Description

The DIODES™ AL1692K is a high-performance, high-power factor, high-efficiency, and high-current precision Boost, Buck-Boost, and Flyback dimmable LED driver. The device is suited for TRIAC-dimmable LED lamp applications and provides an accurate output current over wide line and load regulation. It achieves higher than 90% efficiency by using a Boost topology to meet the latest high-efficiency requirements. The wide switching frequency operates at boundary conduction mode (BCM) to ease EMI/EMC design and testing.

The AL1692K LED driver integrates a 600V/2A high-voltage MOSFET. It can cover both 120Vac and 230Vac TRIAC-dimmable applications without the need for an external high-voltage MOSFET, which reduces system bill-of-materials (BOM) cost. The AL1692K has built-in thermal fold-back protection to automatically reduce output current. Other protection features also enhance LED lighting system's safety and reliability.

The device's TRIAC dimming curve is compliant with the NEMA SSL6 standard and applies to a wide range of leading and trailing edge dimmers, achieving a deep dim down to 1%.

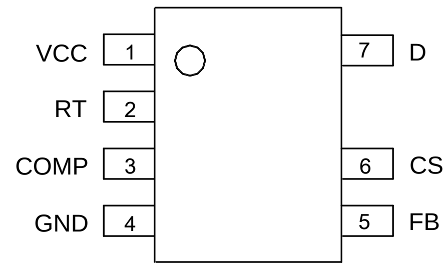
The AL1692K is available in the SO-7 package.

Features

- High Efficiency > 90% (Boost Topology)
- Tight Current Sense Tolerance: ± 3%
- Low Startup Current: 100µA Typical
- Low Operation Current: 210µA (Switching Frequency at 4kHz)
- Single Winding Inductor
- Wide Range of TRIAC Dimmer Compatibility
- Integration of 600V/2A MOSFET
- NEMA SSL6 Dimming Curve Compliant
- Internal Protections
    - Undervoltage Lockout (UVLO)
    - Leading-Edge Blanking (LEB)
    - Cycle-By-Cycle Overcurrent Protection (OCP)
    - Output Open/Short Protection (OVP/OSP)
    - Thermal Foldback Protection (TFP)
    - Overtemperature 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 or your local Diodes representative.**
  https://www.diodes.com/quality/product-definitions/

Pin Assignments

(Top View)



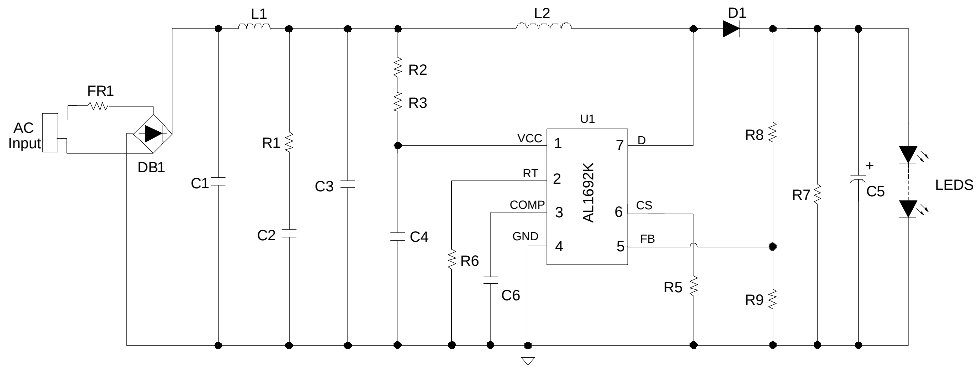
SO-7

Applications

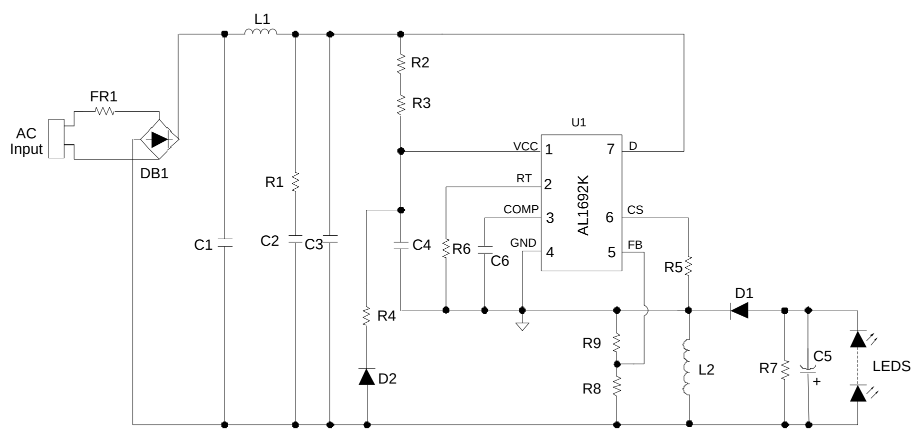
- Mains TRIAC-dimmable LED lamps
- Offline LED power supply drivers

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.

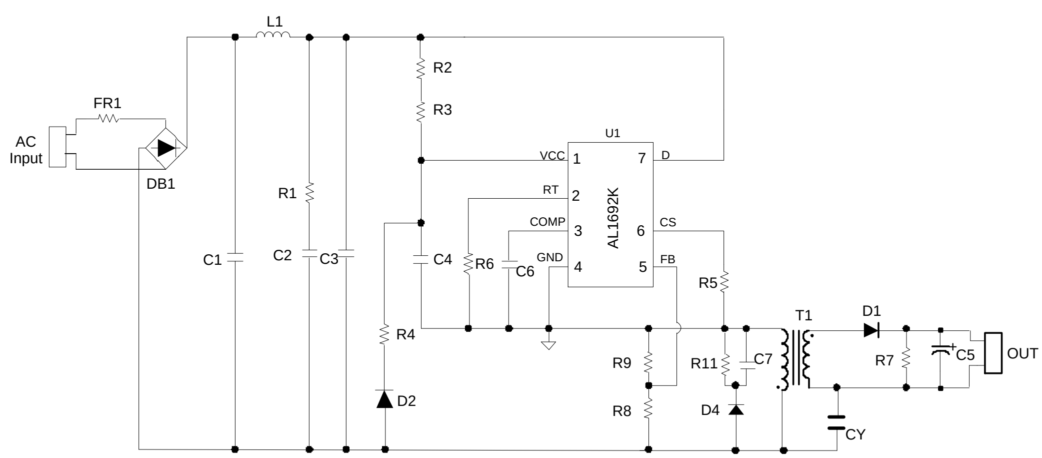
Typical Application Circuits



AL1692K Boost Application Circuit



AL1692K Buck-Boost Application Circuit

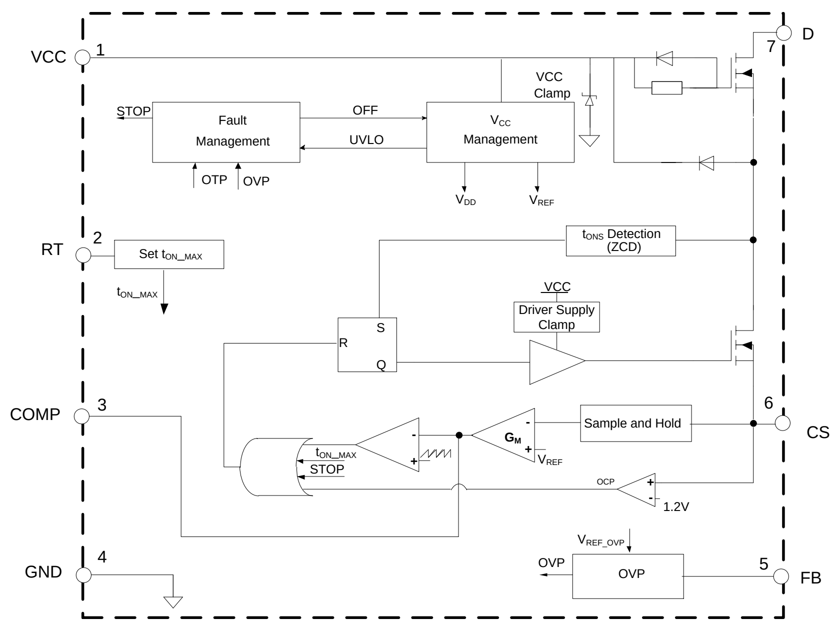


AL1692K Flyback Application Circuit

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



AL1692K 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 Drain 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_{RT}	Voltage on RT 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, 10 seconds)	+260	°C
P_D	Power Dissipation (T_A = +50°C) (Note 5)	0.8	W
θ_{JA}	Thermal Resistance (Junction to Ambient) (Note 5)	123	°C/W
θ_{JC}	Thermal Resistance (Junction to Case) (Note 5)	19	°C/W
—	ESD (Human Body Model)	2,000	V

Notes: 4. Stresses greater than those listed under "*Absolute Maximum Ratings*" can cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "Recommended Operating Conditions" is not implied. Exposure to "*Absolute Maximum Ratings*" for extended periods can affect device reliability. All voltages unless otherwise stated and measured with respect to GND.
5. Device mounted on 1"x1" FR-4 substrate PCB, 2oz copper, with minimum recommended pad layout.

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

Symbol	Parameter	Min	Max	Unit
T_A	Ambient Temperature (Note 6)	-40	+105	°C
V_{CC}	Operating V_{CC} Voltage	10	V_{CC_CLAMP}(Min)	V

Note: 6. The device may operate normally at +125°C ambient temperature under the condition not trigger temperature protection.

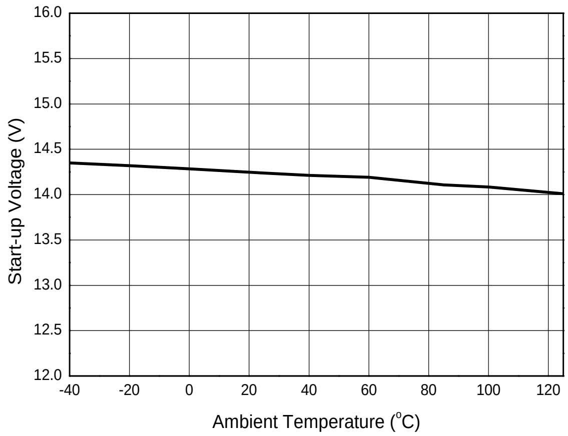
Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
UVLO						
$V_{TH(ST)}$	Startup Voltage	—	—	14.5	—	V
$V_{OPR(MIN)}$	Minimal Operating Voltage	After Turn On	—	8.5	—	V
V_{CC_CLAMP}	V_{CC} Clamp Voltage	I_{CC} = 1mA	14	15.5	—	V
Standby Current						
I_{ST}	Start-Up Current	V_{CC} = $V_{TH(ST)}$-0.5V, Before Start Up	—	100	—	µA
$I_{CC(OPR)}$	Operating Current	Switching Frequency at 4kHz	—	210	—	µA
Source Driver						
$R_{DS(ON)LV}$	Internal Low Voltage MOSFET On-State Resistance (Note 7)	—	—	1	—	Ω
High Voltage and Super-Junction MOSFET						
$R_{DS(ON)HV}$	Drain-Source On-State Resistance	—	—	4	5.5	Ω
V_{DS}	Drain-Source Breakdown Voltage	—	600	—	—	V
I_{DSS}	Drain-Source Leakage Current	—	—	—	1	µA
RT						
V_{RT_REF}	Reference Voltage of RT Pin	—	—	0.5	—	V
Current Sense						
V_{CS_CLAMP}	CS 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}	—	—	550	—	ns
t_{ON_MAX}	Maximum t_{ON}	R_T = 51kΩ, V_{COMP} = 4V	—	5.4	—	µs
t_{OFF_MIN}	Minimum t_{OFF} (Note 7)	—	—	4	—	µs
t_{OFF_MAX}	Maximum t_{OFF}	—	—	290	—	µs
FB						
V_{FB}	Feedback Voltage	—	3.7	3.95	4.18	V
I_{FB}	Feedback Pin Input Leakage Current	V_{FB} = 2V	—	4	—	µA
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} = 1.5V	—	28	—	µA
Thermal Foldback and Overtemperature Protection (OTP)						
T_{FOLD}	Thermal Foldback (Note 7)	—	—	+145	—	°C
—	Thermal Shutdown (Notes7 & 8)	—	—	+160	—	°C

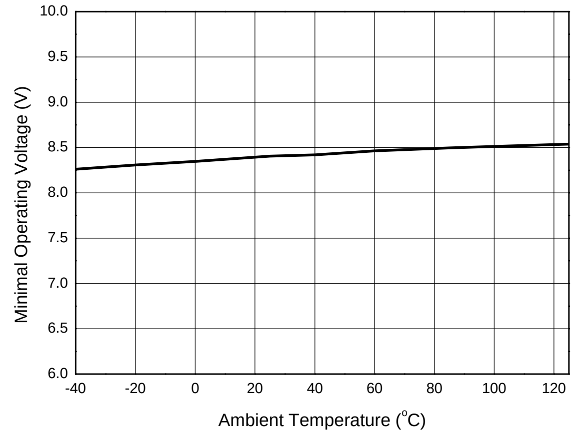
Notes: 7. These parameters, although guaranteed by design, are not tested in production.
8. The device will latch off when OTP happens, recovered after power cycle and the device won't operate normally at this temperature.

Performance Characteristics (Note 9)

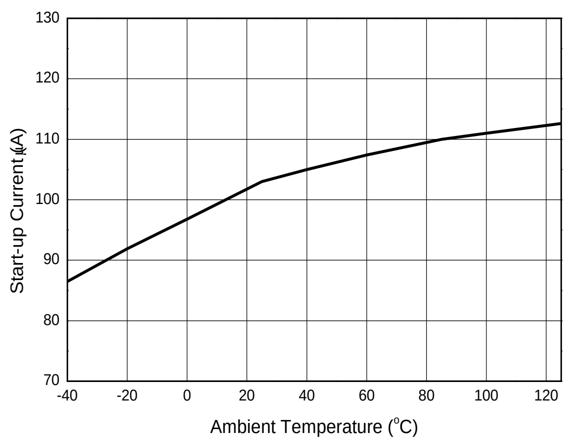
Start-up Voltage vs. Ambient Temperature



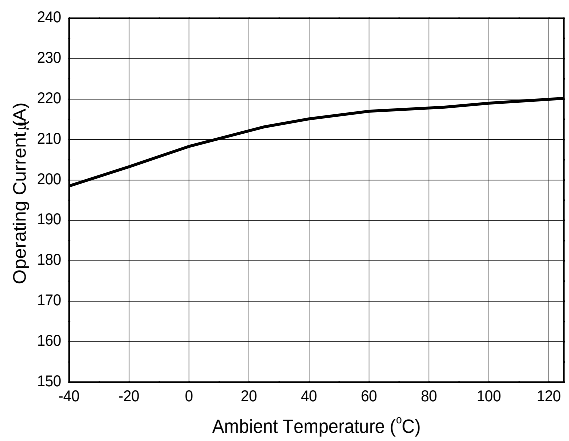
Minimum Operating Voltage vs. Ambient Temperature



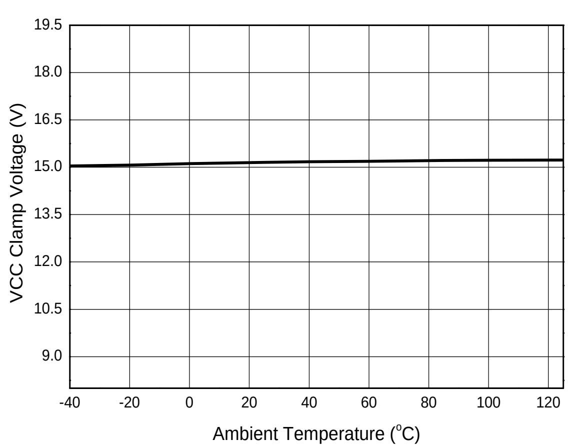
Start-up Current vs. Ambient Temperature



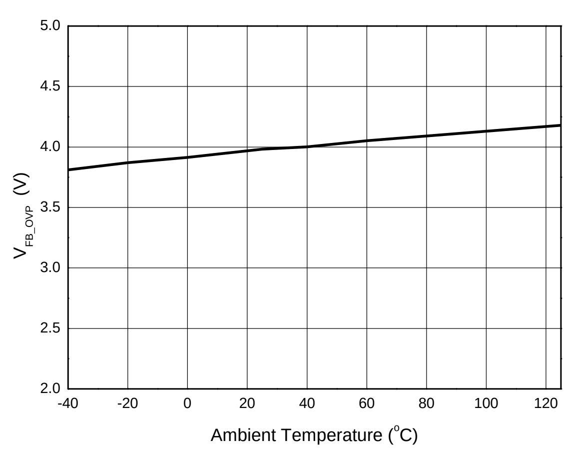
Operating Current vs. Ambient Temperature



VCC Clamp Voltage vs. Ambient Temperature



Feedback Voltage vs. Ambient Temperature



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

Functional Description and Application Information

Operation

The AL1692K is a single-stage, single-winding, high-efficiency, and high-power factor dimmable LED driver for TRIAC-dimmable LED lamp applications. The device integrates a 600V/2A high-voltage MOSFET, and can cover both 120Vac and 230Vac TRIAC dimmable applications while eliminating the need for an external high-voltage MOSFET.

The AL1692K adopts a source-driver technique to decrease system operating current. It uses a novel method to detect the t_{OFF} time, which removes the need for an auxiliary winding. The AL1692K operates at boundary conduction mode (BCM), which eased EMI design and achieved high efficiency. High power factor (HPF) is achieved by using constant on-time mode. Coupled with a closed loop of constant current control, the AL1692K achieves good line and load regulation.

Start-Up and Supply Voltage

Before start-up, the V_{CC} capacitor (C4) is charged by the startup resistors (R2, R3) from the high-voltage mains. When the start-up voltage is reached, the AL1692K starts switching. During normal operation, the V_{CC} supply is provided by start-up resisters (R2, R3) and the output voltage (V_{OUT}) is rectified by one diode (D2). This way, the system can provide V_{CC} supply at low dimming angle.

The AL1692K has an internal VCC clamp voltage (typical 15.5V), which is limited by one internal active Zener diode.

When VCC voltage drops below the $V_{OPR(MIN)}$, the switching is stopped. The device returns to normal operation when the voltage on the VCC pin is between $V_{OPR(MIN)}$ and VCC clamp voltage.

Protections

Undervoltage Lockout (UVLO)

When the voltage on the VCC pin drops to below $V_{OPR(MIN)}$, the IC stops switching. The IC restarts 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 Overcurrent Protection (OCP)

The AL1692K has a built-in peak current detector. It triggers when the voltage on the CS pin reaches the peak level, V_{CS_CLAMP}. The R5 connects 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:

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

The detection circuit is activated after the LEB time. When the detection circuit senses that 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 overcurrent detection and actual source-switch off, so the actual peak current is a little higher than the OCP level set by the R5.

Overvoltage Protection and Output-Open Protection (OVP)

The FB pin senses the output voltage, providing an overvoltage protection (OVP) function. When the output is open or a large transient occurs, the output voltage will exceed the rated value (R8, R9). When the voltage exceeds V_{FB}, overvoltage protection is triggered and the IC will discharge V_{CC}. When the V_{CC} is below the UVLO threshold voltage, the IC will restart and the V_{CC} capacitor is charged again by the start-up resistance. If the overvoltage 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)

The AL1692K has a thermal foldback protection (TFP) function and a self-adaptive control method, which prevent the system from breaking down due to high temperature. The overheating temperature is set at +145°C typical. When the junction temperature of the IC is higher than +145°C, the device will linearly decrease the internal reference voltage to lower output current. As a result of this feature, the device can control the system's output power at high ambient temperatures to control the quantity of heat of the system. This enhances the safety of the system at high temperatures.

Thermal foldback waveform is shown as below:

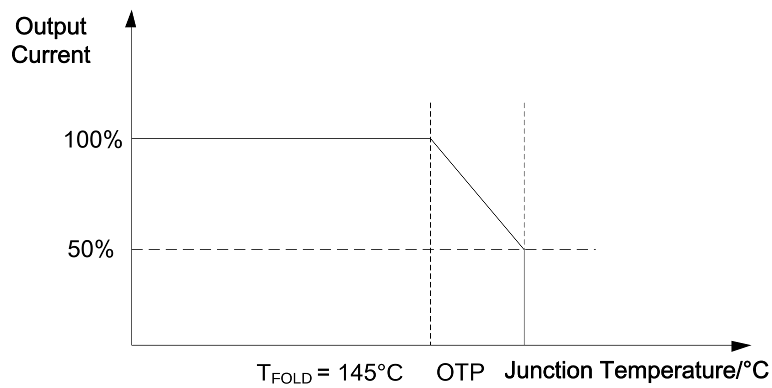


Figure 1. Thermal Foldback Waveform

Overtemperature Protection (OTP)

The AL1692K has overtemperature protection (OTP) function. When the junction temperature reaches to +160°C typical, the IC will trigger an overtemperature protection, which causes the device to shut down and latch. Once OTP triggers, the system will resume after the system's AC source supply resets and powers up.

Design Parameters

Setting the Current Sense Resistor R5

The AL1692K adopts boundary conduction mode. The output current is calculated as below,

$$I_{O\_MEAN} = \frac{1}{\pi} \cdot \int_0^{\pi} \frac{1}{2} \cdot I_{PEAK} \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} dt$$

.... (2) (Boost, Buck-Boost)

$$I_{O\_MEAN} = \frac{N_P}{N_S} \cdot \frac{1}{\pi} \cdot \int_0^{\pi} \frac{1}{2} \cdot I_{PEAK} \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} dt$$

.... (3) (Flyback)

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

N_P are the turns of primary winding

N_S are the turns of secondary winding

The AL1692K is a closed-loop constant-current control with the relationship between output current and current sense voltage below:

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

.... (4) (Boost, Buck-Boost)

$$V_{REF} = \frac{N_P}{N_S} \cdot \frac{1}{\pi} \cdot \int_0^{\pi} I_{PEAK} \cdot \mathrm{R5} \cdot \frac{t_{OFF}}{t_{ON} + t_{OFF} + t_{DELAY}} dt$$

.... (5) (Flyback)

Functional Description and Application Information (continued)

Where,

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

R5 is the current sense resistor

Output current equation as below:

$$I_{O\_MEAN} = \frac{1}{2} \cdot \frac{V_{REF}}{R5}$$ .... (6) (Boost, Buck-Boost)

$$I_{O\_MEAN} = \frac{1}{2} \cdot \frac{N_P}{N_S} \cdot \frac{V_{REF}}{R5}$$ .... (7) (Flyback)

Inductance Selection (L2, or L_P of T1)

The peak current of the inductance can be calculated below:

$$I_{PEAK} = \frac{\pi \cdot V_{REF}}{R5 \cdot \int_0^{\pi} \sin(\theta) \cdot \frac{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta)}{V_O} d\theta}$$ .... (8) (Boost)

$$I_{PEAK} = \frac{\pi \cdot V_{REF}}{R5 \cdot \int_0^{\pi} \sin(\theta) \cdot \frac{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta)}{\sqrt{2} \cdot V_{IN\_RMS} \cdot \sin(\theta) + Vo} d\theta}$$ .... (9) (Buck-Boost)

$$I_{PEAK} = \frac{\pi \cdot N_S \cdot V_{REF}}{N_P \cdot R5 \cdot \int_0^{\pi} \sin(\theta) \cdot [1 + \frac{N_P \cdot V_O}{\sqrt{2} \cdot N_S \cdot V_{IN\_RMS} \cdot \sin(\theta)}] d\theta}$$ .... (10) (Flyback)

Where,

V_{IN_RMS} is the input voltage's RMS value

V_O is the system output voltage

The AL1692K controls the system operating at boundary conduction mode, which results in an inconstant operating frequency. To set the minimum switching frequency f_{MIN} at the crest of the minimum AC input, see the below equations:

$$L2 = \frac{\sqrt{2} V_{IN\_RMS} \cdot (V_O - \sqrt{2} V_{IN\_RMS})}{I_{PEAK} \cdot V_O \cdot f_{MIN}}$$ .... (11) (Boost)

$$L2 = \frac{\sqrt{2} V_{IN\_RMS} \cdot V_O}{I_{PEAK} \cdot (\sqrt{2} V_{IN\_RMS} + V_O) \cdot f_{MIN}}$$ .... (12) (Buck-Boost)

$$L_P = \frac{\sqrt{2} V_{IN\_RMS} \cdot N_P \cdot V_O}{I_{PEAK} \cdot (N_P \cdot V_O + \sqrt{2} N_S \cdot V_{IN\_RMS}) \cdot f_{MIN}}$$ .... (13) (Flyback)

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

$$N_{L2} = \frac{L2 \cdot I_{PEAK}}{A_e \cdot B_m}$$ .... (14) (Boost, Buck-Boost)

$$N_P = \frac{L_P \cdot I_{PEAK}}{A_e \cdot B_m}$$ .... (15) (Flyback)

Where,

A_e is the core effective area

B_m is the maximum magnetic flux density

Functional Description and Application Information (continued)

t_{ON_MAX} Setting

In order to get good dimmer compatibilities and dimming depths, the device sets a t_{ON_MAX} by one external resistor R_T (R6).
The t_{ON_MAX} time has the below equation:

$$t_{ON\_MAX} = \frac{3.3C_{REF}}{\frac{V_{RT\_REF}}{10R_6} + 0.33uA}$$ .... (16) (Boost, Buck-Boost, Flyback)

Where

V_{RT_REF} is the internal RT pin 0.5V's reference

C_{REF} is the internal 1.5pF capacitor

TRIAC Dimming Control

The AL1692K is a closed-loop control device; the dimming function is realized by t_{ON_MAX} limited when a TRIAC dimmer is connected. When the dimmer is at the largest conduction angle, the device still has adjustability to control the output current constant before COMP voltage is adjusted to the maximum 4V. Thus at the largest conduction angle, the output current for most TRIAC dimmers is nearly the same as conditions without a dimmer. If the conduction angle is decreased, the COMP pin voltage will continue to increase quickly to the maximum level (typical 4V), the device will output t_{ON_MAX} to limit the system's output current. t_{ON_MAX} is set by the RT pin connected to a resistor, so the dimming depth can be adjusted by an RT resistor (R6).

Before the AL1692K enters t_{ON_MAX} mode, it keeps the output current the same as conditions with no dimmers. When entering t_{ON_MAX} mode, the following equation is achieved:

$$I_{PEAK\_DIM} = \frac{\sqrt{2}V_{IN\_RMS} \cdot Sin(\theta) \cdot t_{ON\_MAX}}{L2}$$ .... (17) (Boost, Buck-Boost, Flyback)

From the output current equation, one can get the output current when dimming:

$$I_O(\alpha) = \begin{cases} \frac{1}{2} \cdot \frac{V_{REF}}{R5} & if\ t_{ON} < t_{ON\_MAX} \\ \frac{1}{\pi}\int_0^{\alpha} \frac{1}{2} \cdot I_{PEAK\_DIM} \cdot \frac{\sqrt{2}V_{IN\_RMS} \cdot Sin(\theta)}{V_O} d\theta & else \end{cases}$$ .... (18) (Boost)

$$I_O(\alpha) = \begin{cases} \frac{1}{2} \cdot \frac{V_{REF}}{R5} & if\ t_{ON} < t_{ON\_MAX} \\ \frac{1}{\pi}\int_0^{\alpha} \frac{1}{2} \cdot I_{PEAK\_DIM} \cdot \frac{\sqrt{2}V_{IN\_RMS} \cdot Sin(\theta)}{\sqrt{2}V_{IN\_RMS} \cdot Sin(\theta) + V_O} d\theta & else \end{cases}$$ .... (19) (Buck-Boost)

$$I_O(\alpha) = \begin{cases} \frac{1}{2} \cdot \frac{N_P}{N_S} \cdot \frac{V_{REF}}{R5} & if\ t_{ON} < t_{ON\_MAX} \\ \frac{N_P}{2\pi} \cdot \int_0^{\alpha} I_{PEAK\_DIM} \cdot \frac{\sqrt{2}V_{IN\_RMS} \cdot Sin(\theta)}{N_P \cdot V_O + \sqrt{2}N_S \cdot V_{IN\_RMS} \cdot Sin(\theta)} d\theta & else \end{cases}$$ .... (20) (Flyback)

Where,

α is the TRIAC dimmer conduction angle

Functional Description and Application Information (continued)

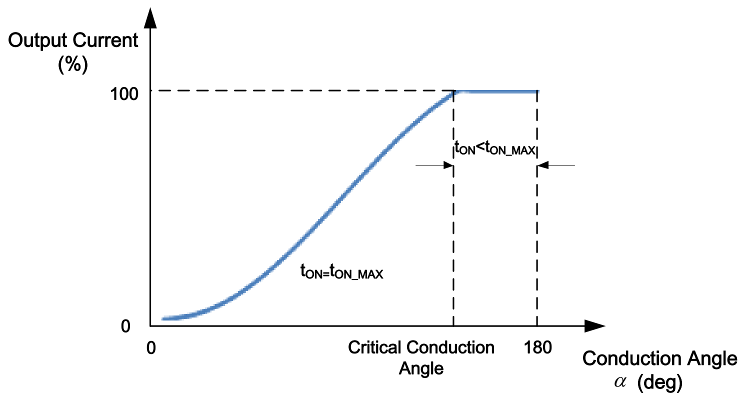


Figure 2. TRIAC Dimming Curve

Dimmer Compatibility

Passive Bleeder Design

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

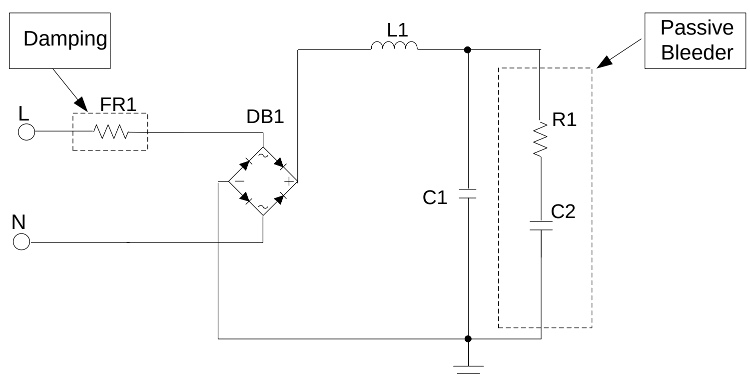


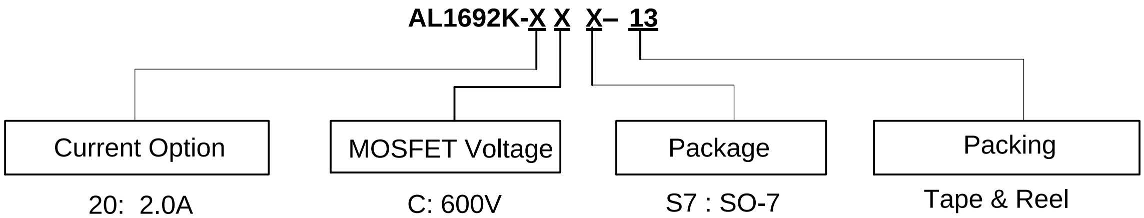
Figure 3. LED Driver Schematic with Passive Bleeder

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 sufficient 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

FR-1 is the damper for reducing the spike current caused by quick charging of C2 at firing. In General, FR-1 is selected from 20Ω to 100Ω for low line, such as 120V_{AC} applications, and 51Ω to 200Ω for high line, such as 230V_{AC} applications.

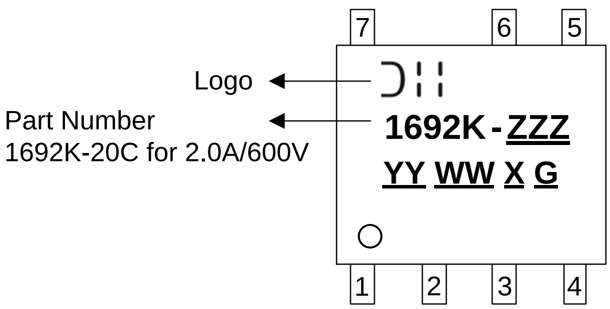
Ordering Information



Part Number	Package Code	Package	13" Tape and Reel	
			Quantity	Part Number Suffix
AL1692K-20CS7-13	S7	SO-7	4,000/Tape & Reel	-13

Marking Information

SO-7
(Top View)

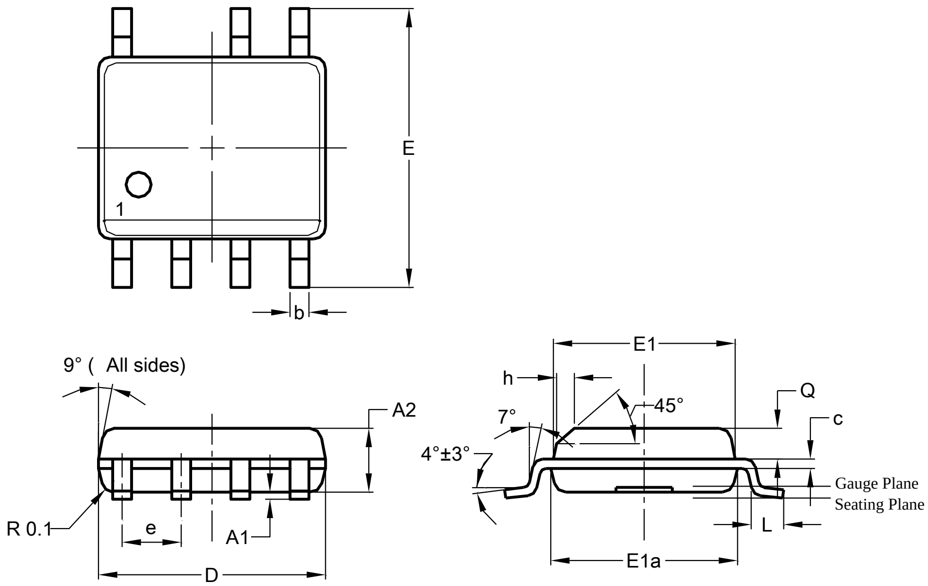


YY : Year : 21,22,23~
WW : Week : 01 to 52; 52 Represents 52 and 53 Week
X : T to Z for CAT
T = Sunday X = Thursday
U = Monday Y = Friday
V = Tuesday Z = Saturday
W = Wednesday
G: Green Compound

Package Outline Dimensions

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

SO-7

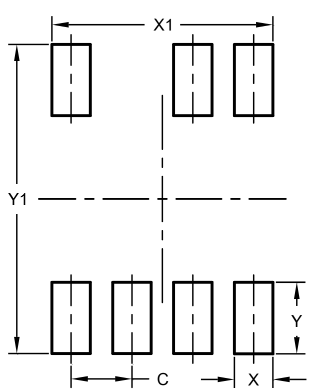


SO-7			
Dim	**Min**	**Max**	**Typ**
A2	1.40	1.50	1.45
A1	0.10	0.20	0.15
b	0.30	0.50	0.40
c	0.15	0.25	0.20
D	4.85	4.95	4.90
E	5.90	6.10	6.00
E1	3.80	3.90	3.85
E1a	3.85	3.95	3.90
e	-	-	1.27
h	-	-	0.35
L	0.62	0.82	0.72
Q	0.60	0.70	0.65
All Dimensions in mm			

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 e3
- Weight: 0.077 grams (Approximate)

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