HIGHLY INTEGRATION OFFLINE DIMMABLE LED DRIVER

Description

The AL1696 is a highly integrated high power factor constant current converter for mains dimmable LED driver applications. The AL1696 controls the system operating in boundary conduction mode (BCM) for ease in EMI/EMC qualification and testing to meet the latest regulatory standards.

The AL1696 with built-in MOSFET solution reduces the bill of material (BOM) cost by eliminating the need of auxiliary winding and external high-voltage MOSFET.

The AL1696 can be compatible with a wide range of dimmers including leading edge and trailing edge dimmers. Some dimmers can achieve deep dimming down to 1%. The AL1696 dimming curve is compliant with the standard of NEMA SSL6.

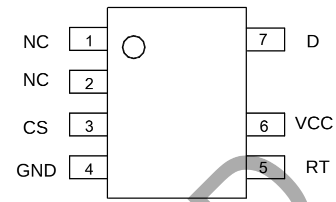
The AL1696 is available in SO-7 package, which provides an extra pin spacing between the high-voltage MOSFET's drain and low-voltage pins to increase electricity isolation.

Features

- Internal MOSFET up to 300V/3A, 400V/3A, 500V/2A, 600V/2A
- Tight Current Sense Tolerance: ±3%
- Low Startup Current: 150µA
- Low Operation Current: 120µA (Switching Frequency at 5kHz)
- Single Winding Inductor
- Wide Range of Dimmer Compatibility
- Dimming Curve Compliant with NEMA SSL6
- Internal Protections
  - Undervoltage Lockout (UVLO)
  - Leading-Edge Blanking (LEB)
  - Cycle-by-Cycle Overcurrent Protection (OCP)
  - Output Short Protection (OSP)
  - 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)



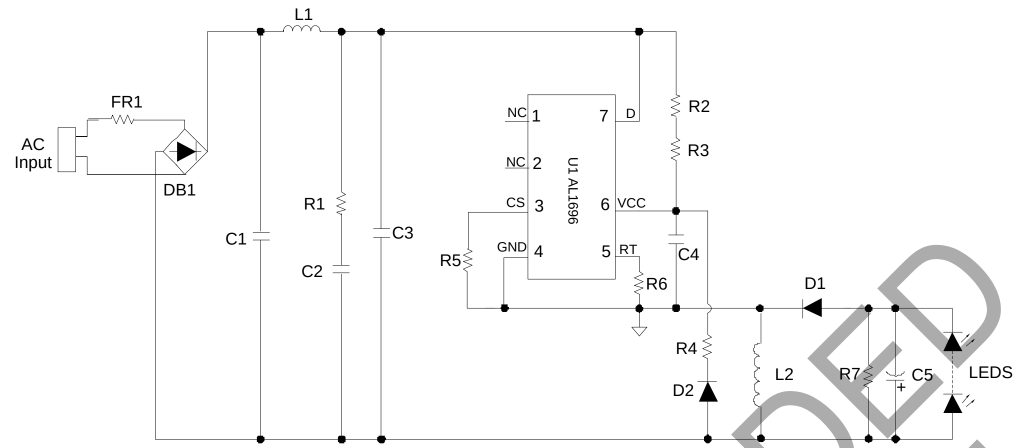
SO-7

Applications

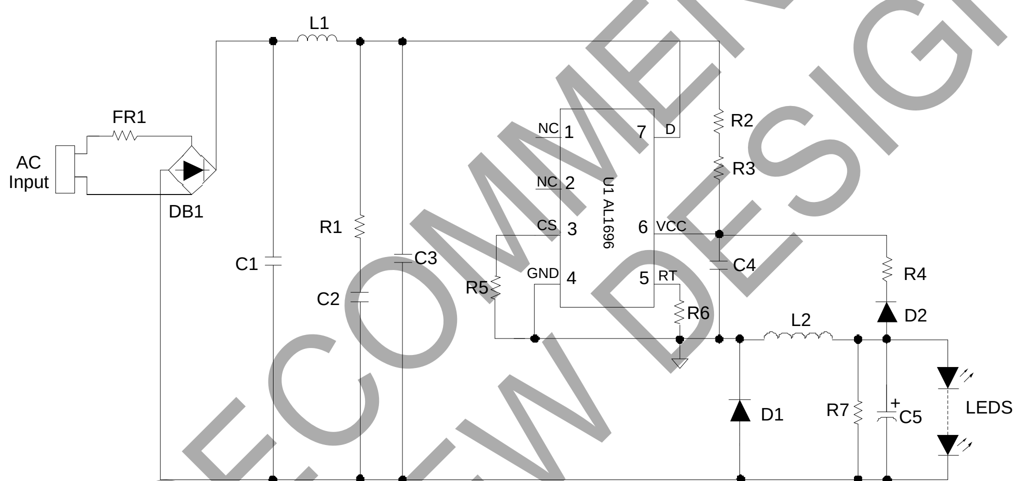
- Mains dimmable LED lamps
- Offline LED power supply drivers

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 Applications Circuit



Buck-Boost Application Circuit

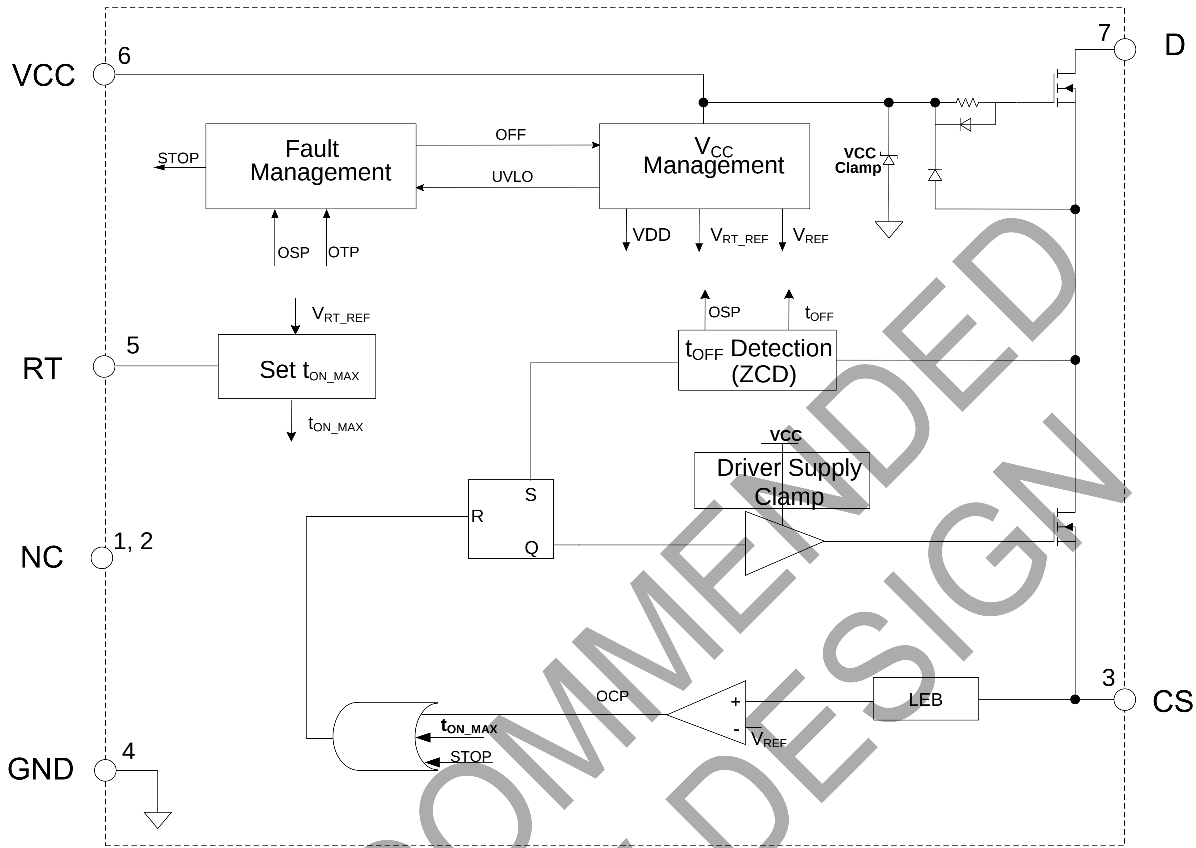


Buck Application Circuit

Pin Descriptions

Pin Number	Pin Name	Function
1, 2	NC	No connection
3	CS	Current sensing
4	GND	Ground
5	RT	Resistor set the system's maximum t_{ON}
6	VCC	Power supply voltage
7	D	Drain of the internal high-voltage MOSFET

Functional 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 (AL1696-30AS7-13)	300	V
	Voltage on D Pin (AL1696-30BAS7-13)	400	V
	Voltage on D Pin (AL1696-20BS7-13)	500	V
	Voltage on D Pin (AL1696-20CS7-13)	600	V
I_D	Continuous Drain Current T_C = +25°C (AL1696-30AS7-13)	3.0	A
	Continuous Drain Current T_C = +25°C (AL1696-30BAS7-13)	3.0	A
	Continuous Drain Current T_C = +25°C (AL1696-20BS7-13)	2.0	A
	Continuous Drain Current T_C = +25°C (AL1696-20CS7-13)	2.0	A
V_{CS}	Voltage on CS Pin	-0.3 to 7	V
V_{RT}	Voltage on RT 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 and Thermal Characteristics (T_A = +50°C)	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
	ESD (Machine Model)	200	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.
5. Device mounted on 1" x 1" 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 (Note 6)	Ambient Temperature	-40	+105	°C

Note: 6. The device can operate normally at +125°C ambient temperature under the condition that the junction temperature is less than +150°C.

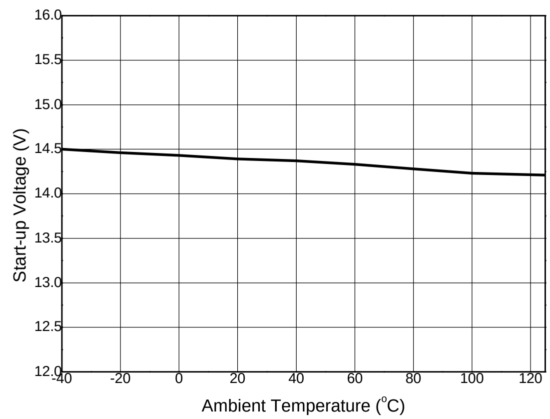
Electrical Characteristics (@T_A = +25°C, unless otherwise specified.)

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	—	16	—	V
Standby Current						
I_{ST}	Startup Current	V_{CC} = $V_{TH(ST)}$-0.5V Before Startup	—	150	—	µA
$I_{CC(OPR)}$	Operating Current	Switching Frequency at 5kHz	—	120	—	µA
Internal High-Voltage MOSFET						
$R_{DS(ON)}$	Drain-Source On-State Resistance	AL1696-30A	—	—	3	Ω
		AL1696-30BA	—	—	3.4	Ω
		AL1696-20B	—	—	6	Ω
		AL1696-20C	—	—	5.5	Ω
I_{DS}	Continuous Drain-Source Current	AL1696-30A	—	—	3.0	A
		AL1696-30BA	—	—	3.0	A
		AL1696-20B	—	—	2.0	A
		AL1696-20C	—	—	2.0	A
V_{DS}	Drain-Source Breakdown Voltage	AL1696-30A	300	—	—	V
		AL1696-30BA	400	—	—	V
		AL1696-20B	500	—	—	V
		AL1696-20C	600	—	—	V
I_{DSS}	Drain-Source Leakage Current	AL1696-30A @V_{DS} = 300V, V_{GS} = 0V	—	—	1	µA
		AL1696-30BA @V_{DS} = 400V, V_{GS} = 0V	—	—	1	µA
		AL1696-20B @V_{DS} = 500V, V_{GS} = 0V	—	—	1	µA
		AL1696-20C @V_{DS} = 600V, V_{GS} = 0V	—	—	1	µA
RT						
V_{RT}	Reference Voltage of RT Pin	—	—	0.5	—	V
Current Sense						
V_{REF}	Current Sense Reference	—	0.388	0.400	0.412	V
t_{ON_MIN}	Minimum t_{ON}	—	—	550	—	ns
t_{ON_MAX}	Maximum t_{ON}	R_T = 27kΩ	—	8	—	µs
t_{OFF_MAX}	Maximum t_{OFF}	—	—	180	—	µs
t_{OFF_MIN}	Minimum t_{OFF} (Note 7)	—	—	6	—	µs
Overtemperature Protection						
—	Shutdown Temperature (Notes 7 & 8)	—	—	+170	—	°C

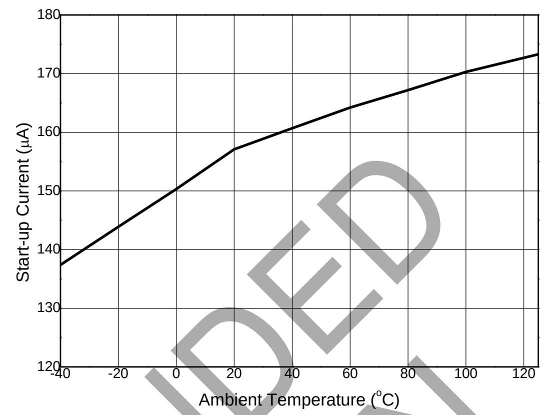
Notes: 7. These parameters, although guaranteed by design, are not 100% tested in production.
8. The device will latch when OTP happens and the device will not operate constantly at this temperature.

Performance Characteristics (Note 9)

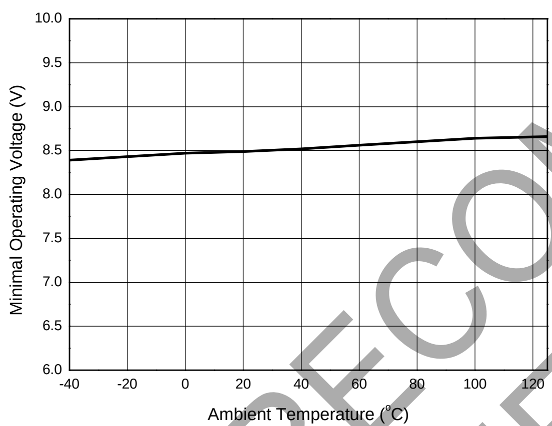
Startup Voltage vs. Ambient Temperature



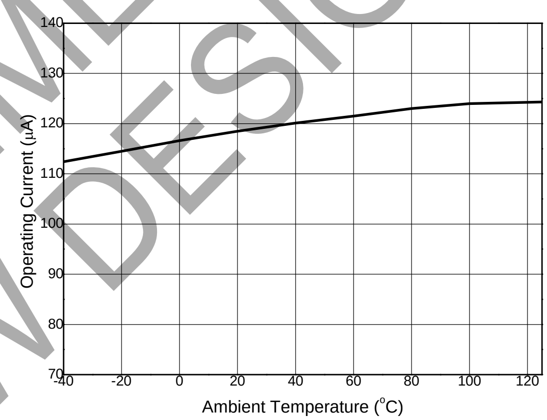
Startup Current vs. Ambient Temperature



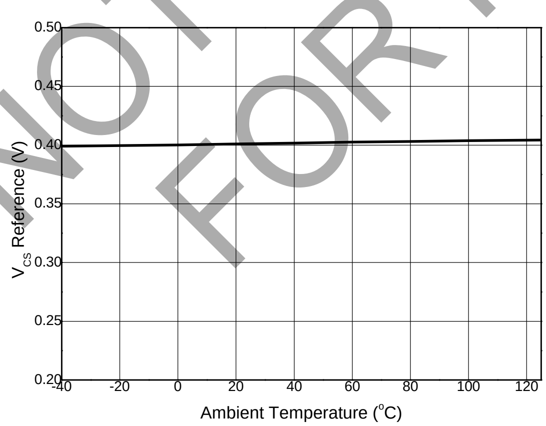
Minimal Operating Voltage vs. Ambient Temperature



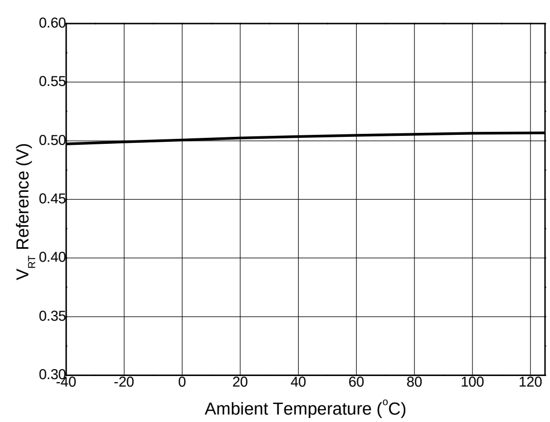
Operating Current vs. Ambient Temperature



V_{CS} Reference vs. Ambient Temperature



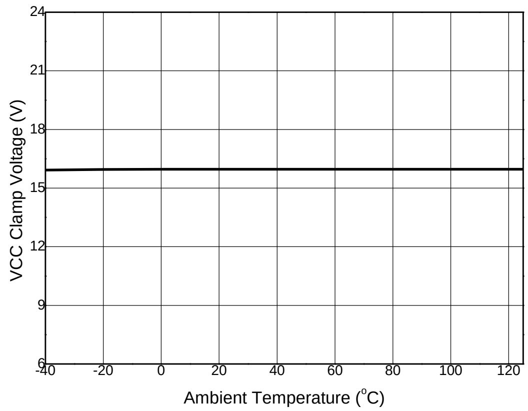
V_{RT} Reference vs. Ambient Temperature



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

Performance Characteristics (continued) (Note 9)

VCC Clamp 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

Convertor Operation

The AL1696 is a single stage, single winding inductor, high-efficiency, and high-power-factor LED driver solution for mains input phase-cutting dimmable application. It is available for four internal MOSFET options (300V/3A, 400V/3A, 500V/2A and 600V/2A) which helps to reduce the overall LED driver solution's size and optimize BOM cost. The three different MOSFET options can cover most of 3 to 12W dimmable applications.

The AL1696 internal MOSFET's on time is limited by t_{ON_MAX} which is set through RT pin and internal 0.4V reference. The MOSFET will be turned off either its on-time triggers t_{ON_MAX} or input voltage on CS pin triggers internal 0.4V reference voltage. So if the t_{ON_MAX} is set to a very small value, the system will operate in constant on-time (t_{ON_MAX}) mode during the whole rectified mains cycle. It will result in a good power factor, but the line regulation will be worse. Normally, a recommended t_{ON_MAX} should make the system operate in constant on-time (t_{ON_MAX}) mode at valley of input voltage and peak current mode at the crest. A trade-off between PF and line regulation need to be done when setting t_{ON_MAX}.

The AL1696 adopts source-driver technology to decrease the system operating current. Besides, it uses a novel t_{OFF} time detection method without auxiliary winding. The AL1696 operates in boundary conduction mode (BCM) which can ease EMI design. All of them help AL1696 to have an extremely low bill of material (BOM).

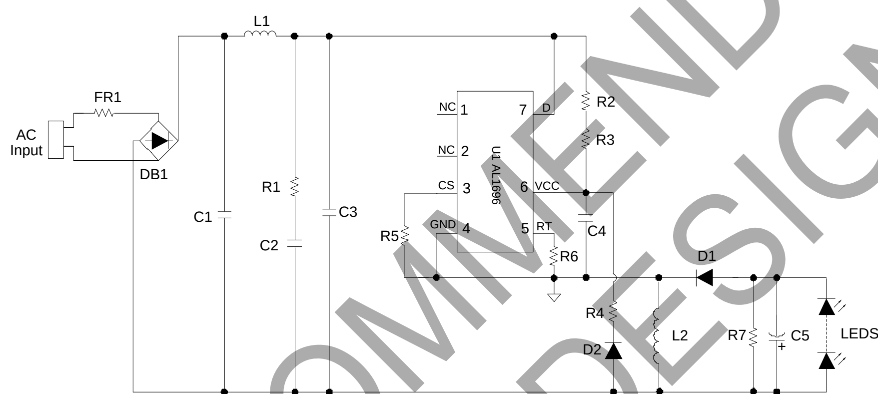


Figure 1. Typical Buck-Boost Application Circuit

Startup and Supply Voltage

During startup, the VCC capacitor C4 is charged through startup resistors (R2, R3) from the rectified mains input until the startup voltage is reached, the AL1696 starts switching. In normal operation, the VCC supply is provided from two paths: one is from startup resisters (R2, R3) and the other is from output voltage (V_{OUT}) through one diode (D2). In this way the system can provide sufficient VCC supply at low dimming angle.

The AL1696 has internal VCC clamp, the typical voltage is 16V. VCC voltage needs to be between $V_{OPR(MIN)}$ and V_{CC_CLAMP} during normal operation.

When VCC voltage drops below the undervoltage lockout (UVLO), IC will stop switching. The IC will restart once the voltage on VCC pin exceeds the startup voltage ($V_{TH(ST)}$) again.

Protections

Undervoltage Lockout (UVLO)

When the voltage on the VCC pin drops below $V_{OPR(MIN)}$, the IC will stop switching. The IC will restart until the VCC voltage exceeds the startup voltage ($V_{TH\ (ST)}$) again.

Leading-Edge Blanking (LEB)

To prevent false detection of the peak current through MOSFET, a blanking time following switch-on is designed. When the internal switch turns on, a short current spike may appear because of the discharge of the parasitic capacitor over MOSFET's drain and source. It will be ignored during the LEB time (t_{ON_MIN}).

Functional Description and Application Information (continued)

Cycle-by-Cycle Overcurrent Protection (OCP)

The AL1696 has a built-in peak current detector. The R5 connected to the CS pin is used to sense the current through MOSFET and will be one of the inputs. The detection circuit is activated after the LEB time. When the voltage on CS pin reaches V_{REF}, the IC will turn off the switch to limit the output current.

The peak current (I_{PEAK}) of the MOSFET can be set as below:

$$I_{PEAK} = \frac{V_{REF}}{R5}$$

It automatically provides a cycle-by-cycle protection of maximum current through MOSFET during operation. A propagation delay exists between over current detection and actual source-switch off, so the actual peak current will be a little higher than the OCP level set by R5.

Output-Short Protection (OSP)

When LED is shorted, the device cannot detect the t_{OFF} time, and the system will work with low switching frequency of 5kHz.

Overtemperature Protection (OTP)

The AL1696 has OTP protection function. When the junction temperature reaches +170°C typical, it will trigger an overtemperature protection which makes IC shut down and latched. Once OTP is triggered, the system will only restart after the system's power supply powers off and on again.

Design Parameters Based on Buck-Boost Topology

Setting the Current Sense Resistor R5

In AL1696 typical application, a t_{ON_MAX} is recommended to make the system operate at constant on-time (t_{ON_MAX}) mode at valley of input voltage and peak current mode at the crest. In most cases, the t_{ON_MAX} will set to be 1.3 times of the t_{ON} at crest, and the critical angle of two operation modes will be:

$$\theta = a\sin\left(\frac{1}{1.3}\right)$$

Then the output current can be calculated as below:

$$I_{O\_MEAN} = \frac{V_{REF}}{2\pi \cdot R5}\left(\int_0^{\theta} 1.3\cdot\sin(\theta)\frac{\sqrt{2}V_{IN\_RMS}\sin(\theta)}{\sqrt{2}V_{IN\_RMS}\sin(\theta)+V_O}dt + \int_{\theta}^{\pi-\theta}\frac{\sqrt{2}V_{IN\_RMS}\sin(\theta)}{\sqrt{2}V_{IN\_RMS}\sin(\theta)+V_O}dt + \int_{\pi-\theta}^{\pi} 1.3\cdot\sin(\theta)\frac{\sqrt{2}V_{IN\_RMS}\sin(\theta)}{\sqrt{2}V_{IN\_RMS}\sin(\theta)+V_O}dt\right)$$

Where,

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

R5 is the current sense resistor.

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

V_O is the system output voltage.

Inductance Selection (L2)

The peak current of the MOSFET is calculated as below:

$$I_{PEAK} = \frac{V_{REF}}{R5}$$

The AL1696 is operating in boundary conduction mode which results in a variable operating frequency. The minimum switching frequency f_{MIN} should be set at the crest of the minimum AC input voltage. Inductance should be calculated according to the chosen f_{MIN}:

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

Functional Description and Application information (continued)

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

$$N_{L2} = \frac{L2 \cdot I_{PEAK}}{A_e \cdot B_m}$$

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 high-power-factor and good dimmer compatibility, the system should operate in constant on time mode at valley of input voltage. It can be realized by setting the maximum on time, which is set by an external resistor connected to RT pin.

And the t_{ON} time has the below equation:

$$t_{ON\_MAX} = \frac{25 \cdot C_{REF} \cdot R6}{V_{RT\_REF}}$$

Where,
V_{RT_REF} is the internal RT pin 0.5V's reference.
C_{REF} is the internal 6pF capacitor.

Dimmer Compatibility

Passive Bleeder Design

The passive bleeder is designed to supply latching and holding current to get rid of dimmer's misfire and flicker.

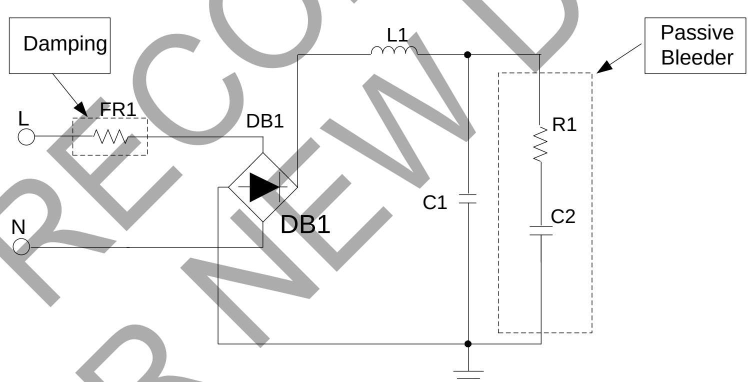


Figure 2. LED Driver Schematic with Passive Bleeder

The passive bleeder includes a capacitor (C2, in hundreds of nF) to provide latching current and a resistor (R1) to limit the current spike. Because a large C2 will affect the PF, THD and efficiency negatively, the value of the capacitor (C2) should be selected carefully. Generally, a capacitance from 100nF/400V to 330nF/400V is recommended. R1 is used to limit the latching current. If R1 is too big, the latching current will be not enough and the TRIAC dimmer will be misfired, resulting in LED flicker. If R1 is too small, it will result in greater power dissipation. Generally, a 200Ω to 2kΩ resistor is recommended for R1.

Passive Damping Design

FR1 is to limit the spike current caused by quick charging of C2 when dimmer on. Normally, FR1 will be chosen from 20Ω to 100Ω for low line like $120V_{AC}$ application, and 51Ω to 200Ω for high line like $230V_{AC}$ application.

Ordering Information

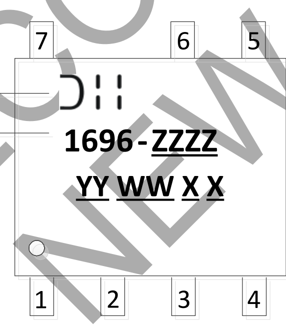
AL1696 – XX XX XX – 13

Current Option	MOSFET Voltage	Package	Packing
20 : 2.0A 30 : 3.0A	A: 300V BA: 400V B: 500V C: 600V	S7 : SO-7	13 :13" Tape & Reel

Part Number	Part Number Suffix	Package Code	Package	Packing	
				Qty.	Carrier
AL1696-30AS7-13	-13	S7	SO-7	4000	Tape & Reel
AL1696-30BAS7-13	-13	S7	SO-7	4000	Tape & Reel
AL1696-20BS7-13	-13	S7	SO-7	4000	Tape & Reel
AL1696-20CS7-13	-13	S7	SO-7	4000	Tape & Reel

Marking Information

(Top View)



Logo

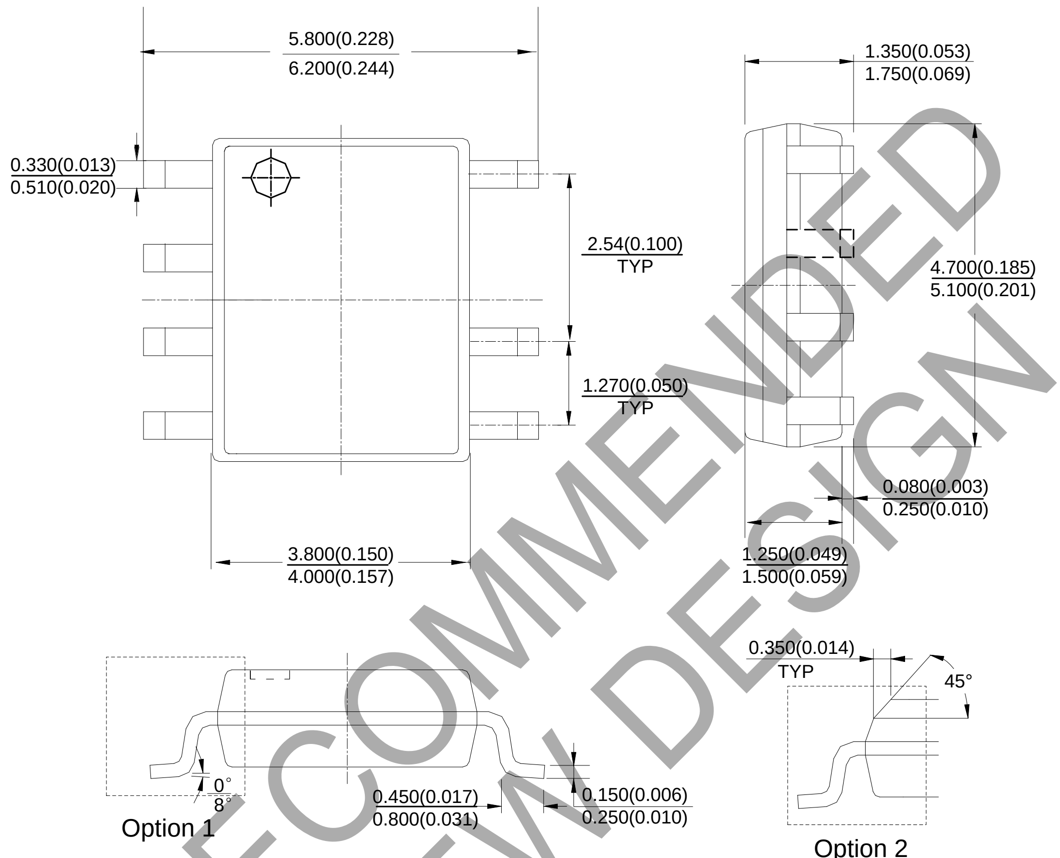
Marking ID
1696-30A for 3.0A/300V
1696-30BA for 3.0A/400V
1696-20B for 2.0A/500V
1696-20C for 2.0A/600V

YY : Year (ex: 23 = 2023)
WW : Week : 01 to 52; 52 represents week 52 and 53
X X : Internal Code

Package Outline Dimensions (All dimensions in mm(inch))

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

(1) Package Type: SO-7

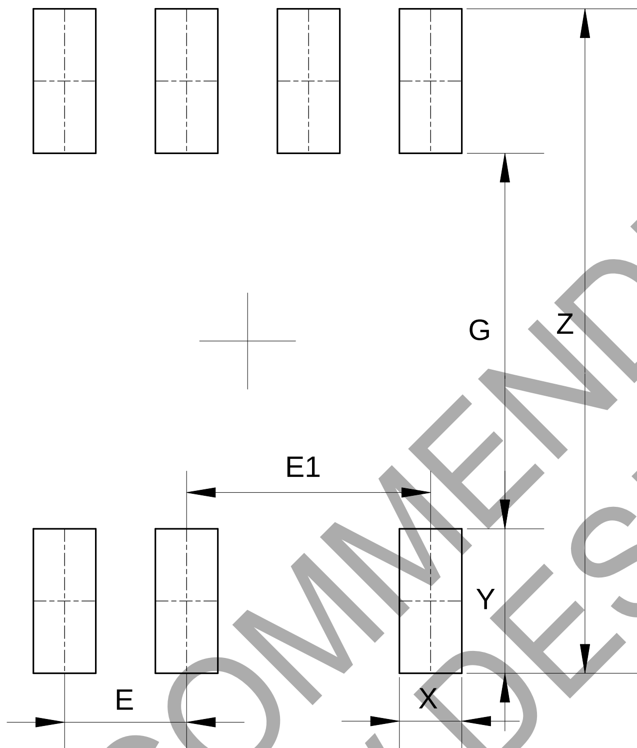


Note: Eject hole, oriented hole and mold mark is optional.

Suggested Pad Layout

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

(1) Package Type: SO-7



Dimensions	Z (mm)/(inch)	G (mm)/(inch)	X (mm)/(inch)	Y (mm)/(inch)	E (mm)/(inch)	E1 (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

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