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Description

The AL1788 is a high performance AC/DC Power Factor Correction (PFC) controller targeting at LED lighting applications. Based on Primary Side Regulation (PSR) implementation, AL1788 does not require opto-coupler and any secondary feedback circuit to save overall BOM cost. It operates at Quasi-Resonant (QR) mode where MOSFET is turned on at the valley of the drain voltage, which minimizes switching loss to result in high efficiency.

With either Flyback or Buck topology, AL1788 system supports high efficiency, high Power Factor (PF>0.9) and low Total Harmonic Distortion (THD <20%) for universal input at wide loading range (50% loading to 100% loading)

The AL1788 features low start-up current, low operation current and low standby power. It has rich protection features including Over Voltage Protection (OVP), Short Circuit Protection (SCP), Over Current Protection (OCP) and Over Temperature Protection (OTP).

The AL1788 is available in SOT26 (SC74R) package for the controller.
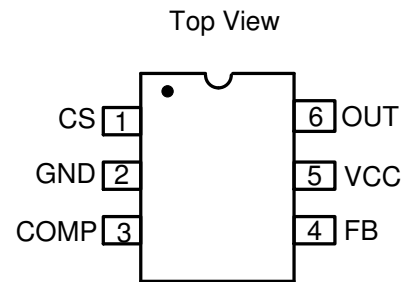
Features

- PSR Implementation Based on Flyback and Buck Topology
- Universal AC Voltage Input for Constant Voltage (CV) Regulation
- Valley Detection for Primary MOSFET Switch to Achieve Low Switching Loss and High Efficiency
- High PF (>0.9) and Low THD (<20%) for Wide Loading Range (50% to Full Loading)
- Internal Protections:
    - Under Voltage Lockout (UVLO)
    - Over Voltage Protection (OVP)
    - Over Current Protection (OCP)
    - Output Short Protection (OSP)
    - Over-Temperature Protection (OTP): Thermal Shutdown and Auto Thermal Recovery
- Low Standby Power
- Low System BOM Cost
- Controller with External MOSFET
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**

Pin Assignments

Top View

CS 1	6 OUT
GND 2	5 VCC
COMP 3	4 FB

Applications

- General LED Lighting
- Smart Connected LED Light Bulbs
- Smart Connected LED Tubes, Panel Lights, Troffers, and Ceiling Lights
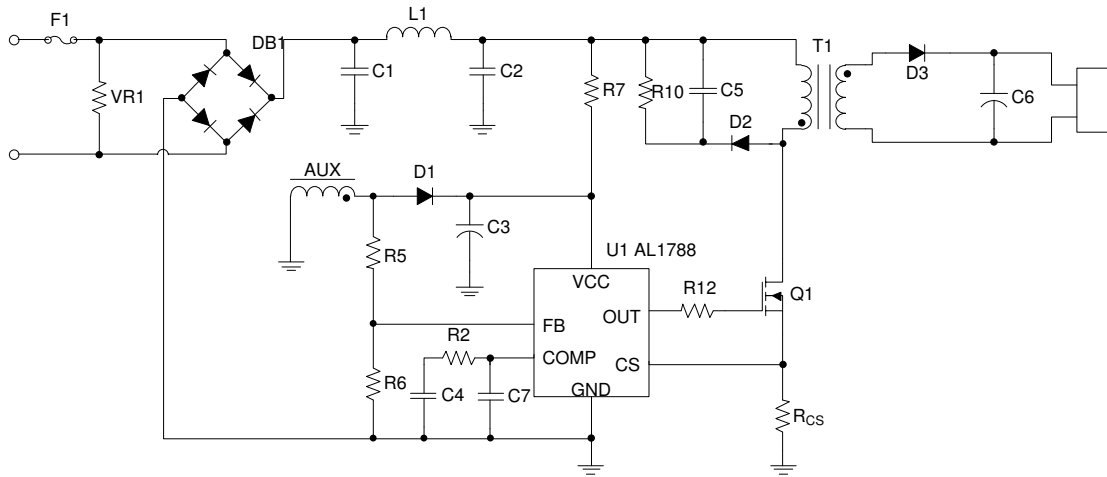- High PFC and low THD power supply

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 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.

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Typical Applications Circuit

Figure 1. AL1788 Controller Flyback Application
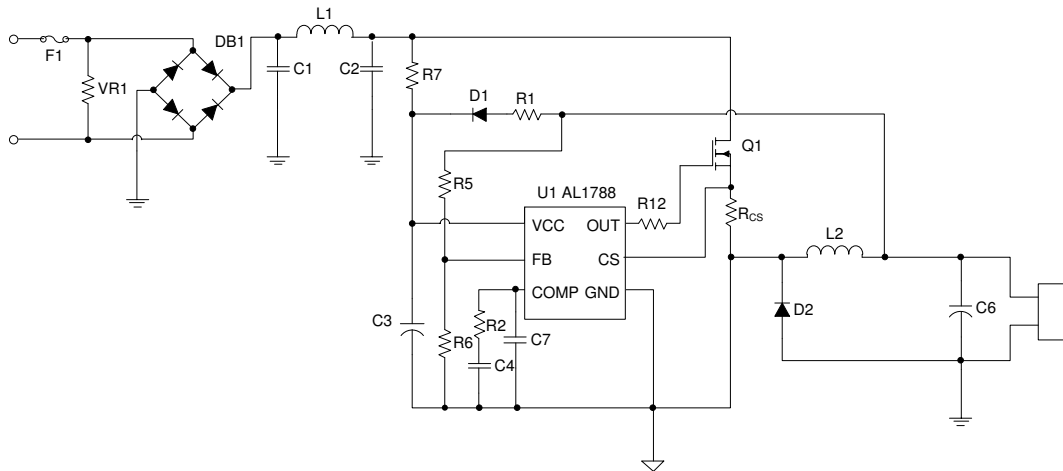
Figure 2. AL1788 Controller Buck Application

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Pin Descriptions

Pin Name	Pin Number	Descriptions
CS	1	Primary Current Sensing
GND	2	Ground
COMP	3	Loop Compensation Pin
FB	4	Voltage Sensing Feedback
VCC	5	Power Supply
OUT	6	Gate Driver Output

Functional Block Diagram
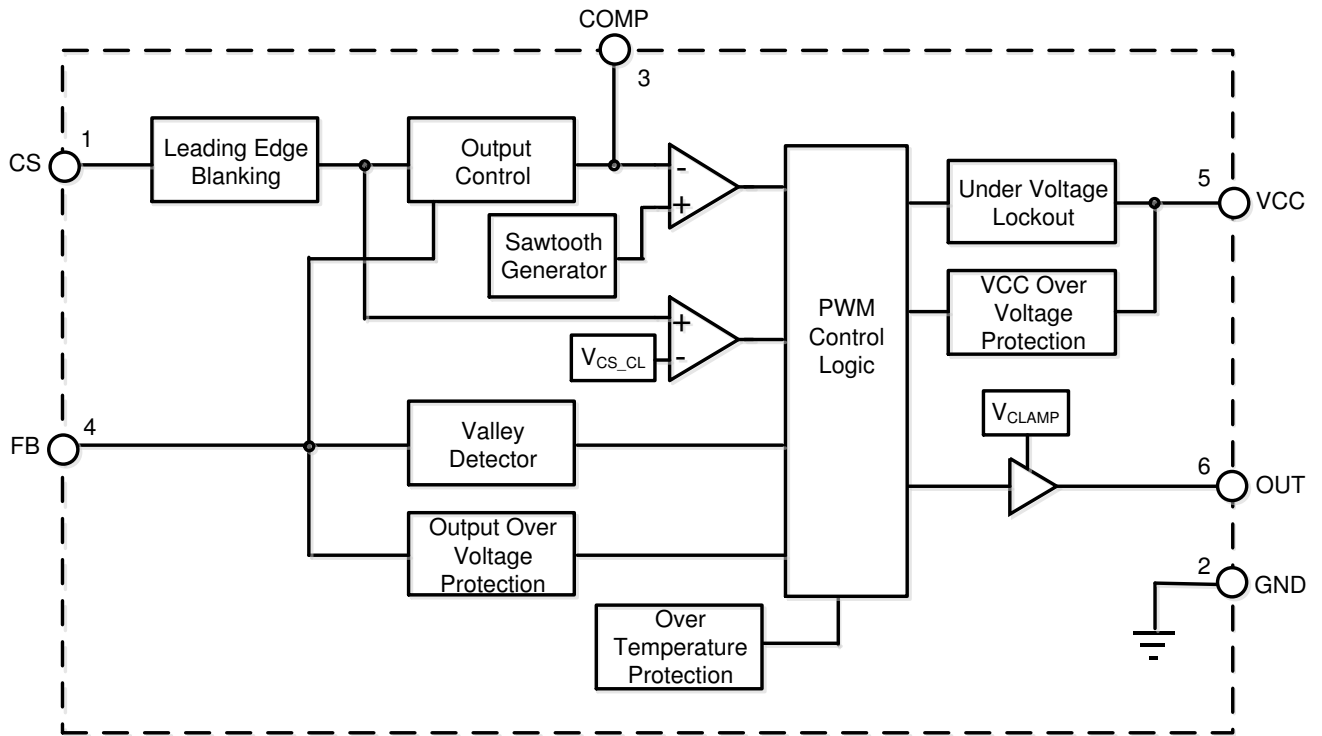
Figure 3. AL1788 Controller Functional Block Diagram

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

Symbol	Parameter		Rating	Unit
V$_{IN}$	Input Voltage		-0.3 to 30	V
V$_{CS}$	Voltage at CS		-0.3 to 7	V
V$_{FB}$	Voltage at FB		-0.3 to 7	V
V$_{COMP}$	Voltage at COMP		-0.3 to 7	V
T$_J$	Junction Temperature		-40 to +150	°C
T$_{ST}$	Storage Temperature Range		-65 to +150	°C
T$_{LEAD}$	Lead Temperature (Soldering, 10 sec)		+260	°C
P$_D$	Power Dissipation (Note 5)		0.7	W
θ$_{JA}$	Thermal Resistance Junction-to-Ambient) (Note 5)		160	°C/W
θ$_{JC}$	Thermal Resistance Junction-to-Case) (Note 5)		36	°C/W
ESD	HBM	Human Body Model ESD Protection	2,000	V
	CDM	Charged Device Model ESD Protection	1,000	V

Notes:
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. All voltages unless otherwise stated and measured with respect to GND.
5. Device mounted on 1"x1" FR-4 MRP substrate PC board, 2oz cooper, with minimum recommended pad layout.

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

Symbol	Parameter	Min	Max	Unit
V$_{CC}$	Input Voltage at VCC	9.0	25	V
T$_J$	Operating Junction Temperature	-40	+125	°C

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Electrical Characteristics (V$_{CC}$=12V@T$_A$ = +25°C, unless otherwise specified.)

| Symbol	Parameter	Condition	Min	Typ	Max	Unit
UVLO Section						
V$_{ST}$	Startup Threshold Voltage	-	-	19	-	V
V$_{OPR\_MIN}$	Minimal Operating Voltage	After Turn On	7.0	-	8.5	V
V$_{CC\_OVP}$	V$_{CC}$ OVP Voltage	-	-	30	-	V
Standby Current Section						
I$_{ST}$	Startup Current	V$_{CC}$ = V$_{ST}$ -0.5V, Before Start-up	-	3	-	µA
I$_{CC\_OPR}$	Operating Current	Static - No Switching (V$_{CS}$=0.6V)	-	500	-	µA
I$_{CC\_OVP}$	Shunt Current in OVP Mode	V$_{CC}$ =15V after V$_{CC}$ >V$_{CC\_OVP}$ Triggered	-	2.5	-	mA
Drive Output Section						
V$_{OUT\_CLAMP}$	Output Clamp Voltage	V$_{CC}$ =18V	12	13.5	15	V
V$_{OL}$	Output Low Level	I$_{GD\_SINK}$=20mA, V$_{CC}$ =12V	-	-	1	V
t$_R$	Output Voltage Rise Time	C$_L$=1nF	-	100	-	ns
t$_F$	Output Voltage Fall Time	C$_L$=1nF	-	50	-	ns
t$_{ON\_MIN}$	Minimum t$_{ON}$	-	-	0.7	-	µs
t$_{ON\_MAX}$	Maximum t$_{ON}$	-	-	17	-	µs
t$_{OFF\_MIN}$	Minimum t$_{OFF}$	-	-	1.2	-	µs
t$_{OFF\_MAX}$	Maximum t$_{OFF}$	-	-	40	-	µs
f$_{MAX}$	Maximum Frequency	-	-	120	-	kHz
CS Section						
V$_{CS\_OCP}$	Primary Current OCP	-	-	0.5	-	V
COMP Section						
GM$_{\_COMP}$	COMP Transconductance	-	-	100	-	µA/V
I$_{MAX\_COMP\_SOURCE}$	COMP Maximum Source Current	V$_{FB}$=0.8V	-	16	-	µA
I$_{MAX\_COMP\_SINK}$	COMP Maximum Sink Current	V$_{FB}$=1.5V	-	16	-	µA
V$_{COMP\_PRO}$	COMP Protection Voltage	-	-	3.5	-	V
FB Section						
V$_{FB\_CV}$	FB CV Threshold	-	1.15	1.2	1.25	V
V$_{FB\_OVP}$	FB OVP Threshold	-	-	1.35	-	V
Over Temperature Protection Section (Note 6)						
T$_{SH}$ (Note 7)	Shutdown Temperature	-	-	+160	-	°C
T$_{HY}$	Temperature Hysteresis	-	-	+30	-	°C

Notes:
6. The over temperature protection parameters are guaranteed by design.
7. When the junction temperature reaches Thermal Shutdown Temperature (T$_{SH}$), AL1788 enters Thermal Shutdown Mode with Hiccup Restart until junction temperature drops below Shutdown Temperature minus Temperature Hysteresis (T$_{SH}$- T$_{HY}$). Once junction temperature drops below (T$_{SH}$- T$_{HY}$), AL1788 restarts as in normal operation.
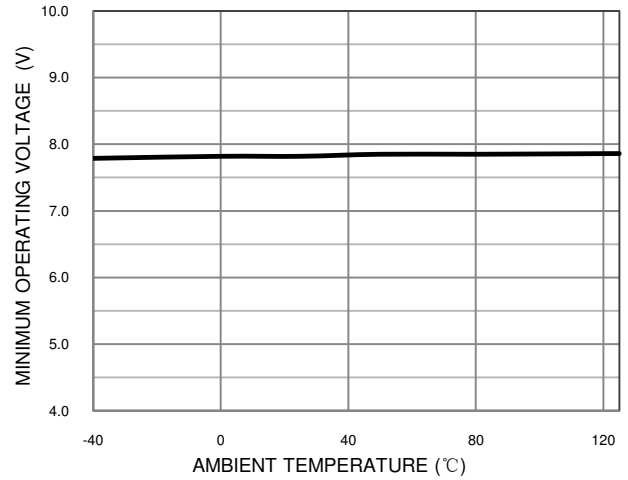
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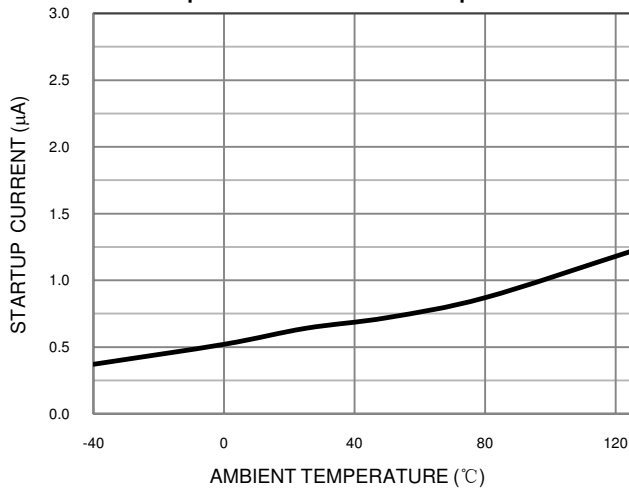## Typical Performance Characteristics (@T_A=+25°C, unless otherwise specified.)

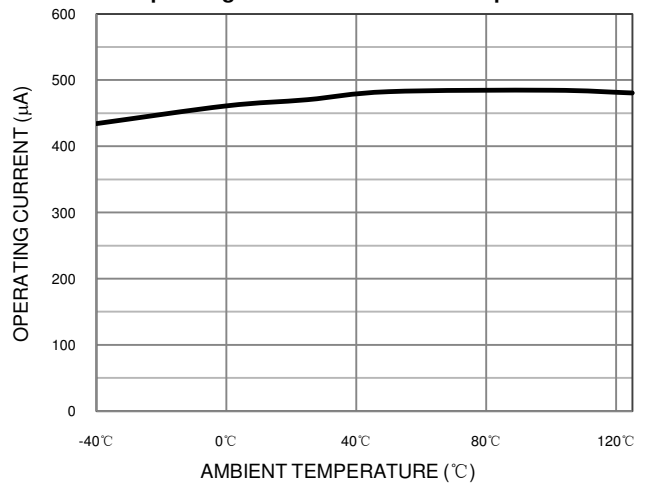**Startup Voltage vs. Ambient Temperature**
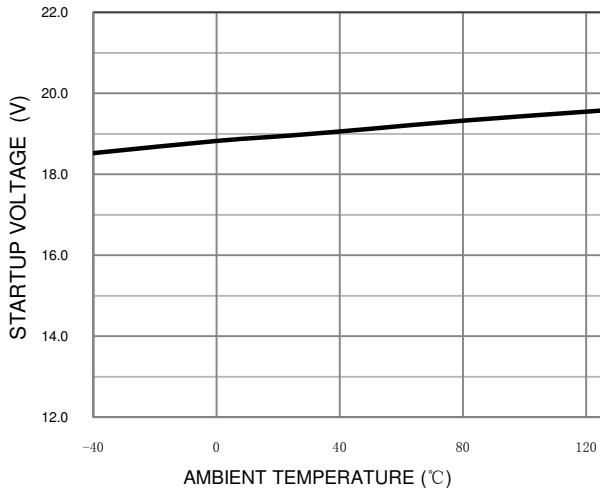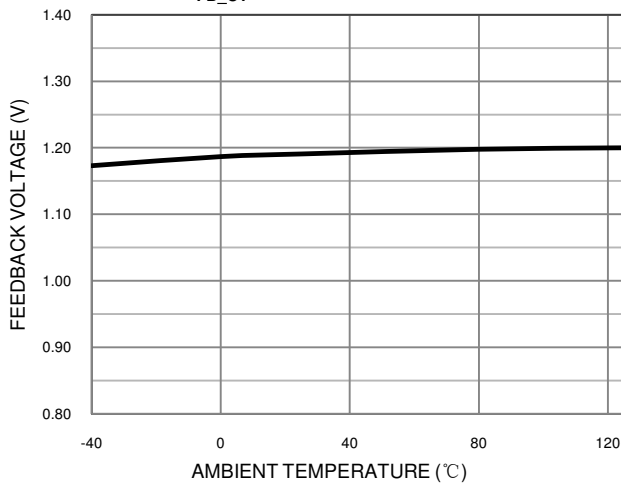
Minimum Operating Voltaqge vs. Ambient Temperature

Startup Current vs. Ambient Temperature

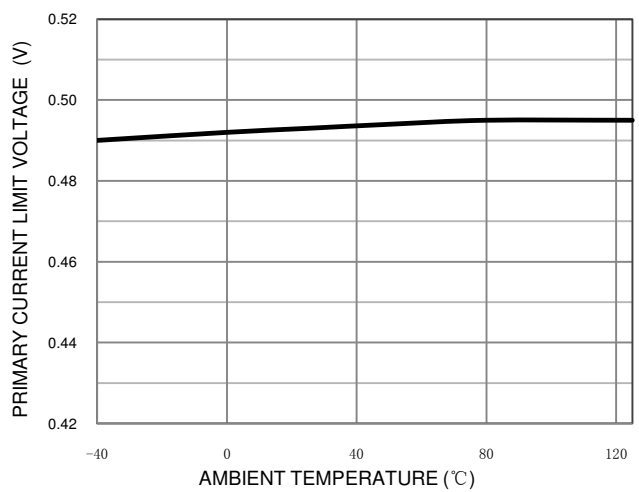**Operating Current vs. Ambient Temperature**

V_{FB_CV} vs. Ambient Temperature

Current Limit Voltage vs. Ambient Temperature

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Functional Description and Application Information

The AL1788 is a high performance AC/DC Power Factor Correction (PFC) constant voltage controller targeting at LED lighting applications. It operates with constant on time to achieve high power factor. And it adopts the Quasi-Resonant (QR) mode valley switching method to reduce switching loss and improve EMI performance.
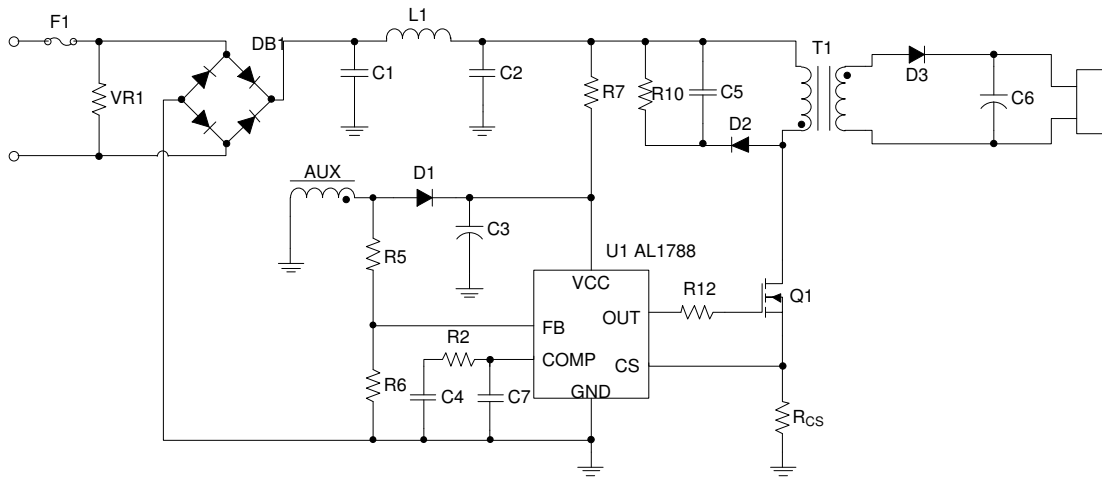

Figure 4. AL1788 Controller Flyback Application

Start-up

After AC supply is powered on, the capacitor C3 across V_{CC} and GND pin will be charged up by BUS voltage through a start-up resistor R7. Once V_{CC} reaches V_{ST}, the internal blocks start to work. V_{CC} will be supplied by V_{BUS} until the auxiliary winding of Flyback transformer could supply enough energy to maintain V_{CC} above V_{OPR_MIN}. If V_{CC} voltage is lower than V_{OPR_MIN}, the switch will be turned off.

To accelerate the start-up process, the COMP voltage is internally pulled up and clamped high, leading to large MOSFET duty cycle and fast climbing up of the output voltage. When the FB voltage reaches the reference voltage V_{FB_CV}, the start-up process ends and the COMP voltage turns to be modulated by the external compensation network.
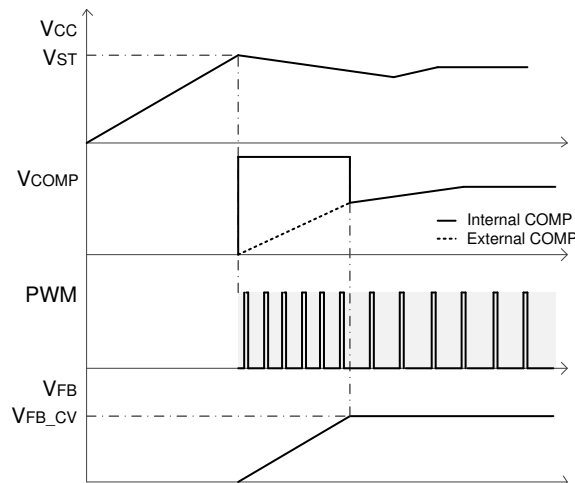

Figure 5. Start Up Waveform

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Functional Description and Application Information (Cont.)

Constant Voltage Operation

As to constant-voltage (CV) operation mode, the AL1788 detects the auxiliary winding voltage at FB pin to regulate the output voltage. The auxiliary winding voltage is coupled with secondary side winding voltage, so the auxiliary winding voltage at D3 conduction time is:

$$V_{AUX} = \frac{N_{AUX}}{N_S} \times (V_O + V_D) \qquad (1)$$

$$V_{FB\_CV} = V_{AUX} \times \left(\frac{R6}{R5 + R6}\right) \quad (2)$$

Where: V_O is the output voltage

V_D is the output rectifier diode forward voltage drop

N_{AUX} is the turns of auxiliary winding

N_S is turns of the secondary winding

V_{FB_CV} is the output voltage setting

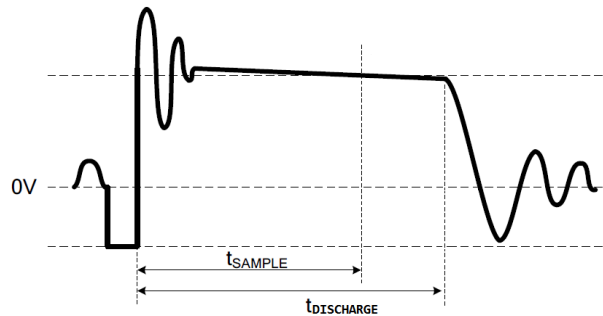R_5 and R_6 that is shown as Figure 4 divide reflected voltage.

Figure 6. Auxiliary Voltage Waveform

Figure 6 shows the voltage waveform of the auxiliary winding. To accurately sample the divided auxiliary winding voltage, the AL1788 FB pin delays a t_{SAMPLE} time before sampling. And $t_{DISCHARGE}$ is the demagnetization time for the transformer.

Load Transition Operation

To obtain good load transition performance, the AL1788 COMP regulation mechanism is optimized. When the load changes from heavy to light causing the FB voltage reaching V_{FB_OVP} (typically 1.35V), the IC will pull down the COMP voltage and enter the max-off-time mode, accelerating the discharge of the output voltage. When the load changes from light to heavy leading to the FB voltage touching 1.0V, the IC will charge up the COMP voltage and raise the MOSFET on time, quickening the increase of the output voltage.
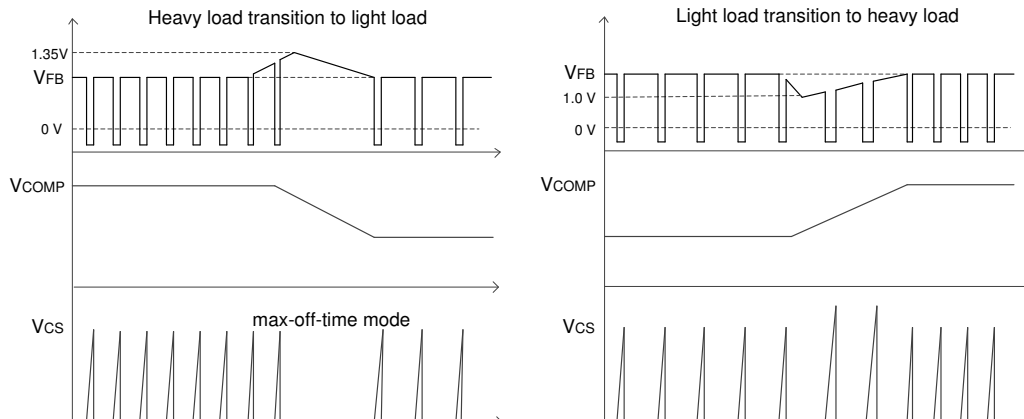

Figure 7. Load Transition Waveform

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Functional Description and Application Information (Cont.)

Protections

1. Output-Open Protection (VCC_OVP; VFB_OVP)

The output voltage is reflected by the voltage on transformer's auxiliary winding. Both FB pin and V_{CC} pin of IC have OVP function.

When there is a rapid line and load transient, the output voltage may exceed the regulated value. If V_{FB} exceeds V_{FB_OVP}, the OVP will be triggered, and then AL1788 increases the OFF time to reduce output voltage.

If V_{CC} exceeds V_{CC_OVP} the OVP will be triggered, the switch will be turned off and V_{CC} will be discharged. Once V_{CC} is below V_{OPR_MIN}, the IC will shut down and power on again by BUS voltage through start up resistor.

2. Output Short Protection (OSP)

When the output is shorted, the output voltage is clamped to zero. The output voltage of the auxiliary winding, which is proportional to the secondary winding, will drop down too. Once Vcc is below V_{OPR_MIN}, the IC will shut down and power on again by the BUS voltage through the startup resistor.

3. Over Current Protection (OCP)

AL1788 has a built-in cycle-by-cycle OCP of primary inductor current. When CS pin voltage reaches the voltage V_{CS_OCP}, the switch will be turned off until the next switch period. The maximum peak current ($I_{PEAK\ (MAX)}$) of the inductor can be calculated as below:

$$I_{PEAK(MAX)} = \frac{V_{CS\_OCP}}{R_{CS}} \quad (3)$$

Where: V_{CS_OCP} means primary current clamp voltage that is 0.5V

R_{CS} is current sense resister shown as Figure 4

4. Over Temperature Protection (OTP)

The AL1788 has built-in OTP function. When the junction temperature goes up to shut down temperature, the OTP will be triggered, the switch will be shutdown. Until the junction temperature falls to the recovery temperature, the AL1788 will be restarted.

Operation Parameters Design

1. Setting the Current Sense Resistor R_{CS}

The current sense resistance can be calculated as following:

$$R_{CS} = \frac{N_{PS} \times V_{CS\_OCP}}{2 \times K_{CS} \times I_{O\_MEAN}} \quad (4)$$

Where: I_{O_MEAN} is the mean output current

$K_{CS} = 1.5$

R_{CS} is current sense resister which is shown as Figure 4

V_{CS_OCP} means primary current clamp voltage that is equal to 0.5V

N_{PS} is the turns ratio of Flyback transformer

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Functional Description and Application Information (Cont.)

2. Setting Transformer Selection (T1)

N_{PS} is limited by the electrical stress of the switch MOSFET, can be calculated by below formula.

$$N_{PS} \leq \frac{V_{MOS\_DS} \times 90\% - \sqrt{2} \times V_{IN\_MAX} - \Delta V_S}{V_O + V_D} \qquad (5)$$

Where: V_{MOS_DS} is the breakdown voltage of the switch MOSFET

V_{IN_MAX} is the maximum rated input voltage

ΔV_S is the overshoot voltage clamped by RCD snubber during OFF time

V_O is the output voltage

V_D is the forward voltage of secondary diode

N_{PS} is the turn ratio of Flyback transformer;

For boundary conduction mode and constant on time method, the peak current of primary inductance can be calculated as below.

$$I_P = \frac{\pi \times I_{O\_MEAN}}{N_{PS} \times \int_0^\pi \sin\theta \times \frac{\sqrt{2} \times V_{IN\_RMS} \times \sin\theta}{\sqrt{2} \times V_{IN\_RMS} \times \sin\theta + N_{PS} \times V_O} d\theta} \qquad (6)$$

Where: V_{IN_RMS} is the rate input voltage

I_P is the primary inductance current

N_{PS} is the turn ratio of Flyback transformer

I_{O_MEAN} is the mean output current

V_O is the output voltage;

The switching frequency is not constant for AL1788 due to QR operation. To set the minimum switching frequency f_{MIN} at the crest of the minimum AC input, primary inductance can be obtained by below formula.

$$L_P = \frac{\sqrt{2} \times V_{IN\_RMS} \times N_{PS} \times V_O}{I_P \times (\sqrt{2} \times V_{IN\_RMS} + N_{PS} \times V_O) \times f_{MIN}} \qquad (7)$$

Where: V_{IN_RMS} is the rate input voltage

I_P is the primary inductance current

N_{PS} is the turn ratio of Flyback transformer

I_{O_MEAN} is the mean output current; V_O is the output voltage

f_{MIN} is the minimum switching frequency at the crest of the minimum AC input

According to the Faraday's Law, the winding number of the inductance can be calculated by:
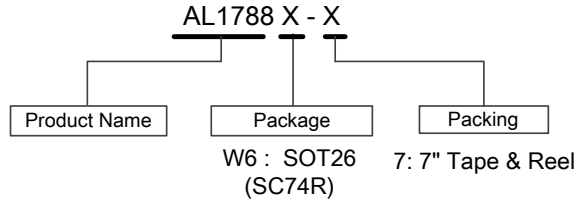
$$N_P = \frac{L_P \times I_P}{A_e \times B_m} \qquad (8)$$

$$N_S = \frac{N_P}{N_{PS}} \qquad (9)$$

Where: A_e is the core effective area

B_m is the maximum magnetic flux density

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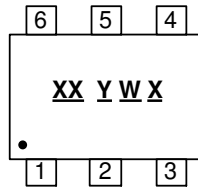Document number: DS39401 Rev. 1 - 2

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Ordering Information

AL1788 X - X

| Product Name | Package | Packing |

W6 : SOT26
(SC74R)

7: 7" Tape & Reel

Part Number	Package Code	Packaging	7" Tape and Reel	
			Quantity	Part Number Suffix
AL1788W6-7	W6	SOT26 (SC74R) (Note 8)	3,000/Tape & Reel	-7

Note :   8. For packaging details, go to our website at https://www.diodes.com/design/support/packaging/diodes-packaging/.

Marking Information

SOT26 (SC74R)

(Top View)

```
6  5  4

  XX Y W X

1  2  3
```

XX : Identification Code
Y : Year 0~9
W : Week : A~Z : 1~26 week;
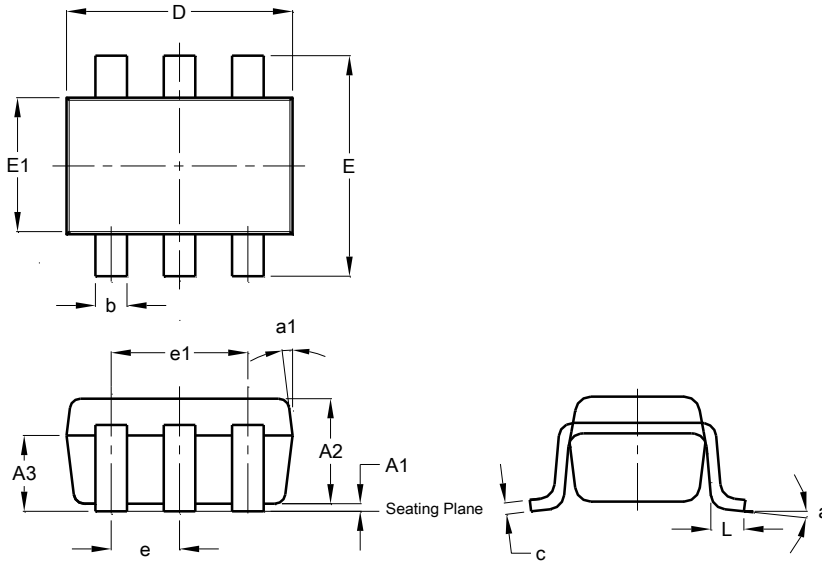   a~z : 27~52 week; z represents
       52 and 53 week
X : Internal Code

Part Number	Package	Identification Code
AL1788W6-7	SOT26 (SC74R)	A8

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Package Outline Dimensions (All dimensions in mm.)

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

SOT26 (SC74R)

SOT26 (SC74R)			
Dim	**Min**	**Max**	**Typ**
A1	0.013	0.10	0.05
A2	1.00	1.30	1.10
A3	0.70	0.80	0.75
b	0.35	0.50	0.38
c	0.10	0.20	0.15
D	2.90	3.10	3.00
e	-	-	0.95
e1	-	-	1.90
E	2.70	3.00	2.80
E1	1.50	1.70	1.60
L	0.35	0.55	0.40
a	-	-	8°
a1	-	-	7°
All Dimensions in mm			

Suggested Pad Layout

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

SOT26 (SC74R)
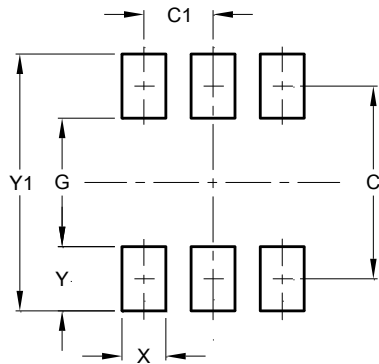
Dimensions	Value (in mm)
C	2.40
C1	0.95
G	1.60
X	0.55
Y	0.80
Y1	3.20

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> 2. support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in significant injury to the user.

B. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or to affect its safety or effectiveness.

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