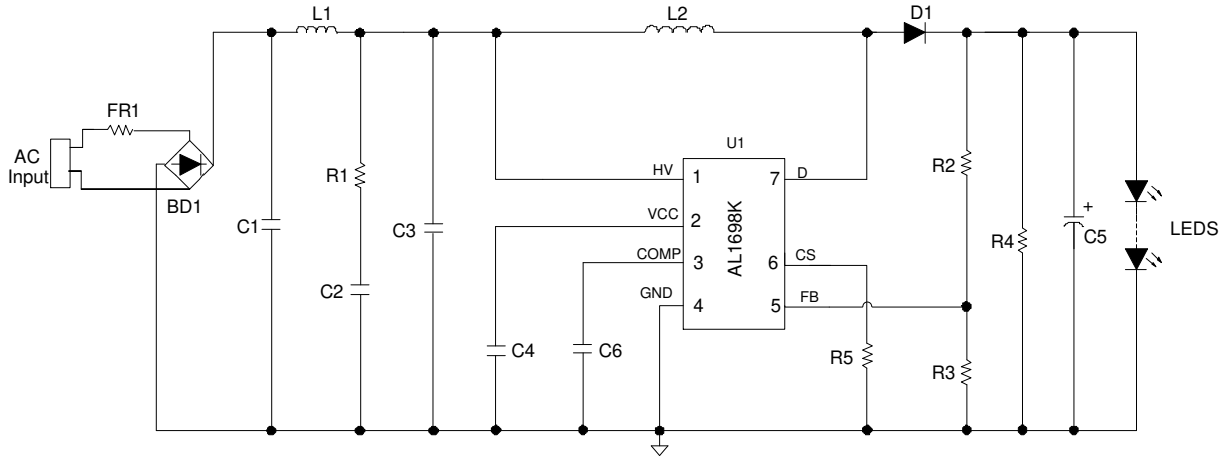


SO-7

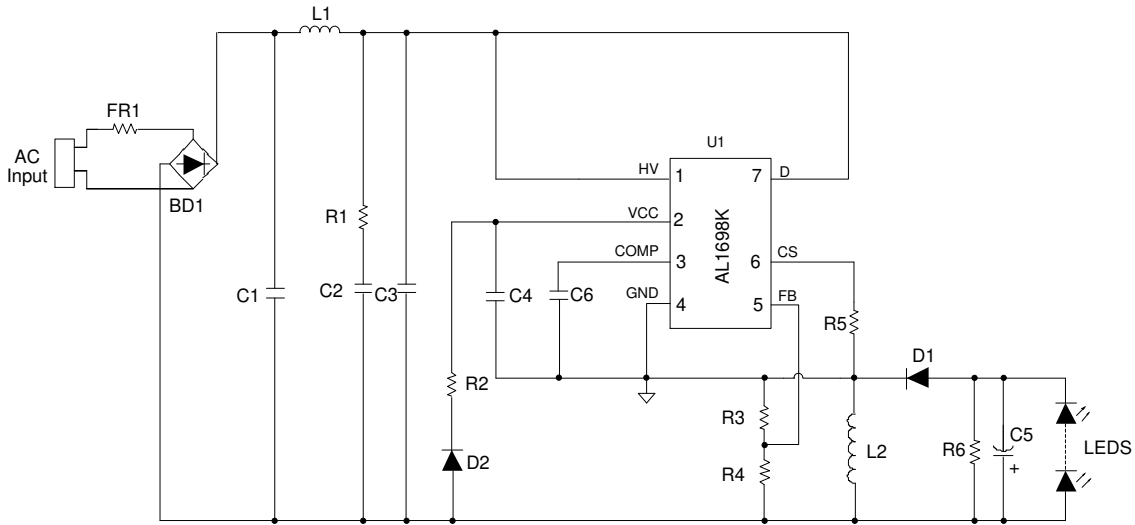
Applications

- Mains dimmable LED lamps
- Offline LED power supply drivers

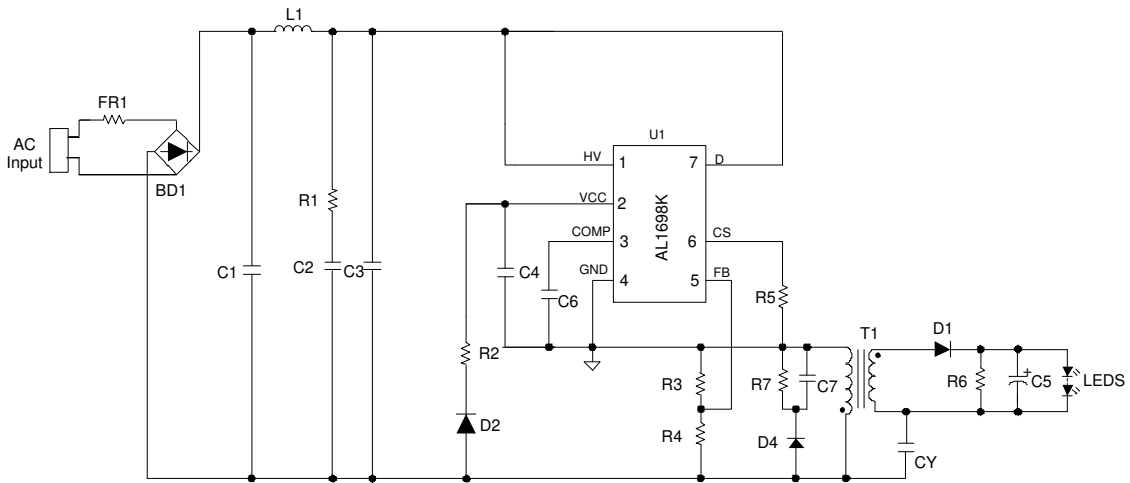
Typical Application Circuits



AL1698K Boost Application Circuit



AL1698K Buck-Boost Application Circuit

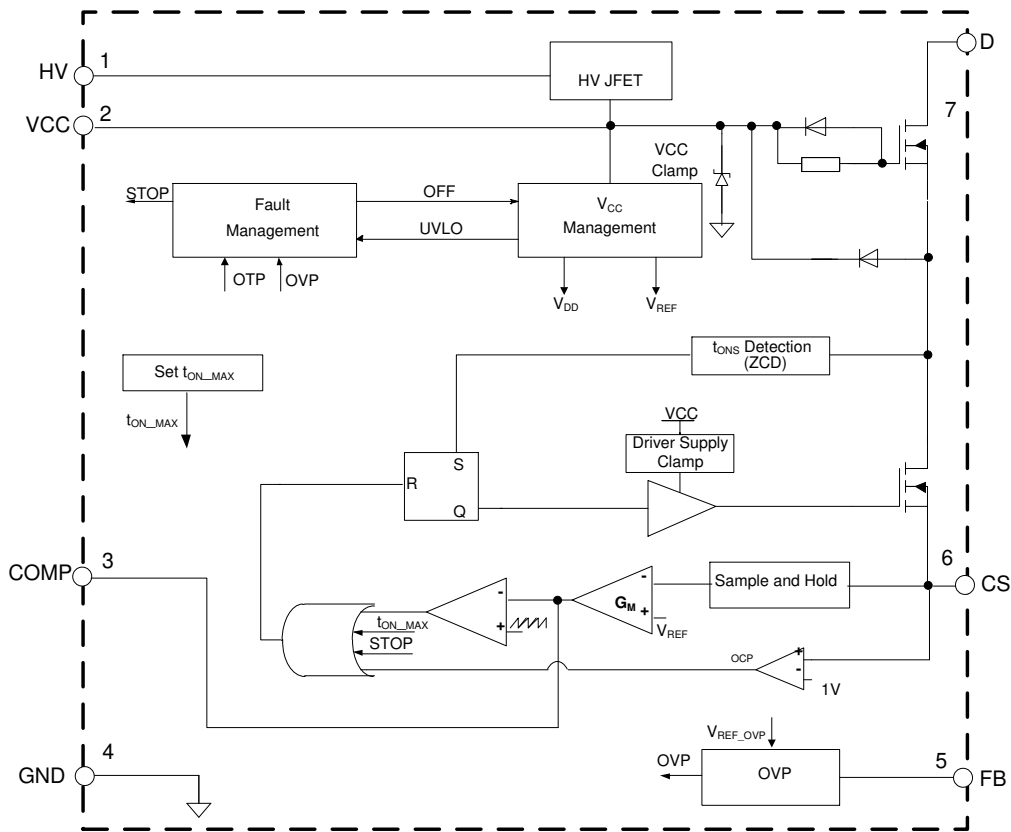


AL1698K Flyback Application Circuit

Pin Descriptions

Pin Number	Pin Name	Function
1	HV	High Voltage Input Pin
2	VCC	Power Supply Voltage
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



AL1698K Block Diagram

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

Symbol	Parameter	Rating	Unit
V _{CC}	Power Supply Voltage	18	V
V _D	Voltage on D Pin	600	V
V _{HV}	Voltage on HV Pin	600	V
I _{DS}	Continuous Drain Current T _C = +25°C	2	A
V _{CS}	Voltage on CS Pin	-0.3 to 7	V
V _{FB}	Voltage on FB Pin	-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)	+260	°C
P _D	Power Dissipation (T _A = +50°C) (Note 5)	0.8	W
θ _{JA}	Thermal Resistance (Junction to Ambient) (Note 5)	115	°C/W
θ _{JC}	Thermal Resistance (Junction to Case) (Note 5)	19	°C/W
—	ESD (Human Body Model) (Note 6)	2,000	V
	ESD (Charged-Device Model)	1,000	V

- Notes:
- 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.
 - Device mounted on 1"x1" FR-4 substrate PCB, 2oz copper, with minimum recommended pad layout.
 - All other pins pass 2000V except for Pin1. Pin1 passes 1000V.

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

Symbol	Parameter	Min	Max	Unit
T _A	Ambient Temperature (Note 7)	-40	+105	°C
V _{CC}	Operating V _{CC} Voltage	7.3	V _{CC_CLAMP} (Min)	V
V _{DS}	Drain-Source Breakdown Voltage	—	500	V

- Note: 7. The device may operate normally at +125°C ambient temperature under the condition not trigger temperature protection.

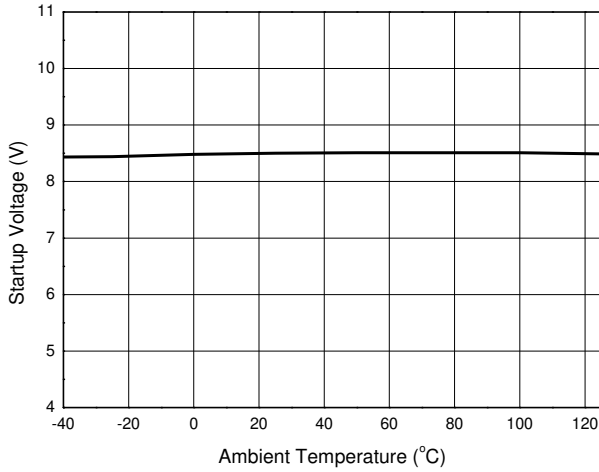
Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
UVLO						
V _{TH(ST)}	Startup Voltage	—	7	8.8	10	V
V _{OPR(MIN)}	Minimum Operating Voltage	After Turn On	5.5	7.1	8.5	V
V _{CC_CLAMP}	V _{CC} Clamp Voltage	I _{CC} = 1mA	7.5	9.5	10.5	V
V _{CC_CHARGE}	V _{CC} UVLO	—	3.5	4.2	5.5	V
Standby Current						
I _{CC(OPR)}	Operating Current	Switching Frequency at 3kHz	—	310	—	μA
High Voltage Startup Current Source						
I _{HV}	High Voltage Supply Current	V _{CC} = V _{TH(ST)} – 1.5V, V _D = 40V	7	10.5	—	mA
I _{LEAK}	Leakage Current of Drain	V _{CC} = V _{TH(ST)} + 0.5V, V _D = 500V	—	5	—	μA
Source Driver						
R _{DS(ON)_LV}	Internal Low Voltage MOSFET On-State Resistance (Note 8)	—	—	1	—	Ω
High Voltage MOSFET						
R _{DS(ON)_HV}	Static Drain-Source On-State Resistance	—	—	4.7	5.5	Ω
V _{DS}	Drain-Source Breakdown Voltage	(Note 9)	600	—	—	V
Current Sense						
V _{CS_CLAMP}	Current Sense Clamp Voltage	—	1.1	1.2	1.3	V
V _{REF}	Internal Current Loop Control Reference	—	0.388	0.4	0.412	V
t _{ON_MIN}	Minimum t _{ON}	—	—	610	—	ns
t _{ON_MAX}	Maximum t _{ON}	V _{COMP} = 4V	—	10	—	μs
t _{OFF_MIN}	Minimum t _{OFF} (Note 8)	—	—	4	—	μs
t _{OFF_MAX}	Maximum t _{OFF}	—	—	313	—	μs
FB Pin						
V _{FB}	Feedback Voltage	—	1.88	2	2.12	V
Error Amplifier						
G _M	G _M Trans-Conductance	—	—	25	—	μA/V
I _{SOURCE}	Amplifier Source Current	V _{CS} = 0V	—	10	—	μA
I _{SINK}	Amplifier Sink Current	V _{CS} = 1V	—	15	—	μA
Thermal Foldback and Over Temperature Protection (OTP)						
T _{FOLD}	Thermal Foldback (Note 8)	—	—	+150	—	°C
—	Thermal Shutdown (Notes 8 and 10)	—	—	+170	—	°C

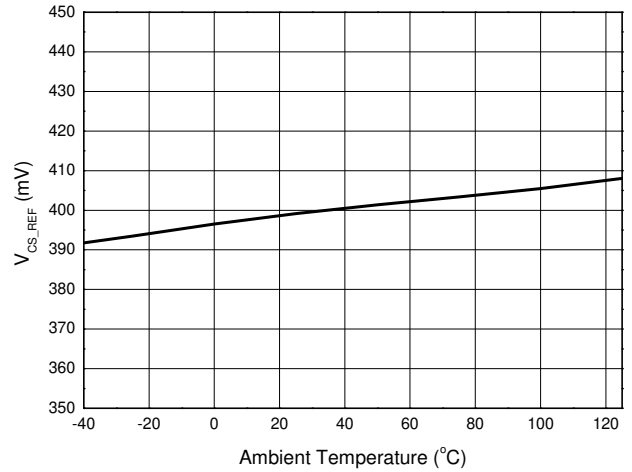
Notes: 8. These parameters, although guaranteed by design, are not tested in production.
9. The drain-source voltage is 80% of V_{DS} in the aging condition.
10. The device will latch off when OTP happens, recovered after power cycle and the device won't operate normally at this temperature.

Performance Characteristics (Note 11)

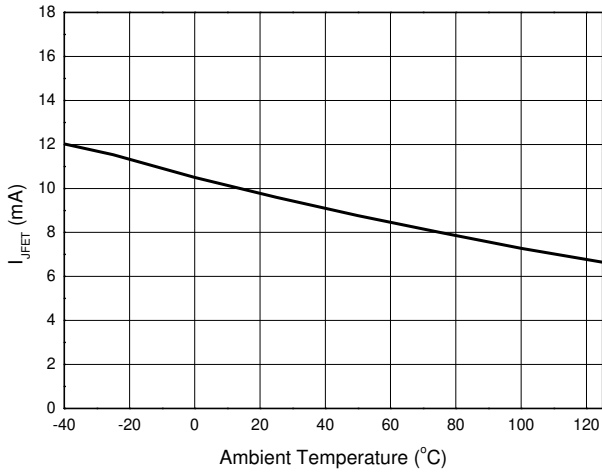
Startup Voltage $V_{TH(ST)}$



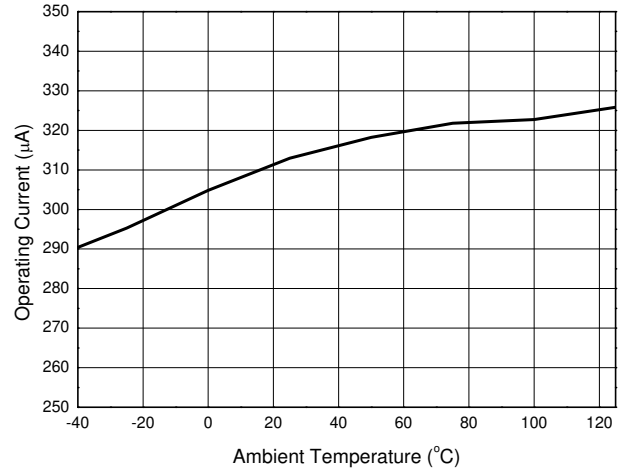
Internal Current Loop Control Reference V_{REF}



High Voltage Supply Current I_{HV}



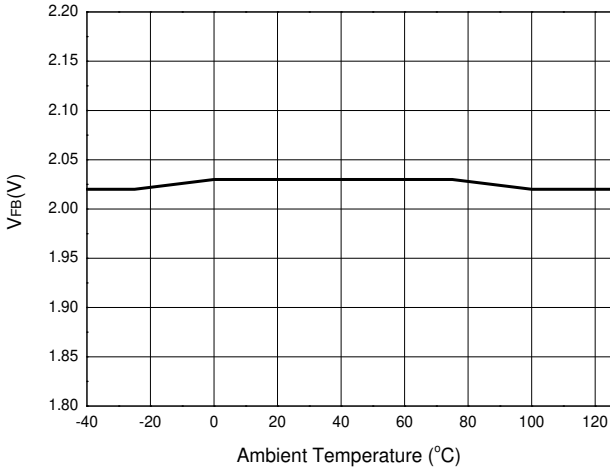
Operating Current $I_{CC(OPR)}$



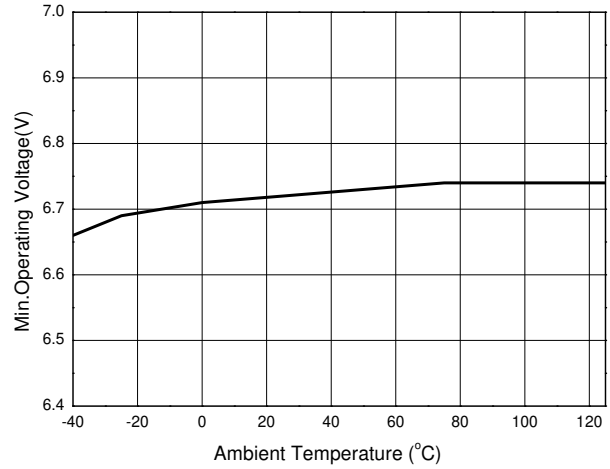
Note: 11. These electrical characteristics are tested under DC condition. The ambient temperature is equal to the junction temperature of the device.

Performance Characteristics (continued) (Note 11)

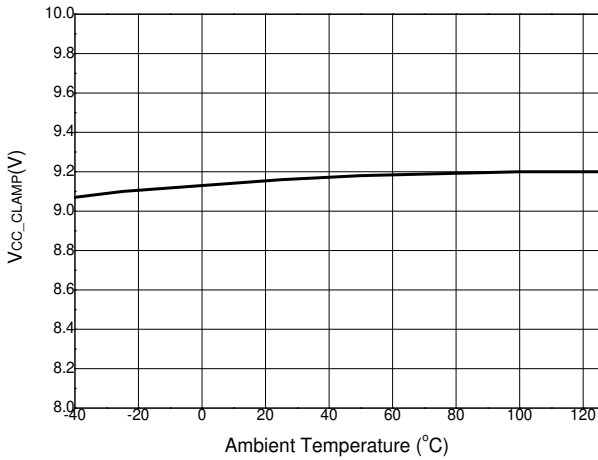
Feedback Voltage V_{FB}



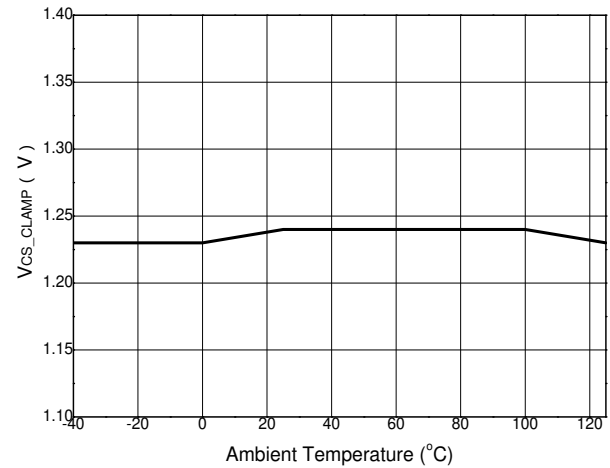
Minimum Operating Voltage $V_{OPR(MIN)}$



V_{CC} Clamp Voltage V_{CC_CLAMP}



Current Sense Clamp Voltage V_{CS_CLAMP}



Note: 11. 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

Operation

The AL1698K is a single stage, single winding, high efficiency, and high power factor dimmable LED driver for triac dimmable LED lamp applications. The AL1698K integrates a high voltage JFET and a 600V/2A high voltage MOSFET, and it can cover 230V_{AC} triac dimmable applications with eliminating external high voltage MOSFET and V_{CC} startup resistors.

The AL1698K 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. The AL1698K operates at Boundary Conduction Mode (BCM) which can ease EMI design and achieve high efficiency. High Power Factor (HPF) is achieved by using constant on-time mode. Coupled with a closed loop of constant current control, the AL1698K achieves good line and load regulation.

Startup and Supply Voltage

Before startup, the V_{CC} capacitor C4 is charged by internal HV JFET. When the start-up voltage is reached, the AL1698K starts switching.

The AL1698K has an internal V_{CC} clamp voltage (typical 9.5V), which is limited by one internal active Zener diode.

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

Protections

Under Voltage Lockout (UVLO)

When the voltage on the V_{CC} pin drops below V_{CC_CHARGE}, the IC stops switch. The IC can restart when the voltage on V_{CC} 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 voltages over the drain and source. It is disregarded during the LEB time (t_{ON_MIN}).

Cycle-by-Cycle Over Current Protection (OCP)

The AL1698K has a built-in peak current detector. It is triggered 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:

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

The detection circuit is activated after the LEB time. When the detection circuit senses the CS voltage 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 (OVP) and Output Open Protection

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 (R4, R3). 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.

Functional Description and Application Information (continued)

Thermal Foldback Protection (TFP)

AL1698K has a Thermal Foldback Protection (TFP) function and adopts self-adaptive control method, which can prevent the system breaking down caused by high temperature. The overheating temperature is set at +150°C typical. When the junction temperature of the IC is higher than +150°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 system heat quality. This enhances the safety of the system at high temperature.

Thermal foldback waveform is shown below.

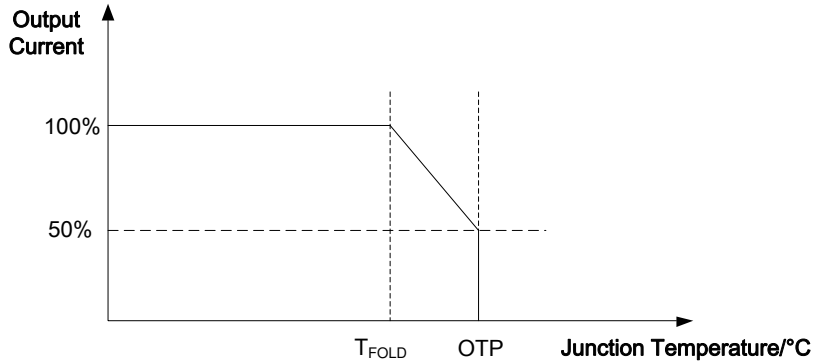


Figure 1. Thermal Foldback Waveform

Over-Temperature Protection (OTP)

The AL1698K has Over Temperature Protection (OTP) function. When the junction temperature reaches +170°C typical, the IC will trigger an over-temperature protection, which causes the device to shut down and latch up. Once OTP is triggered, the system needs to be resumed after the system’s AC source supply has been reset and powered up.

Design Parameters

Setting the Current Sense Resistor R5

The AL1698K adopts Boundary Conduction Mode, the output current is calculated as below:

$$I_{O_MEAN} = \frac{1}{\pi} \cdot \int_0^{\pi} \frac{1}{2} \cdot I_{PEAK} \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} dt \dots\dots\dots (2)$$

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 0.4μs.

The AL1698K is a closed loop constant current control with the relationship between output current and current sense voltage follows this equation:

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

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:

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

Functional Description and Application Information (continued)

Inductance Selection (L2)

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

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

Where,

- V_{IN_RMS} is the input voltage's RMS value.
- V_O is the system output voltage.

The AL1698K 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:

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

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

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

Where,

- A_e is the core effective area.
- B_m is the maximum magnetic flux density.

Dimming Control

The AL1698K 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 AL1698K enters t_{ON_MAX} mode, it keeps the output current constant the same as no dimmer condition. When enter t_{ON_MAX} mode, we can get the following equation:

$$I_{PEAK_DIM} = \frac{V_{IN_RMS} \cdot \sin(\theta) \cdot t_{ON_MAX}}{L2} \dots \dots \dots (8)$$

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

$$I_o(\theta) = \begin{cases} \frac{1}{2} \cdot \frac{V_{REF}}{R5} & \text{if } t_{ON} < t_{ON_MAX} \\ \frac{1}{\pi} \int_0^{\alpha} \frac{1}{2} \cdot I_{PEAK_DIM} \cdot \frac{\sqrt{2} V_{IN_RMS} \cdot \sin(\theta)}{\sqrt{2} V_{IN_RMS} \cdot \sin(\theta) + V_O} d\theta & \text{else} \end{cases} \dots \dots \dots (9)$$

Where,

- α is the dimmer conduction angle.

Functional Description and Application Information (continued)

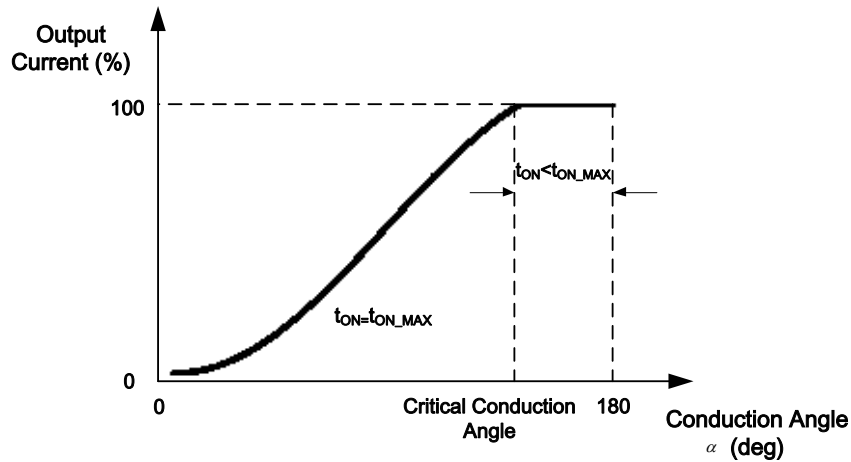


Figure 2. Dimming Curve

Dimmer Compatibility

Passive Bleeder Design

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

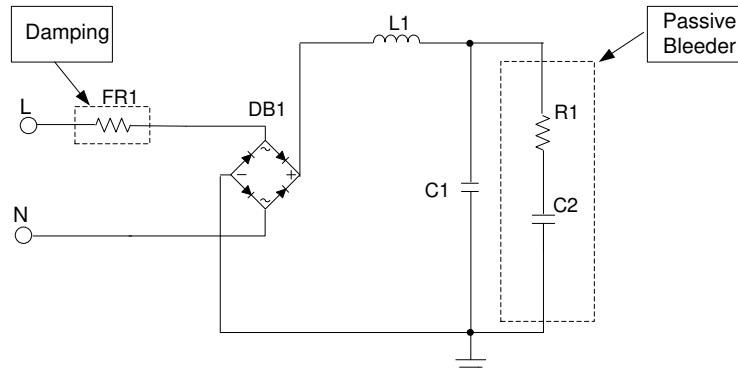


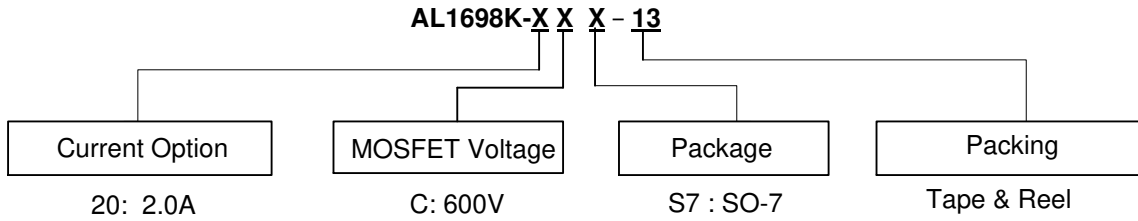
Figure 3. LED Driver Schematic with Passive Bleeder

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_{AC} application, and 51Ω to 200Ω for high line like 230V_{AC} application.

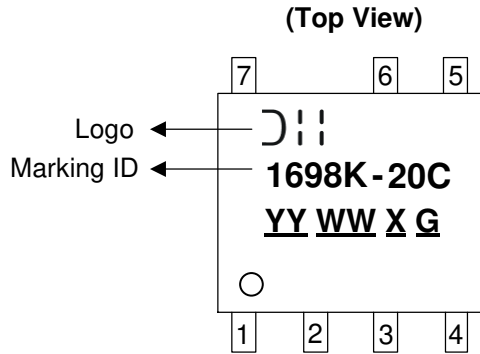
Ordering Information



Part Number	Package Code	Package	Marking ID	Packing	
				Qty.	Carrier
AL1698K-20CS7-13	S7	SO-7	1698K-20C	4,000	13" Tape & Reel

Marking Information

SO-7

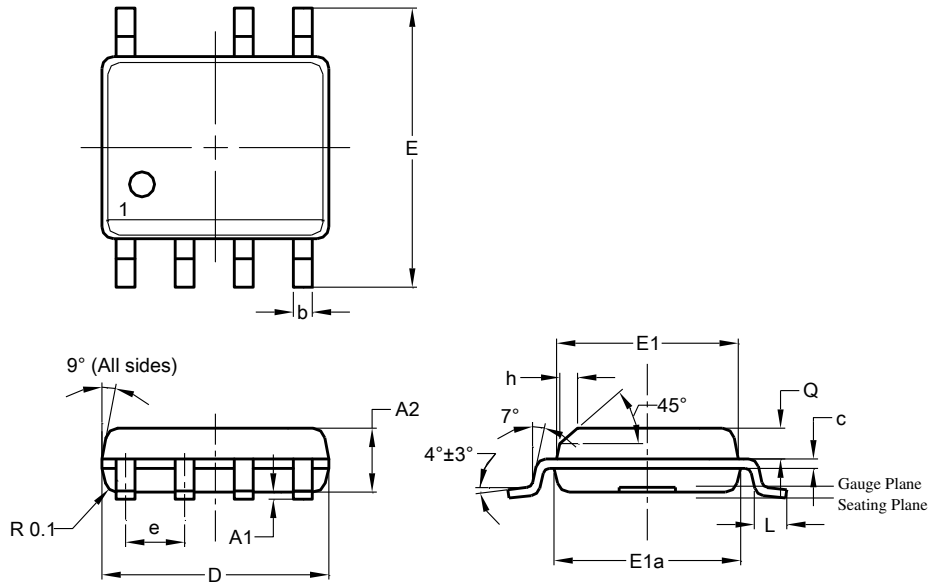


YY : Year : 15,16,17~
WW : Week : 01~52; 52 represents 52 and 53 week
X : T~Z for CAT
 T=Sunday X=Thursday
 U=Monday Y=Friday
 V=Tuesday Z=Saturday
 W=Wednesday
G: Green Compound

Package Outline Dimensions

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

SO-7

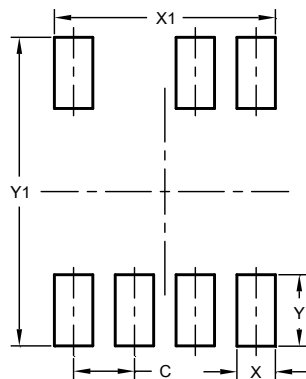


SO-7			
Dim	Min	Max	Typ
A2	1.40	1.50	1.45
A1	0.10	0.20	0.15
b	0.30	0.50	0.40
c	0.15	0.25	0.20
D	4.85	4.95	4.90
E	5.90	6.10	6.00
E1	3.80	3.90	3.85
E1a	3.85	3.95	3.90
e	-	-	1.27
h	-	-	0.35
L	0.62	0.82	0.72
Q	0.60	0.70	0.65
All Dimensions in mm			

Suggested Pad Layout

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

SO-7



Dimensions	Value (in mm)
C	1.270
X	0.802
X1	4.612
Y	1.505
Y1	6.500

Mechanical Data

- Moisture Sensitivity: Level 1 per JESD22-A113
- Terminals: Finish - Matte Tin Plated Leads, Solderable per M2003 JESD22-B102 ③
- Weight: 0.077 grams (Approximate)

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