NOT RECOMMENDED FOR NEW DESIGN
USE AP1694AS-13

Lead-free Green

AP1685

OFFLINE, HIGH PF, HIGH EFFICIENCY LED DRIVER IC

Description

The AP1685 is a high performance AC/DC power factor corrector for mains dimmable LED driver applications. The device uses Pulse Frequency Modulation (PFM) technology to regulate output current while achieving high power factor and low THD. It operates as a BCM (Boundary Conduction Mode) which is good for EMI.

The AP1685 internally integrates a 500V high voltage MOSFET which can realize a lower BOM cost. The AP1685 provides accurate constant current (CC) regulation while removing the opto-coupler and secondary control circuitry. It also eliminates the need of loop compensation circuitry while maintaining stability. It can meet the requirement of IEC6100-3-2 harmonic standard.

The AP1685 features low start-up current, low operation current. It adopts valley on switching mode to achieve high efficiency. It also has rich protection features including over voltage, short circuit, over temperature protection.

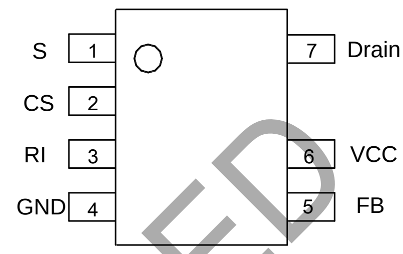
The AP1685 is available in SO-7 package.

Features

- Boundary Conduction Mode (BCM) Operation to Achieve High-efficiency
- High PF and Low THD (PF>0.9, THD<30%)
- High Efficiency
- Low Start-up Current
- Tight LED Current
- Tight LED Open Voltage
- Valley-mode Switching to Minimize the Transition Loss
- Internal Integrated 2.5A/500V MOSFET can Cover up to 10W
- Easy EMI
- Internal Protections:
  - Under Voltage Lock Out (UVLO)
  - Leading-edge Blanking (LEB)
  - Output Short Protection
  - Output Open Protection
  - Over Temperature Protection
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**

Pin Assignments

(Top View)



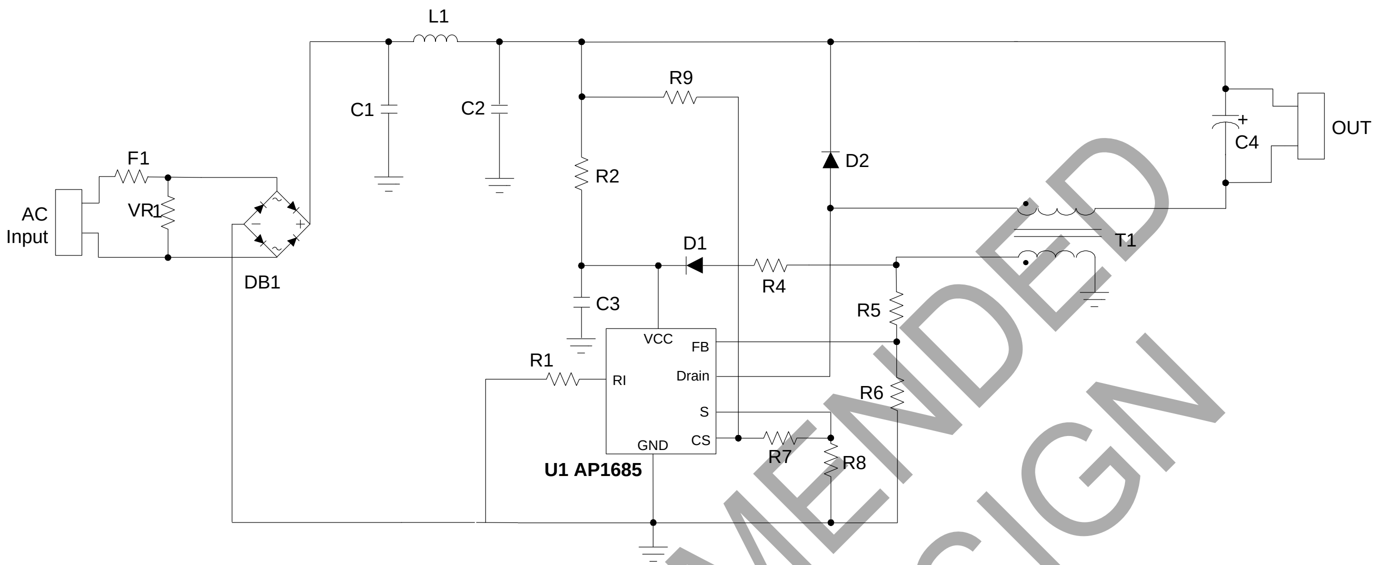
SO-7

Applications

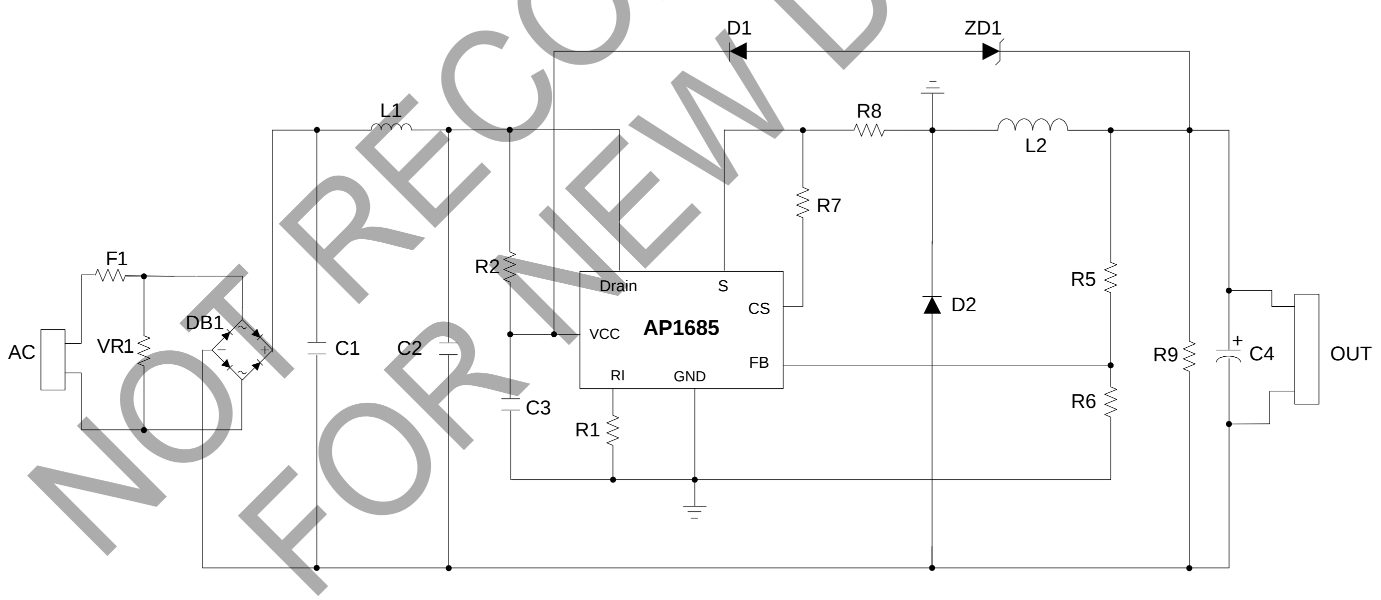
- Non-dimmable LED drivers

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



Typical Buck Application with Auxiliary Winding

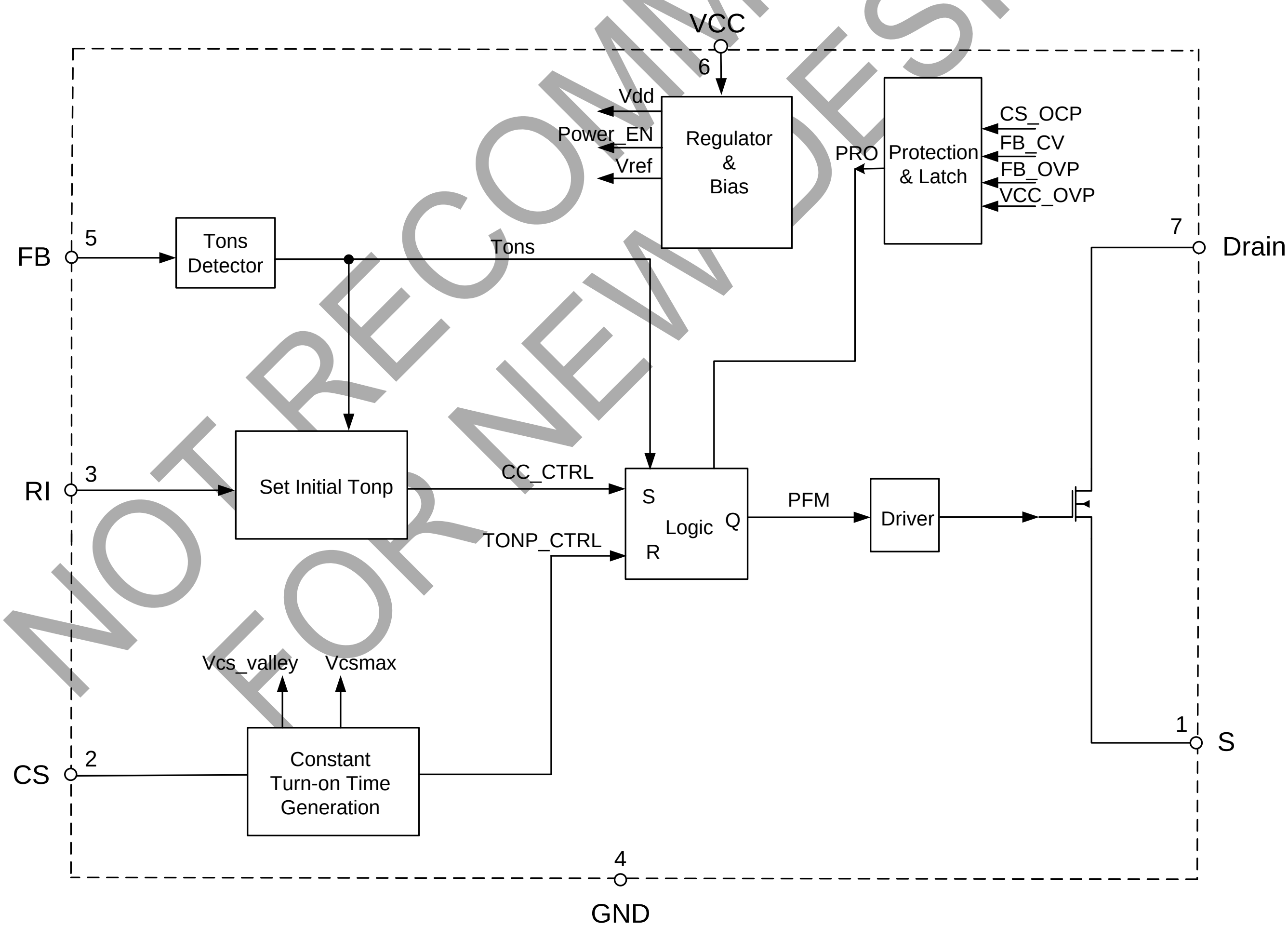


Typical Floating Buck Application without Auxiliary Winding

Pin Descriptions

Pin Number	Pin Name	Function
1	S	Internal MOSFET's Source
2	CS	Current sensing
3	RI	Setting the initial on time
4	GND	Ground
5	FB	The feedback voltage from auxiliary winding
6	VCC	Supply voltage of gate driver and control circuits of the IC.
7	Drain	Internal MOSFET's Drain

Functional Block Diagram



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

Symbol	Parameter	Rating	Unit
V_{CC}	Power Supply Voltage	-0.3 to 35	V
V_{CS}	Voltage at CS to GND	-0.3 to 7	V
V_{FB}	FB Input Voltage	-40 to 10	V
V_{Drain}	Voltage on Drain	500	V
I_D	Continue Drain Current T_C = +25°C	2.5	A
T_J	Operating Junction Temperature	-40 to +150	°C
T_{STG}	Storage Temperature	-65 to +150	°C
T_{LEAD}	Lead Temperature (Soldering, 10 sec)	+300	°C
P_D	Power Dissipation (T_A = +50°C)	0.65	W
$θ_{JA}$	Thermal Resistance (Junction to Ambient)	160	°C/W
–	ESD (Human Body Model)	±2000	V
–	ESD (Machine Model)	±200	V

Note 4: 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.

Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
V_{CC}	Power Supply Voltage	8	25	V
T_A	Ambient Temperature	-40	+105	°C

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

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
UVLO Section						
V_{TH} (ST)	Start-up Threshold	–	13	14.5	16	V
V_{OPR} (Min)	Minimum Operating Voltage	After turn on	5.5	6.5	7.5	V
V_{CC_OVP}	VCC OVP Voltage	–	27	29	31	V
–	VCC Delatch Voltage (Note 5)	–	3	4	5	V
Standby Current Section						
I_{ST}	Start-up Current	V_{CC} = V_{TH} (ST)-0.5V, Before start up	–	–	20	µA
I_{CC} (OPR)	Operating Current	Static	–	900	1300	µA
Current Sense Section						
V_{CS_REF}	Current Sense Reference	–	–	1	–	V
V_{CS_CLAMP}	Current Sense Reference Clamp	–	1.2	1.4	–	V
t_{ONP_MIN}	Minimum t_{ONP}	–	700	–	1000	ns
$t_{D(H-L)}$	Delay to Output (Note 5)	–	50	150	250	ns
Feedback Input Section						
I_{FB}	Feedback Pin Input Leakage Current	V_{FB} = 2V	–	–	4	µA
V_{FB_CV}	FB CV Threshold	–	3.8	4	4.2	V
V_{FB_OVP}	FB OVP Threshold	–	4.5	6	7.5	V
Internal MOSFET Section						
$R_{DS(ON)}$	Drain-Source On-State Resistance	V_{GS} = 10V, I_D = 1.25A	–	–	6	Ω
$V_{BR(Drain)}$	Drain-Source Breakdown Voltage	V_{GS} = 0V, I_D = 250µA	500	–	–	V
I_{DSS}	Drain-Source Leakage Current	V_{DS} = 500V, V_{GS} = 0V	–	–	1	µA
Output Current						
–	System Output Current On Final Test Board	–	–	–	±2	%
Over Temperature Protection Section						
–	Shutdown Temperature (Note 5)	–	+150	–	–	°C
–	Temperature Hysteresis (Note 5)	–	–	+20	–	°C

Note 5: These parameters, although guaranteed by design, are not 100% tested in production.

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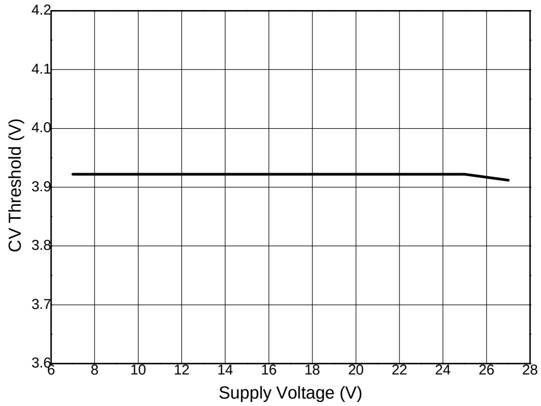
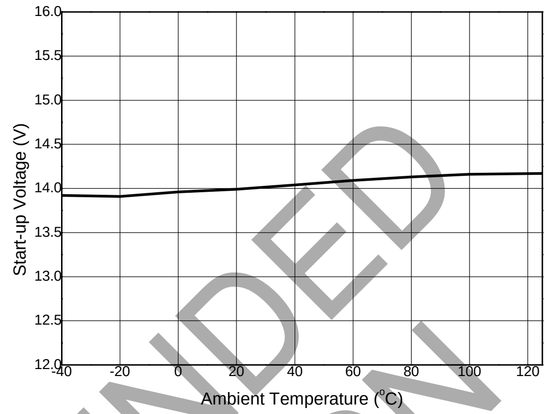
Performance Characteristics

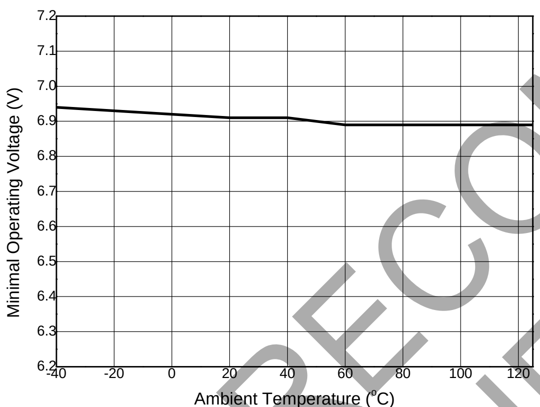
CV Threshold vs. Supply Voltage



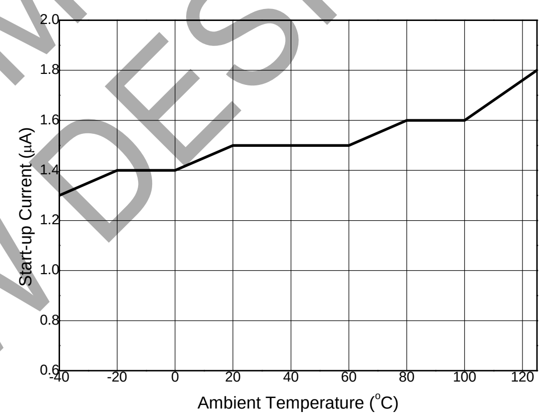
Start-up Voltage vs. Ambient Temperature



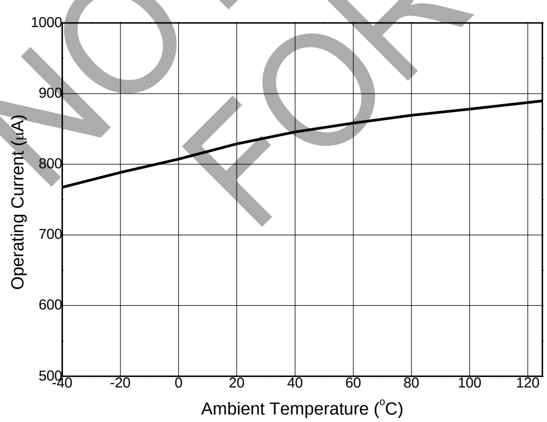
Minimal Operating Voltage vs. Ambient Temperature



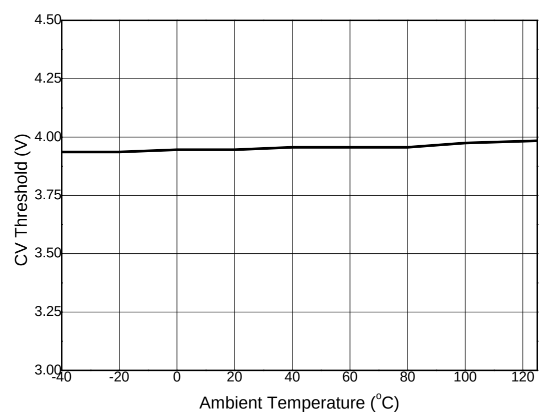
Start-up Current vs. Ambient Temperature



Operating Current vs. Ambient Temperature

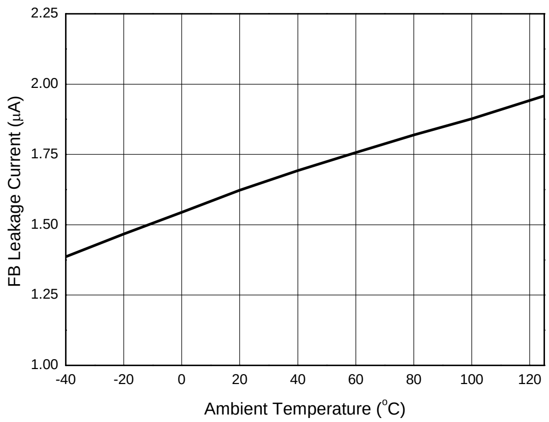


CV Threshold vs. Ambient Temperature

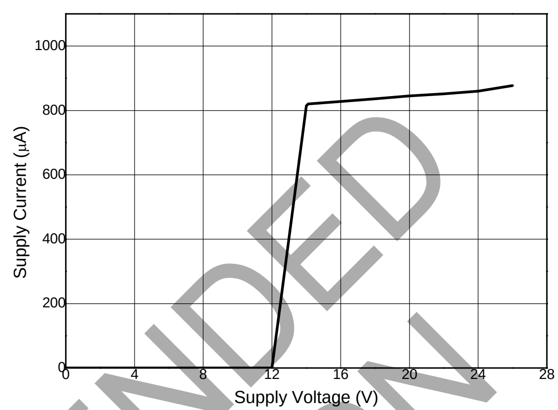


Performance Characteristics (Cont.)

FB Leakage Current vs. Ambient Temperature



Supply Current vs. Supply Voltage



Application Information

The AP1685 is designed for single voltage application, and it features high power factor correction (PFC), low total harmonic distortion (THD), low BOM cost and good EMI performance. The device can be widely used in non-dimmable LED application such as GU10, bulb lamps, down lamp, etc. The AP1685 adopts constant on time control method within one AC cycle to achieve the high power factor and low THD. The control scheme is very simple, the power factor correction effectiveness is obvious, and the constant current control is also good enough.

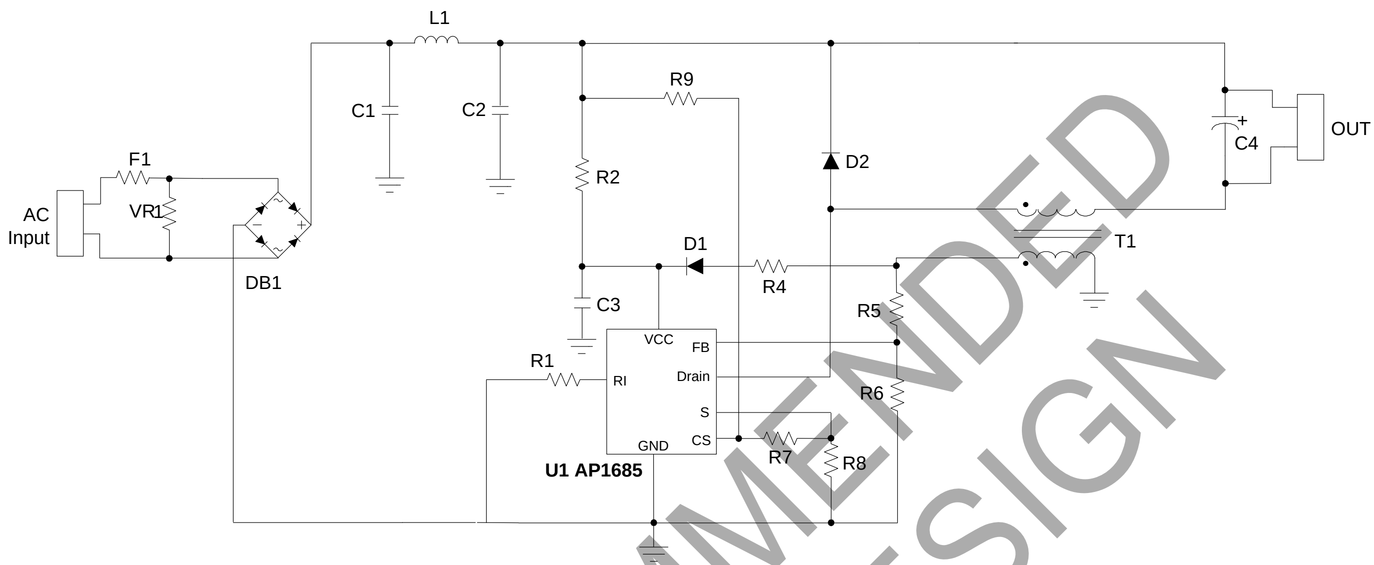


Figure 1. Typical Application Circuit

Design Parameters

Setting the Current Sense Resistor R8

As the AP1685 adopts constant on time control method, the current of the inductance will follow the input voltage to get a sinusoidal wave. The current sense pin CS of the AP1685 will sense the peak current of the inductance by sensing the voltage dropped on the current sense resistor R8, and the constant current control is realized by controlling the peak current. In buck structure, when the V_O is higher than V_{IN}, no energy will be transferred from input to output which is called dead zone, and considering the dead zone of buck structure, the output current can be calculated as below:

$$I_{o\_mean} = k \cdot \frac{1}{\pi} \cdot \frac{V_{cs\_ref}}{R8}$$

Where,

V_{cs_ref} is the reference of the current sense, and the typical value is 1V.

k is the current modification coefficient, and the value of k is approximate to be 0.7.

So, the current sense resistor R8 is determined:

$$R8 = k \cdot \frac{V_{cs\_ref}}{\pi \cdot I_{o\_mean}}$$

Transformer Selection (T1)

The non-isolated buck circuit in Figure 1 is usually selected, and the system is operating at boundary conduction mode. The system's operating frequency does not keep constant, the minimum switching frequency at the crest is set as f_{min}, and then the buck inductance value L can be got:

$$L = \frac{(\sqrt{2} \cdot V_{in\_rms} - V_o) \cdot R8 \ \cdot V_o}{V_{cs\_ref} \cdot \sqrt{2} \cdot V_{in\_rms} \cdot f_{\min}}$$

Where,
V_O is the output voltage.
V_{in_rms} is the RMS value of the input voltage.

Application Information (Cont.)

The next step is determining the transformer's winding turns number, the worst case operation condition of transformer is at the peak voltage area of sine waveform input voltage where the current of across the inductance is the maximum value. The transformer design should be based on the worst case operation condition to guarantee that the transformer is not saturated. According to Ferrari's law of electromagnetic induction, the winding turns number of the buck inductance N_L is:

$$N_L = \frac{L \cdot I_{pk}}{A_e \cdot B_m} = \frac{L \cdot V_{cs\_ref}}{A_e \cdot B_m \cdot R8}$$

Where,

A_e is the core effective area.

B_m is the maximum magnetic flux density.

The auxiliary winding is power supply for V_{CC}, the winding turns number N_{aux} is:

$$N_{aux} = N_L \cdot \frac{V_{cc}}{V_o + V_d}$$

Where,

V_{CC} is the power supply voltage for IC from auxiliary winding.

V_d is the voltage drop of the freewheel diode.

Setting the Initial On Time

As the AP1685 adopts constant on-time control method, the AP1685 will generate an initial on time to start a working cycle. If the initial on time is longer than the rated on time, overshoot will happen which could damage the LED. And a good system performance does not permit overshoot, so the appropriate initial on time should be guaranteed. And initial on time is determined by resister R1 shown in Figure 1.

According to initial on time generation mechanism, the $t_{on\_initial}$ is

$$t_{on\_initial} = 80 \cdot R1 \cdot 10^{-12} s$$

To guarantee the system with no overshoot phenomenon, the resistor is selected

$$R1 = \frac{1.25 \cdot L}{R8 \cdot \sqrt{2} U_{in\_rms\_max}} \cdot 10^{10} \Omega$$

Valley on Control Method

The valley on function can provide low turn-on switching losses for buck converter. The voltage across the drain and source of the power MOSFET is reflected by the auxiliary winding of the buck transformer. The voltage is sensed by the FB pin.

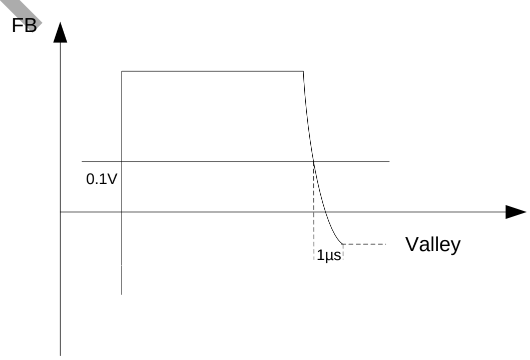


Figure 2. Valley on Control

Application Information (Cont.)

According to Figure 2, when the falling edge of 0.1V is sensed by the FB pin, the AP1685 will see the t_{OFF} time is over and delay 1µs to start a new operating cycle. In this way we can realize valley on function.

Fault Protection

Over Voltage Protection and Output Open Protection

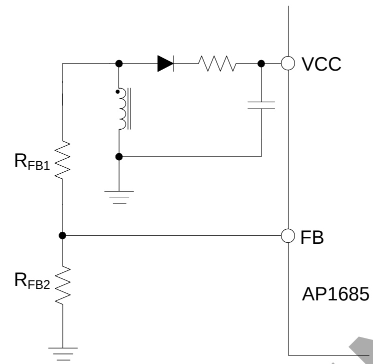


Figure 3. OVP Circuit

The output voltage is sensed by the auxiliary winding voltage of the buck transformer, the VCC pin and FB pin provide over voltage protection function. When the output is open or large transient happens, the output voltage will exceed the rated value. When the voltage of V_{CC} cap exceeds V_{cc_ovp} or V_{FB_CV}, the over voltage is triggered and the IC will discharge V_{CC}. When the V_{CC} is below the UVLO threshold voltage, the IC will start a new work cycle and the V_{CC} cap is charged again by start resistance. If the over voltage condition still exists, the system will work in hiccup mode.

Output Short Protection

When the output is shorted, the output voltage will be clamped at 0. At this condition, V_{CC} will drop down without auxiliary winding for power supply. And the V_{CC} will drop to UVLO threshold voltage, the IC will shut down and restart a new operating cycle, and the V_{CC} is charged by startup resistance. When the V_{CC} is higher than V_{cc_start} voltage, the IC will output a bunch of pulse to control power MOSFET on and off, which will consume the energy stored in the V_{CC} cap, because of no V_{CC} supply from the auxiliary winding, the V_{CC} will drop down to V_{CC} UVLO threshold voltage again. If output short condition still exists, the system will operate in hiccup mode.

Over Temperature Protection

The AP1685 has two kinds of over temperature protection processes. First, the system is operating normally, the ambient temperature is changed to +170°C suddenly, the IC will trigger over temperature protection which leads to a latch work mode. Second, if the system starts, the over temperature protection will be triggered when the ambient temperature is higher than +150°C. So the AP1685 can startup successfully when the ambient temperature is less than +150°C.

Recommended Applications

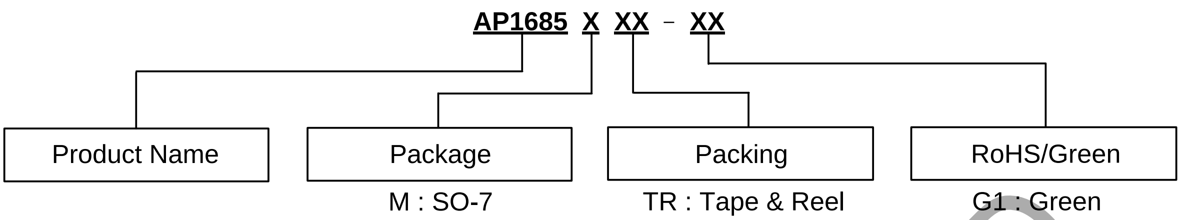
The AP1685 is a device which internally integrates a MOSFET, the output current is limited by the internal integrated MOSFET, using this device can cover up to 10W's application meanwhile the output current is less than 200mA.

Components Selection Guide

If the system's output spec is changed, please refer to the design sheet of the AP1685 and select the compatible system parameter. When the system needs to be adjusted slightly, please refer to the table below and adjust the value of the related component.

Item	Description	Related Components
I_O	LED current	R8
Output Current Ripple	Small current ripple is good for LED life	C4
$t_{on\_initial}$	System initial on time, used to start up the system	R1
Output Open Voltage	Setting the output voltage when the LED is open	R5, R6
Line Compensation	To get a good line regulation	R7, R9
Startup Time	System startup time	R2, C3, T1
EMI	Pass EN 55022 class B with 6DB margin	L1, C1, C2

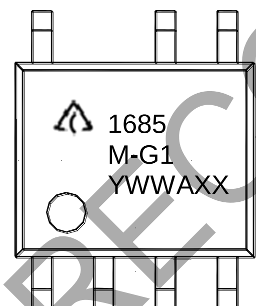
Ordering Information



Package	Temperature Range	Part Number	Marking ID	Packing
SO-7	-40°C to +105°C	AP1685MTR-G1	1685M-G1	4000/13''Tape & Reel

Marking Information

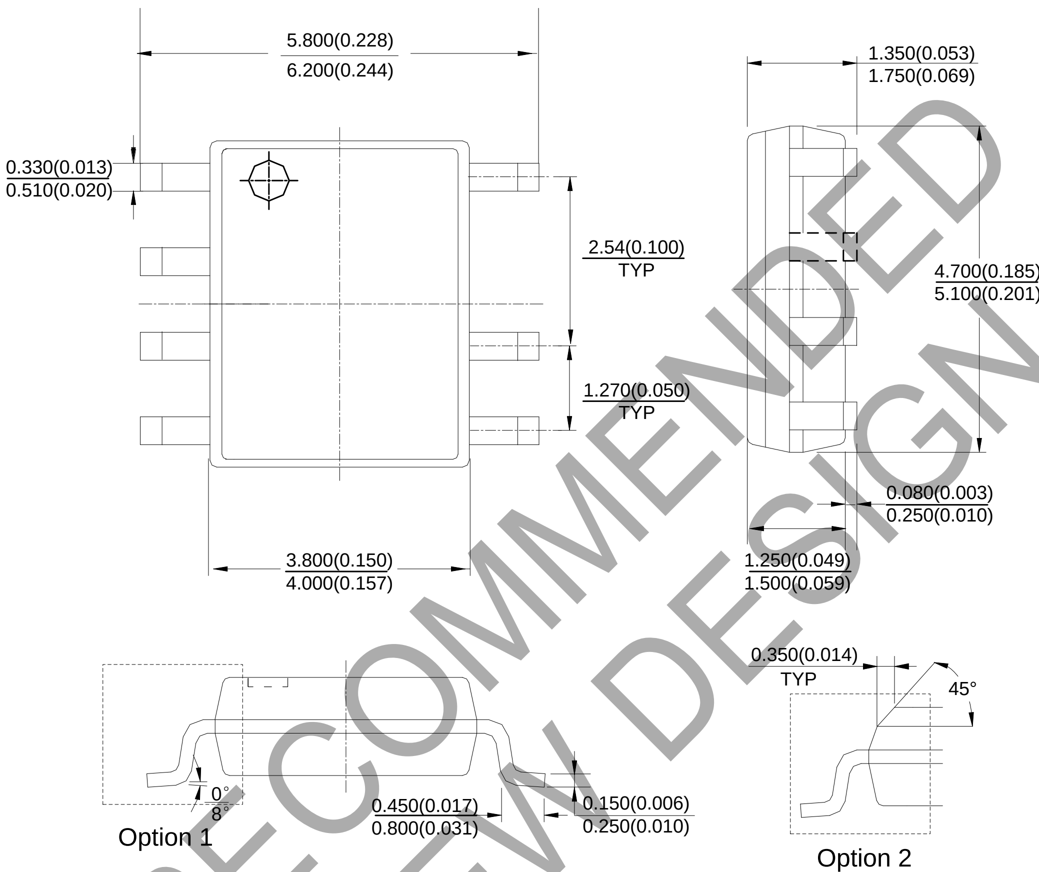
(Top View)



First and Second Lines: Logo and Marking ID
Third Line: Date Code
Y: Year
WW: Work Week of Molding
A: Assembly House Code
XX: 7th and 8th Digits of Batch No.

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

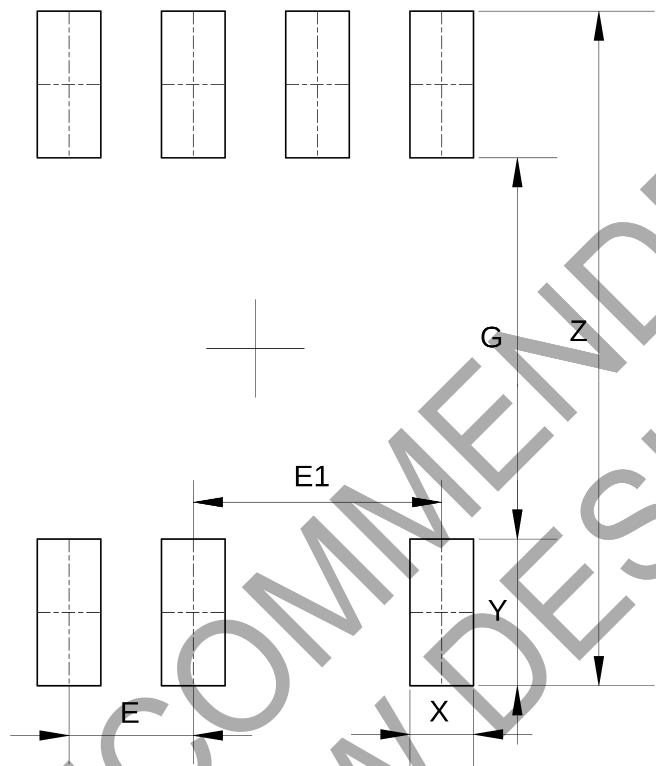
(1) Package Type: SO-7



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

Suggested Pad Layout

(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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