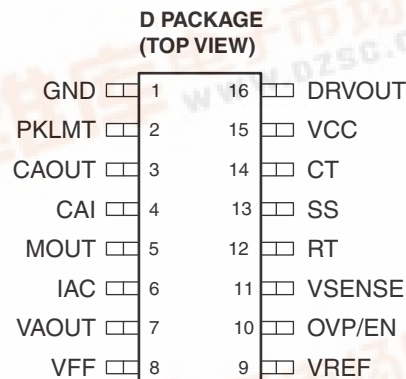


## BiCMOS POWER-FACTOR PREREGULATOR

Check for Samples: [UCC2818A-Q1](#)

### FEATURES

- Qualified for Automotive Applications
- Controls Boost Preregulator to Near-Unity Power Factor
- Limits Line Distortion
- World-Wide Line Operation
- Overvoltage Protection
- Accurate Power Limiting
- Average Current Mode Control
- Improved Noise Immunity
- Improved Feed-Forward Line Regulation
- Leading Edge Modulation
- 150- $\mu$ A Typical Start-Up Current
- Low-Power BiCMOS Operation
- 12-V to 17-V Operation
- Frequency Range of 6 kHz to 220 kHz



### DESCRIPTION/ORDERING INFORMATION

The UCC2818A provides all the functions necessary for active power factor corrected preregulators. The controller achieves near unity power factor by shaping the ac input line current waveform to correspond to that of the ac input line voltage. Average current mode control maintains stable, low distortion sinusoidal line current.

Designed in Texas Instrument's BiCMOS process, the UCC2818A offers new features such as lower start-up current, lower power dissipation, overvoltage protection, a shunt UVLO detect circuitry, a leading-edge modulation technique to reduce ripple current in the bulk capacitor and an improved, low-offset ( $\pm 2$  mV) current amplifier to reduce distortion at light load conditions.

The UCC2818A PFC controller is directly pin-for-pin compatible with the UCC2818 devices. Only the output stage of UCC2818A has been modified to allow use of a smaller external gate drive resistor values. For some power supply designs where an adequately high enough gate drive resistor can not be used, the UCC2818A offers a more robust output stage at the cost of increasing the internal gate resistances. The gate drive of the UCC2818A, however, remains strong at  $\pm 1.2$  A of peak current capability.

UCC2818A is intended for applications with a fixed supply ( $V_{CC}$ ). It is available in the 16-pin D package.

#### ORDERING INFORMATION<sup>(1)</sup>

$T_J = T_A$	PACKAGE <sup>(2)</sup>		ORDERABLE PART NUMBER	TOP-SIDE MARKING
-40°C to 125°C	SOIC – D	Reel of 2500	UCC2818AQDRQ1	2818AQ

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at [www.ti.com](http://www.ti.com).

(2) Package drawings, thermal data, and symbolization are available at [www.ti.com/packaging](http://www.ti.com/packaging).

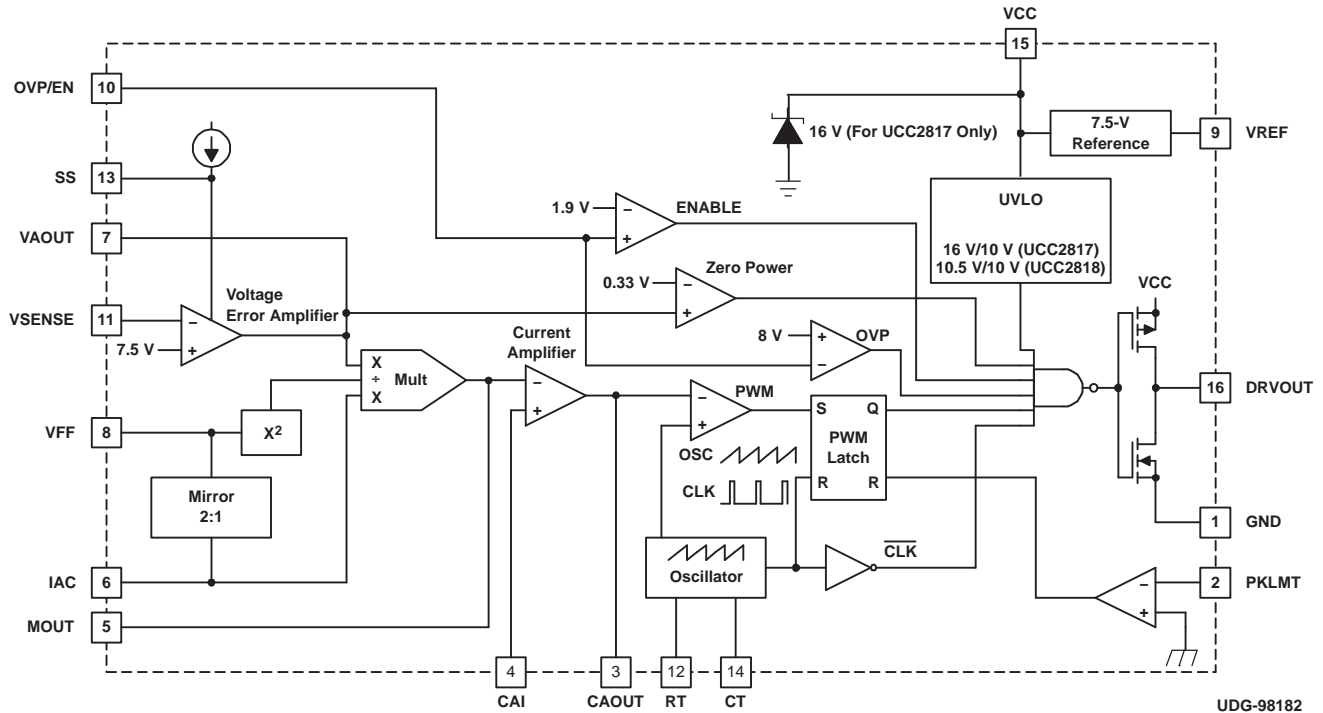


Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of the Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Copyright © 2010, Texas Instruments Incorporated



**BLOCK DIAGRAM****ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>**

over operating free-air temperature range (unless otherwise noted)

		VALUE	UNIT
$V_{CC}$	Supply voltage	18	V
$I_{CC}$	Supply current	20	mA
	Gate drive current, continuous	0.2	A
	Gate drive current	1.2	A
Input voltage	CAI, MOUT, SS	8	V
	PKLMT	5	
	VSENSE, OVP/EN	10	
Input current	RT, IAC, PKLMT	10	mA
	$V_{CC}$ (no switching)	20	
Maximum negative voltage	DRVOUT, PKLMT, MOUT	-0.5	V
Power dissipation		1	W
$\theta_{JA}$	Package thermal impedance <sup>(2)</sup>	73.1	°C/W
$T_J$	Junction temperature	-40 to 150	°C
$T_{stg}$	Storage temperature range	-65 to 150	°C

(1) Stresses beyond 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-rated conditions for extended periods may affect device reliability.

(2) The package thermal impedance is calculated in accordance with JESD 51-5.

**ELECTROSTATIC DISCHARGE RATINGS<sup>(1)</sup>**

PARAMETER	TEST CONDITIONS	MAX	UNIT
ESD Electrostatic discharge rating	Human-body model (HBM)	1000	V

(1) ESD testing performed in accordance with AEC-Q100.

## ELECTRICAL CHARACTERISTICS

 $T_J = T_A = -40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ ,  $V_{CC} = 12\text{ V}$ ,  $R_T = 22\text{ k}\Omega$ ,  $C_T = 270\text{ pF}$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT	
Supply Current						
Supply current, off	$V_{CC} = (V_{CC} \text{ turn-on threshold} - 0.3 \text{ V})$		150	300	$\mu\text{A}$	
Supply current, on	$V_{CC} = 12 \text{ V}$ , No load on DRVOUT	2	4	6	mA	
UVLO						
VCC turn-on threshold		9.7	10.2	10.9	V	
VCC turn-off threshold		9.4	9.7		V	
UVLO hysteresis		0.3	0.5		V	
Voltage Amplifier						
Input voltage		7.369	7.5	7.631	V	
VSENSE bias current	$V_{SENSE} = V_{REF}$ , $V_{AOUT} = 2.5 \text{ V}$		50	200	nA	
Open-loop gain	$V_{AOUT} = 2 \text{ V}$ to $5 \text{ V}$	50	90		dB	
High-level output voltage	$I_L = -150 \mu\text{A}$	5.3	5.5	5.6	V	
Low-level output voltage	$I_L = 150 \mu\text{A}$	0	50	150	mV	
Overvoltage Protection and Enable						
Overvoltage reference		$V_{REF} + 0.48$	$V_{REF} + 0.5$	$V_{REF} + 0.52$	V	
Hysteresis		300	500	600	mV	
Enable threshold		1.7	1.9	2.1	V	
Enable hysteresis		0.1	0.2	0.3	V	
Current Amplifier						
Input offset voltage	$V_{CM} = 0 \text{ V}$ , $V_{CAOUT} = 3 \text{ V}$	$T_A = 25^{\circ}\text{C}$	-3.5	0	3	mV
		$T_A = -40^{\circ}\text{C}$ to $125^{\circ}\text{C}$	-5		5	
Input bias current	$V_{CM} = 0 \text{ V}$ , $V_{CAOUT} = 3 \text{ V}$		-50	-100		nA
Input offset current	$V_{CM} = 0 \text{ V}$ , $V_{CAOUT} = 3 \text{ V}$		25	100		nA
Open-loop gain	$V_{CM} = 0 \text{ V}$ , $V_{CAOUT} = 2 \text{ V}$ to $5 \text{ V}$	90				dB
Common-mode rejection ratio	$V_{CM} = 0 \text{ V}$ to $1.5 \text{ V}$ , $V_{CAOUT} = 3 \text{ V}$	60	80			dB
High-level output voltage	$I_L = -120 \text{ mA}$	5.6	6.5	6.9		V
Low-level output voltage	$I_L = 1 \text{ mA}$	0.1	0.2	0.5		V
Gain bandwidth product <sup>(1)</sup>			2.5			MHz
Voltage Reference						
Input voltage		7.313 to 7.687	7.5	7.631		V
Load regulation	$I_{REF} = 1 \text{ mA}$ to $2 \text{ mA}$	0		10		mV
Line regulation	$V_{CC} = 10.8 \text{ V}$ to $15 \text{ V}$ <sup>(2)</sup>	0		10		mV
Short-circuit current	$V_{REF} = 0 \text{ V}$	-20	-25	-50		mA
Oscillator						
Initial accuracy	$T_A = 25^{\circ}\text{C}$	85	100	115		kHz
Voltage stability	$V_{CC} = 10.8 \text{ V}$ to $15 \text{ V}$	-1		+1		%
Total variation	Over line and temperature	80		120		kHz
Ramp peak voltage		4.5	5	5.5		V
Ramp amplitude voltage (peak to peak)		3.5	4	4.5		V
Peak Current Limit						
PKLMT reference voltage		-15		15		mV
PKLMT propagation delay		150	350	550		ns

(1) Ensured by design, not production tested

(2) Reference variation for  $V_{CC} < 10.8\text{ V}$  is shown in Figure 8.

**ELECTRICAL CHARACTERISTICS (continued)**
 $T_J = T_A = -40^{\circ}\text{C to } 125^{\circ}\text{C}$ ,  $V_{CC} = 12\text{ V}$ ,  $R_T = 22\text{ k}\Omega$ ,  $C_T = 270\text{ pF}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Multiplier						
I <sub>MOUT</sub>	High line, low power output current	I <sub>AC</sub> = 500 μA, V <sub>FF</sub> = 4.7 V, VAOUT = 1.25 V	0	−6	−23	μA
	High-line, high-power output current	I <sub>AC</sub> = 500 μA, V <sub>FF</sub> = 4.7 V, VAOUT = 5 V	−70	−90	−105	
	Low-line, low-power output current	I <sub>AC</sub> = 150 μA, V <sub>FF</sub> = 1.4 V, VAOUT = 1.25 V	−10	−19	−50	
	Low-line, high-power output current	I <sub>AC</sub> = 150 μA, V <sub>FF</sub> = 1.4 V, VAOUT = 5 V	−268	−300	−345	
	IAC limited output current	I <sub>AC</sub> = 150 μA, V <sub>FF</sub> = 1.3 V, VAOUT = 5 V	−250	−300	−400	
Gain constant (K)		I <sub>AC</sub> = 200 μA, V <sub>FF</sub> = 3 V, VAOUT = 2.5 V	0.5	1	1.6	1/V
I <sub>MOUT</sub>	Zero current	I <sub>AC</sub> = 150 μA, V <sub>FF</sub> = 1.4 V, VAOUT = 0.25 V		0	−2	μA
		I <sub>AC</sub> = 500 μA, V <sub>FF</sub> = 4.7 V, VAOUT = 0.25 V		0	−2	
		I <sub>AC</sub> = 500 μA, V <sub>FF</sub> = 4.7 V, VAOUT = 0.5 V		0	−3.5	
		Power limit (I <sub>MOUT</sub> × V <sub>FF</sub> )		I <sub>AC</sub> = 150 μA, V <sub>FF</sub> = 1.4 V, VAOUT = 5 V	−375	
Feed Forward						
VFF output current		I <sub>AC</sub> = 300 μA	−140	−150	−160	μA
Soft Start						
Softstart charge current			−6	−10	−17	μA
Gate Driver						
Pullup resistance		I <sub>O</sub> = −100 mA to −200 mA		9	12	Ω
Pulldown resistance		I <sub>O</sub> = 100 mA		4	10	Ω
Output rise time		C <sub>L</sub> = 1 nF, R <sub>L</sub> = 10 Ω, V <sub>DRVOUT</sub> = 0.7 V to 9 V		25	50	ns
Output fall time		C <sub>L</sub> = 1 nF, R <sub>L</sub> = 10 Ω, V <sub>DRVOUT</sub> = 9 V to 0.7 V		10	50	ns
Maximum duty cycle			93	95	99	%
Minimum controlled duty cycle <sup>(3)</sup>		At 100 kHz			2	%
Zero Power						
Zero-power comparator threshold		Measured on VAOUT	0.2	0.33	0.5	V

(3) Ensured by design, not production tested

## PIN ASSIGNMENTS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
CAI	4	I	Current amplifier noninverting input
CAOUT	3	O	Current amplifier output
CT	24	I	Oscillator timing capacitor
DRVOUT	26	O	Gate drive
GND	2	–	Ground
IAC	6	I	Current proportional to input voltage
MOUT	5	I/O	Multiplier output and current amplifier inverting input
OVP/EN	20	I	Overvoltage/enable
PKLMT	3	I	PFC peak current limit
RT	23	I	Oscillator charging current
SS	24	I	Soft-start
VAOUT	7	O	Voltage amplifier output
VCC	25	I	Positive supply voltage
VFF	8	I	Feed-forward voltage
VSENSE	11	I	Voltage amplifier inverting input
VREF	9	O	Voltage reference output

## Pin Descriptions

**CAI:** Current amplifier noninverting input. Place a resistor between this pin and the GND side of current sense resistor. This input and the inverting input (MOUT) remain functional down to and below GND.

**CAOUT:** Current amplifier output. This is the output of a wide bandwidth operational amplifier that senses line current and commands the PFC pulse-width modulator (PWM) to force the correct duty cycle. Compensation components are placed between CAOUT and MOUT.

**CT:** Oscillator timing capacitor. A capacitor from CT to GND sets the PWM oscillator frequency according to:

$$f \approx \left( \frac{0.6}{RT \times CT} \right)$$

The lead from the oscillator timing capacitor to GND should be as short and direct as possible.

**DRVOUT:** Gate drive. The output drive for the boost switch is a totem-pole MOSFET gate driver on DRVOUT. Use a series gate resistor to prevent interaction between the gate impedance and the output driver that might cause the DRVOUT to overshoot excessively. See characteristic curve (Figure 13) to determine minimum required gate resistor value. Some overshoot of the DRVOUT output is always expected when driving a capacitive load.

**GND:** Ground. All voltages measured with respect to ground. V<sub>CC</sub> and REF should be bypassed directly to GND with a 0.1-μF or larger ceramic capacitor.

**IAC:** Current proportional to input voltage. This input to the analog multiplier is a current proportional to instantaneous line voltage. The multiplier is tailored for very low distortion from this current input (I<sub>IAC</sub>) to multiplier output. The recommended maximum I<sub>IAC</sub> is 500 μA.

**MOUT:** Multiplier output and current amplifier inverting input. The output of the analog multiplier and the inverting input of the current amplifier are connected together at MOUT. As the multiplier output is a current, this is a high-impedance input so the amplifier can be configured as a differential amplifier. This configuration improves noise immunity and allows for the leading-edge modulation operation. The multiplier output current is limited to  $(2 \times I_{IAC})$ . The multiplier output current is given by the equation:

$$I_{MOUT} = \frac{I_{IAC} \times (V_{VAOUT} - 1)}{V_{VFF}^2 \times K}$$

Where:

$K = 1/V$  is the multiplier gain constant

**OVP/EN:** Overvoltage/enable. A window comparator input that disables the output driver if the boost output voltage is a programmed level above the nominal, or disables both the PFC output driver and resets SS if pulled below 1.9 V (typ).

**PKLMT:** PFC peak current limit. The threshold for peak limit is 0 V. Use a resistor divider from the negative side of the current sense resistor to  $V_{REF}$  to level shift this signal to a voltage level defined by the value of the sense resistor and the peak current limit. Peak current limit is reached when PKLMT voltage falls below 0 V.

**RT:** Oscillator charging current. A resistor from RT to GND is used to program oscillator charging current. A resistor between 10 k $\Omega$  and 100 k $\Omega$  is recommended. Nominal voltage on this pin is 3 V.

**SS:** Soft-start.  $V_{SS}$  is discharged for  $V_{VCC}$  low conditions. When enabled, SS charges an external capacitor with a current source. This voltage is used as the voltage error signal during start-up, enabling the PWM duty cycle to increase slowly. In the event of a  $V_{VCC}$  dropout, the OVP/EN is forced below 1.9 V (typ), SS quickly discharges to disable the PWM.

Note: In an open-loop test circuit, grounding the SS pin does not ensure 0% duty cycle. See the application section for details.

**VAOUT:** Voltage amplifier output. This is the output of the operational amplifier that regulates output voltage. The voltage amplifier output is internally limited to approximately 5.5 V to prevent overshoot.

**VCC:** Positive supply voltage. Connect to a stable source of at least 20 mA between 10 V and 17 V for normal operation. Bypass  $V_{CC}$  directly to GND to absorb supply current spikes required to charge external MOSFET gate capacitances. To prevent inadequate gate drive signals, the output devices are inhibited unless  $V_{VCC}$  exceeds the upper under-voltage lockout voltage threshold and remains above the lower threshold.

**VFF:** Feed-forward voltage. The RMS voltage signal generated at this pin by mirroring 1/2 of the  $I_{IAC}$  into a single pole external filter. At low line, the VFF voltage should be 1.4 V.

**VSENSE:** Voltage amplifier inverting input. This is normally connected to a compensation network and to the boost converter output through a divider network.

**VREF:** Voltage reference output.  $V_{REF}$  is the output of an accurate 7.5-V voltage reference. This output is capable of delivering 20 mA to peripheral circuitry and is internally short-circuit current limited. VREF is disabled and remains at 0 V when  $V_{VCC}$  is below the UVLO threshold. Bypass VREF to GND with a 0.1- $\mu$ F or larger ceramic capacitor for best stability. See [Figure 8](#) and [Figure 9](#) for VREF line and load regulation characteristics.

## APPLICATION INFORMATION

The UCC2818A is a BiCMOS average current mode boost controller for high-power-factor high-efficiency preregulator power supplies. Figure 1 shows the UCC2818A in a 250-W PFC preregulator circuit. Off-line switching power converters normally have an input current that is not sinusoidal. The input current waveform has a high harmonic content because current is drawn in pulses at the peaks of the input voltage waveform. An active power-factor correction circuit programs the input current to follow the line voltage, forcing the converter to look like a resistive load to the line. A resistive load has 0° phase displacement between the current and voltage waveforms. Power factor (PF) can be defined in terms of the phase angle between two sinusoidal waveforms of the same frequency:

$$PF = \cos \theta$$

(1)

Therefore, a purely resistive load would have a power factor of 1. In practice, power factors of 0.999 with total harmonic distortion (THD) of less than 3% are possible with a well-designed circuit. Following guidelines are provided to design PFC boost converters using the UCC2818A.

NOTE: Schottky diodes, D5 and D6, are required to protect the PFC controller from electrical over stress during system power up.

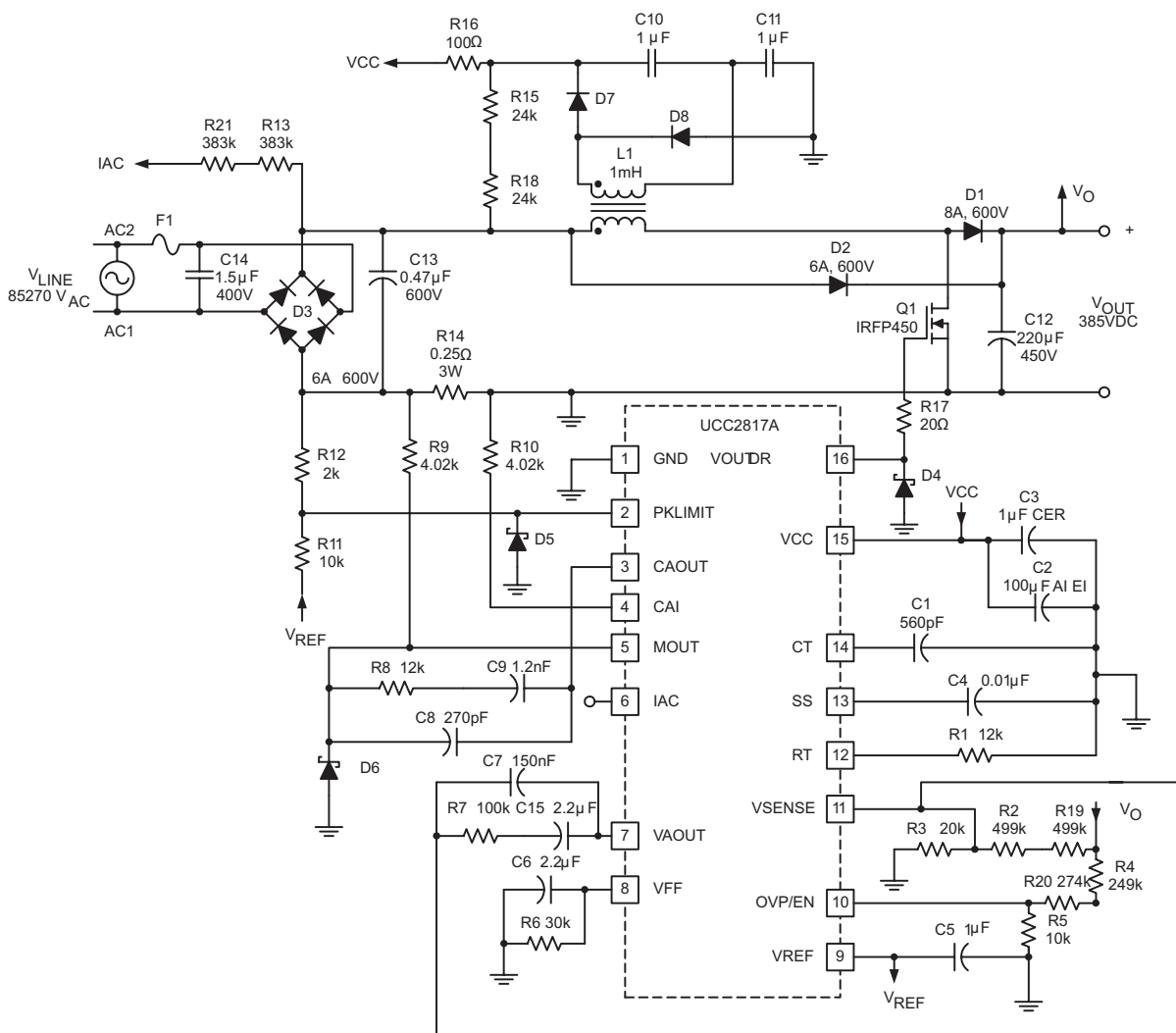


Figure 1. Typical Application Circuit

## Power Stage

**L<sub>BOOST</sub>:** The boost inductor value is determined by [Equation 2](#):

$$L_{\text{BOOST}} = \frac{(V_{\text{IN(min)}} \times D)}{(\Delta I \times f_s)} \quad (2)$$

Where:

D = Duty cycle

ΔI = Inductor ripple current

f<sub>s</sub> = Switching frequency

For the example circuit, a switching frequency of 100 kHz, a ripple current of 875 mA, a maximum duty cycle of 0.688, and a minimum input voltage of 85 V<sub>RMS</sub> produces a boost inductor value of about 1 mH. The values used in this equation are at the peak of low line, where the inductor current and its ripple are at a maximum.

**C<sub>OUT</sub>:** Two main criteria, the capacitance and the voltage rating, dictate the selection of the output capacitor. The value of capacitance is determined by the holdup time required for supporting the load after input ac voltage is removed. Holdup is the amount of time that the output stays in regulation after the input has been removed. For this circuit, the desired holdup time is approximately 16 ms. Expressing the capacitor value in terms of output power, output voltage, and holdup time gives [Equation 3](#):

$$C_{\text{OUT}} = \frac{(2 \times P_{\text{OUT}} \times \Delta t)}{(V_{\text{OUT}}^2 - V_{\text{OUT(min)}}^2)} \quad (3)$$

In practice, the calculated minimum capacitor value may be inadequate because output ripple voltage specifications limit the amount of allowable output capacitor ESR. Attaining a sufficiently low value of ESR often necessitates the use of a much larger capacitor value than calculated. The amount of output capacitor ESR allowed can be determined by dividing the maximum specified output ripple voltage by the inductor ripple current. In this design holdup time was the dominant determining factor and a 220-μF, 450-V capacitor was chosen for the output voltage level of 385 VDC at 250 W.

**Power switch selection:** As in any power-supply design, tradeoffs between performance, cost, and size have to be made. When selecting a power switch, it can be useful to calculate the total power dissipation in the switch for several different devices at the switching frequencies being considered for the converter. Total power dissipation in the switch is the sum of switching loss and conduction loss. Switching losses are the combination of the gate charge loss, C<sub>OSS</sub> loss, and turnon and turnoff losses:

$$P_{\text{GATE}} = Q_{\text{GATE}} \times V_{\text{GATE}} \times f_s$$

$$P_{\text{COSS}} = \frac{1}{2} \times C_{\text{OSS}} \times V_{\text{OFF}}^2 \times f_s \quad (4)$$

$$P_{\text{ON}} + P_{\text{OFF}} = \frac{1}{2} \times V_{\text{OFF}} \times I_L \times (t_{\text{ON}} + t_{\text{OFF}}) \times f_s \quad (5)$$



Where:

$Q_{GATE}$  = Total gate charge

$V_{GATE}$  = Gate drive voltage

$f_S$  = Clock frequency

$C_{OSS}$  = Drain source capacitance of the MOSFET

$I_L$  = Peak inductor current

$t_{ON}$  and  $t_{OFF}$  = Switching times (estimated using device parameters  $R_{GATE}$ ,  $Q_{GD}$  and  $V_{TH}$ )

$V_{OFF}$  = Voltage across the switch during the off time (in this case  $V_{OFF} = V_{OUT}$ )

Conduction loss is calculated as the product of the  $R_{DS(on)}$  of the switch (at the worst-case junction temperature) and the square of RMS current:

$$P_{COND} = R_{DS(on)} \times K \times I_{RMS}^2 \quad (6)$$

Where:

$K$  = temperature factor found in the manufacturer's  $R_{DS(on)}$  vs junction temperature curves

Calculating these losses and plotting against frequency gives a curve that enables the designer to determine which manufacturer's device has the best performance at the desired switching frequency, or which switching frequency has the least total loss for a particular power switch. For this design example, an IRFP450 HEXFET™ from International Rectifier was chosen because of its low  $R_{DS(on)}$  and its  $V_{DSS}$  rating. The IRFP450  $R_{DS(on)}$  of 0.4  $\Omega$  and the maximum  $V_{DSS}$  of 500 V made it an ideal choice. A review of this procedure can be found in the Unitrode™ Power-Supply Design Seminar SEM1200, Topic 6, Design Review: 140 W (Multiple Output High Density DC/DC Converter).

## Soft Start

The soft-start circuitry is used to prevent overshoot of the output voltage during start up. This is accomplished by slowly bringing up the voltage amplifier output ( $V_{VAOUT}$ ), which allows for the PWM duty cycle to slowly increase. Use [Equation 7](#) to select a capacitor for the soft-start pin.

In this example,  $t_{DELAY} = 7.5$  ms, which yields a  $C_{SS}$  of 10 nF.

$$C_{SS} = \frac{10 \mu A \times t_{DELAY}}{7.5 V} \quad (7)$$

In an open-loop test circuit, shorting the soft-start pin to ground does not ensure 0% duty cycle. This is due to the current amplifiers input offset voltage, which could force the current amplifier output high or low depending on the polarity of the offset voltage. However, in the typical application, there is sufficient amount of inrush and bias current to overcome the current amplifier offset voltage.

## Multiplier

The output of the multiplier of the UCC2818A is a signal representing the desired input line current. It is an input to the current amplifier, which programs the current loop to control the input current to give high power factor operation. As such, the proper functioning of the multiplier is key to the success of the design. The inputs to the multiplier are VAOUT, the voltage amplifier error signal,  $I_{IAC}$ , a representation of the input rectified ac line voltage, and an input voltage feed-forward signal,  $V_{VFF}$ . The output of the multiplier,  $I_{MOUT}$ , can be expressed as:

$$I_{MOUT} = I_{IAC} \times \frac{(V_{VAOUT} - 1)}{K \times V_{VFF}^2} \quad (8)$$

Where:

$K$  = Constant typically equal to 1/V

The Electrical Characteristics table covers all the required operating conditions for designing with the multiplier. Additionally, curves in [Figure 10](#), [Figure 11](#), and [Figure 12](#) provide typical multiplier characteristics over its entire operating range.

The  $I_{IAC}$  signal is obtained through a high-value resistor connected between the rectified ac line and the IAC pin of the UCC2818A. This resistor  $R_{IAC}$  is sized to give the maximum  $I_{IAC}$  current at high line. For the UCC2818A, the maximum  $I_{IAC}$  current is about 500  $\mu$ A. A higher current than this can drive the multiplier out of its linear range. A smaller current level is functional, but noise can become an issue, especially at low input line. Assuming a universal line operation of 85  $V_{RMS}$  to 265  $V_{RMS}$  gives a  $R_{IAC}$  value of 750 k $\Omega$ , because of voltage-rating constraints of a standard 1/4-W resistor, use a combination of lower-value resistors connected in series to give the required resistance and distribute the high voltage amongst the resistors. For this design example, two 383-k $\Omega$  resistors were used in series.

The current into the IAC pin is mirrored internally to the VFF pin where it is filtered to produce a voltage feed-forward signal proportional to line voltage. The VFF voltage is used to keep the power-stage gain constant, and to provide input power limiting. See the TI application report [SLUA196](#) for detailed explanation on how the VFF pin provides power limiting. The following equation can be used to size the VFF resistor  $R_{VFF}$  to provide power limiting where  $V_{IN(min)}$  is the minimum RMS input voltage, and  $R_{IAC}$  is the total resistance connected between the IAC pin and the rectified line voltage.

$$R_{VFF} = \frac{1.4 V}{\frac{V_{IN(min)} \times 0.9}{2 \times R_{IAC}}} \approx 30 \text{ k}\Omega \quad (9)$$

Because the VFF voltage is generated from line voltage, it needs to be adequately filtered to reduce THD caused by the 120-Hz rectified line voltage. Refer to Unitrode Power-Supply Design Seminar, SEM-700 Topic 7 (*Optimizing the Design of a High Power Factor Preregulator*). A single pole filter was adequate for this design. Assuming that an allocation of 1.5% total harmonic distortion from this input is allowed, and that the second harmonic ripple is 66% of the input ac line voltage, the amount of attenuation required by this filter is:

$$\frac{1.5 \%}{66 \%} = 0.022 \quad (10)$$

A ripple frequency ( $f_R$ ) of 120 Hz and an attenuation of 0.022 requires that the pole of the filter ( $f_P$ ) be placed at:

$$f_P = 120 \text{ Hz} \times 0.022 \approx 2.6 \text{ Hz} \quad (11)$$

The following equation can be used to select the filter capacitor  $C_{VFF}$  required to produce the desired low-pass filter.

$$C_{VFF} = \frac{1}{2 \times \pi \times R_{VFF} \times f_P} \approx 2.2 \mu\text{F} \quad (12)$$

The  $R_{MOUT}$  resistor is sized to match the maximum current through the sense resistor to the maximum multiplier current. The maximum multiplier current, or  $I_{MOUT(max)}$ , can be determined by the equation:

$$I_{MOUT(max)} = \frac{I_{IAC@V_{IN(min)}} \times (V_{VAOUT(max)} - 1 \text{ V})}{K \times V_{VFF(min)}^2} \quad (13)$$

$I_{MOUT(max)}$  for this design is approximately 315  $\mu$ A. The  $R_{MOUT}$  resistor can then be determined by:

$$R_{MOUT} = \frac{V_{RSENSE}}{I_{MOUT(max)}} \quad (14)$$

In this example,  $V_{RSENSE}$  was selected to give a dynamic operating range of 1.25 V, which gives an  $R_{MOUT}$  of roughly 3.91 k $\Omega$ .

## Voltage Loop

The second major source of harmonic distortion is the ripple on the output capacitor at the second harmonic of the line frequency. This ripple is fed back through the error amplifier and appears as a third harmonic ripple at the input to the multiplier. The voltage loop must be compensated not just for stability but also to attenuate the contribution of this ripple to the total harmonic distortion of the system (see Figure 2).

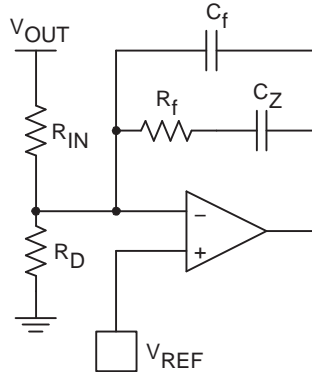


Figure 2. Voltage Amplifier Configuration

The gain of the voltage amplifier,  $G_{VA}$ , can be determined by first calculating the amount of ripple present on the output capacitor. The peak value of the second harmonic voltage is given by the equation:

$$V_{OPK} = \frac{P_{IN}}{2\pi \times f_R \times C_{OUT} \times V_{OUT}} \quad (15)$$

In this example,  $V_{OPK} = 3.91$  V. Assuming an allowable contribution of 0.75% (1.5% peak to peak) from the voltage loop to the THD budget, set the gain equal to:

$$G_{VA} = \frac{(\Delta V_{VAOUT})^{0.015}}{2 \times V_{OPK}} \quad (16)$$

Where:

$\Delta V_{VAOUT}$  = Effective output voltage range of the error amplifier (5 V for the UCC2818A).

The network needed to realize this filter is comprised of an input resistor,  $R_{IN}$ , and feedback components  $C_f$ ,  $C_Z$ , and  $R_f$ . The value of  $R_{IN}$  is already determined because of its function as one-half of a resistor divider from  $V_{OUT}$  feeding back to the voltage amplifier for output voltage regulation. In this case, the value was chosen to be 1 MΩ. This high value was chosen to reduce power dissipation in the resistor. In practice, the resistor value would be realized by the use of two 500-kΩ resistors in series because of the voltage rating constraints of most standard 1/4-W resistors. The value of  $C_f$  is determined by the equation:

$$C_f = \frac{1}{2\pi \times f_R \times G_{VA} \times R_{IN}} \quad (17)$$

In this example,  $C_f = 150$  nF. Resistor  $R_f$  sets the dc gain of the error amplifier and, thus, determines the frequency of the pole of the error amplifier. The location of the pole can be found by setting the gain of the loop equation to one and solving for the crossover frequency. The frequency, expressed in terms of input power, can be calculated by the equation:

$$f_{VI}^2 = \frac{P_{IN}}{(2\pi)^2 \times \Delta V_{VAOUT} \times V_{OUT} \times R_{IN} \times C_{OUT} \times C_f} \quad (18)$$

$f_{VI}$  for this converter is 10 Hz. A derivation of this equation can be found in the Unitrode Power Supply Design Seminar SEM1000, Topic 1 (A 250-kHz, 500-W Power Factor Correction Circuit Employing Zero Voltage Transitions).

Solving for  $R_f$  becomes:

$$R_f = \frac{1}{2\pi \times f_{VI} \times C_f} \quad (19)$$

or  $R_f = 100 \text{ k}\Omega$ .

Due to the low output impedance of the voltage amplifier, capacitor  $C_Z$  was added in series with  $R_f$  to reduce loading on the voltage divider. To ensure the voltage loop crossed over at  $f_{VI}$ ,  $C_Z$  was selected to add a zero at 1/10th of  $f_{VI}$ . For this design, a 2.2- $\mu\text{F}$  capacitor was chosen for  $C_Z$ . The following equation can be used to calculate  $C_Z$ :

$$C_Z = \frac{1}{2 \times \pi \times \frac{f_{VI}}{10} \times R_f} \quad (20)$$

### Current Loop

The gain of the power stage is:

$$G_{ID(s)} = \frac{V_{OUT} \times R_{SENSE}}{s \times L_{BOOST} \times V_P} \quad (21)$$

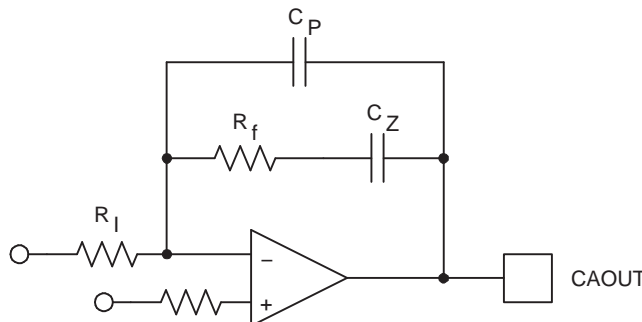
$R_{SENSE}$  has been chosen to give the desired differential voltage for the current sense amplifier at the desired current limit point. In this example, a current limit of 4 A and a reasonable differential voltage to the current amplifier of 1 V gives a  $R_{SENSE}$  value of 0.25  $\Omega$ .  $V_P$  in this equation is the voltage swing of the oscillator ramp, 4 V for the UCC2818A. Setting the crossover frequency of the system to 1/10th of the switching frequency, or 10 kHz, requires a power-stage gain at that frequency of 0.383. In order for the system to have a gain of 1 at the crossover frequency, the current amplifier must have a gain of  $1/G_{ID}$  at that frequency.  $G_{EA}$ , the current amplifier gain is then:

$$G_{EA} = \frac{1}{G_{ID}} = \frac{1}{0.383} = 2.611 \quad (22)$$

$R_I$  is the  $R_{MOUT}$  resistor, previously calculated to be 3.9 k $\Omega$  (see [Figure 3](#)). The gain of the current amplifier is  $R_f/R_I$ , so multiplying  $R_I$  by  $G_{EA}$  gives the value of  $R_f$ , in this case approximately 12 k $\Omega$ . Setting a zero at the crossover frequency and a pole at one-half the switching frequency completes the current loop compensation.

$$C_Z = \frac{1}{2 \times \pi \times R_f \times f_C} \quad (23)$$

$$C_P = \frac{1}{2 \times \pi \times R_f \times \frac{f_S}{2}} \quad (24)$$



**Figure 3. Current Loop Compensation**

The UCC2818A current amplifier has the input from the multiplier applied to the inverting input. This change in architecture from previous TI PFC controllers improves noise immunity in the current amplifier. It also adds a

phase inversion into the control loop. The UCC2818A takes advantage of this phase inversion to implement leading-edge duty cycle modulation. Synchronizing a boost PFC controller to a downstream dc-to-dc controller reduces the ripple current seen by the bulk capacitor between stages, reducing capacitor size and cost and reducing EMI. This is explained in greater detail in a following section. The UCC2818A current amplifier configuration is shown in [Figure 4](#).

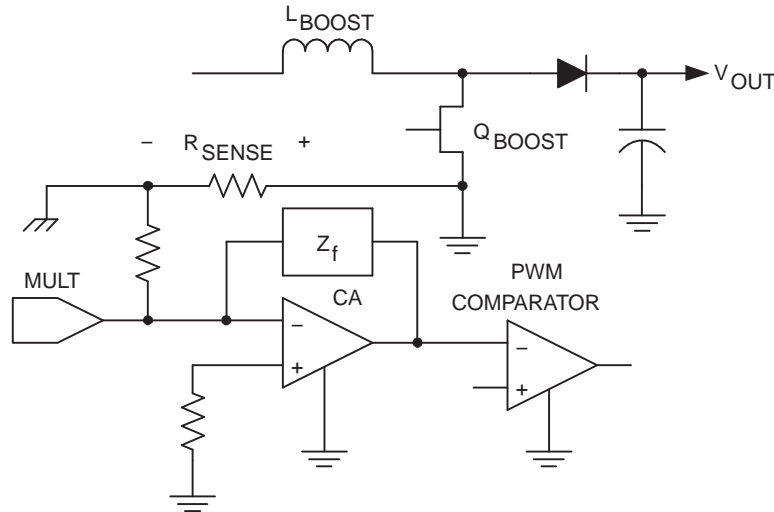


Figure 4. Current Amplifier Configuration

## Start Up

The UCC2818 version of the device is intended to have V<sub>CC</sub> connected to a 12-V supply voltage. The UCC2817A has an internal shunt regulator enabling the device to be powered from bootstrap circuitry, as shown in the typical application circuit of [Figure 1](#). The current drawn by the UCC2818A during undervoltage lockout, or start-up current, is typically 150 μA. Once V<sub>CC</sub> is above the UVLO threshold, the device is enabled and draws 4 mA typically. A resistor connected between the rectified ac line voltage and the V<sub>CC</sub> pin provides current to the shunt regulator during power up. Once the circuit is operational, the bootstrap winding of the inductor provides the V<sub>CC</sub> voltage. Sizing of the start-up resistor is determined by the start-up time requirement of the system design.

$$I_C = C \frac{\Delta V}{\Delta t} \quad (25)$$

$$R = \frac{V_{RMS} \times 0.9}{I_C} \quad (26)$$

Where:

- I<sub>C</sub> = Charge current
- C = Total capacitance at the V<sub>CC</sub> pin
- ΔV = UVLO threshold
- Δt = Allowed start-up time

Assuming a 1-s allowed start-up time, a 16-V UVLO threshold, and a total V<sub>CC</sub> capacitance of 100 μF, a resistor value of 51 kΩ is required at a low line input voltage of 85 V<sub>RMS</sub>. The IC start-up current is sufficiently small as to be ignored in sizing the start-up resistor.

## Capacitor Ripple Reduction

For a power system where the PFC boost converter is followed by a dc-to-dc converter stage, there are benefits to synchronizing the two converters. In addition to the usual advantages, such as noise reduction and stability, proper synchronization can significantly reduce the ripple currents in the boost circuit output capacitor. [Figure 5](#) shows the impact of proper synchronization by showing a PFC boost converter together with the simplified input stage of a forward converter. The capacitor current during a single switching cycle depends on the status of the

switches Q1 and Q2 and is shown in Figure 6. With a synchronization scheme that maintains conventional trailing-edge modulation on both converters, the capacitor current ripple is highest. The greatest ripple current cancellation is attained when the overlap of Q1 offtime and Q2 ontime is maximized. One method of achieving this is to synchronize the turnon of the boost diode (D1) with the turnon of Q2. This approach implies that the boost converter leading edge is pulse width modulated, while the forward converter is modulated with traditional trailing-edge PWM. The UCC2818A is designed as a leading edge modulator with easy synchronization to the downstream converter to facilitate this advantage. Table 1 compares the  $I_{CB(rms)}$  for D1/Q2 synchronization as offered by UCC2818A, versus the  $I_{CB(rms)}$  for the other extreme of synchronizing the turnon of Q1 and Q2 for a 200-W power system with a  $V_{BST}$  of 385 V.

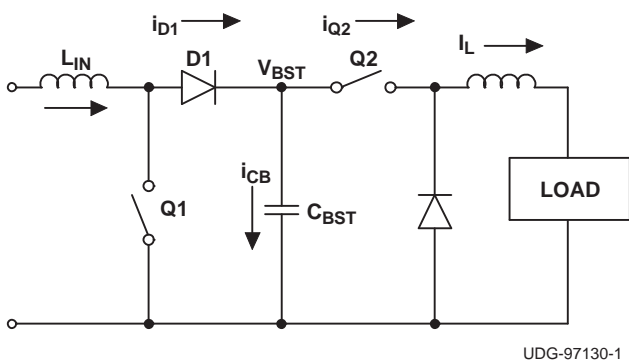


Figure 5. Simplified Representation of a Two-Stage PFC Power Supply

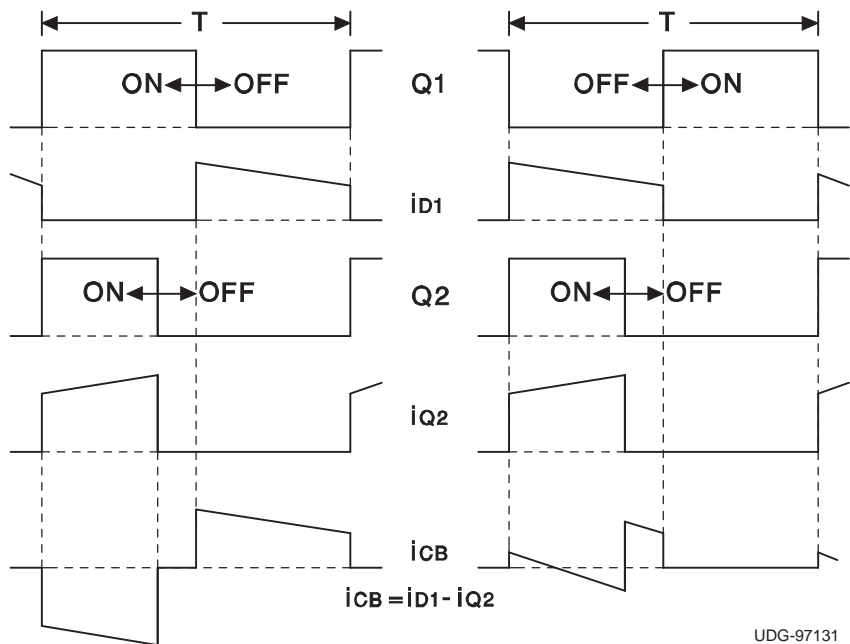


Figure 6. Timing Waveforms for Synchronization Scheme

Table 1. Effects of Synchronization on Boost Capacitor Current

	$V_{IN} = 85 \text{ V}$		$V_{IN} = 120 \text{ V}$		$V_{IN} = 240 \text{ V}$	
	Q1/Q2	D1/Q2	Q1/Q2	D1/Q2	Q1/Q2	D1/Q2
0.35	1.491 A	0.835 A	1.341 A	0.663 A	1.024 A	0.731 A
0.45	1.432 A	0.93 A	1.276 A	0.664 A	0.897 A	0.614 A

Table 1 shows that the boost capacitor ripple current can be reduced by about 50% at nominal line and about 30% at high line with the synchronization scheme facilitated by the UCC2818A. Figure 7 shows the suggested technique for synchronizing the UCC2818A to the downstream converter. With this technique, maximum ripple reduction as shown in Figure 6 is achievable. The output capacitance value can be significantly reduced if its choice is dictated by ripple current or the capacitor life can be increased as a result. In cost-sensitive designs where holdup time is not critical, this is a significant advantage.

An alternative method of synchronization to achieve the same ripple reduction is possible. In this method, the turnon of Q1 is synchronized to the turnoff of Q2. While this method yields almost identical ripple reduction and maintains trailing edge modulation on both converters, the synchronization is much more difficult to achieve and the circuit can become susceptible to noise as the synchronizing edge itself is being modulated.

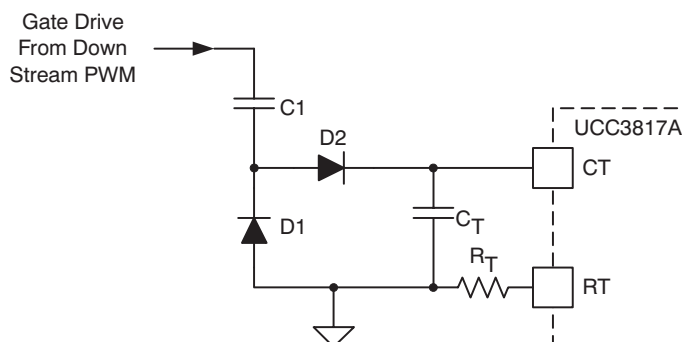


Figure 7. Synchronizing to a Downstream Converter

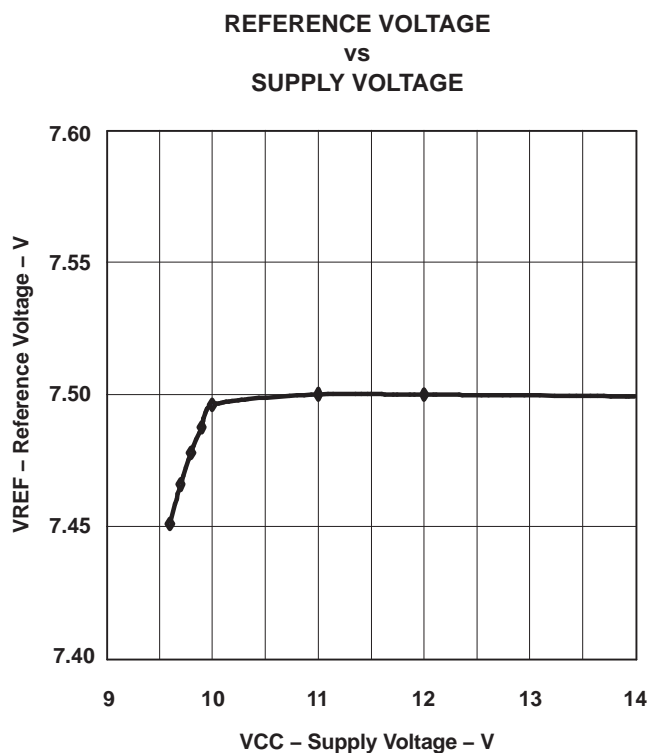


Figure 8.

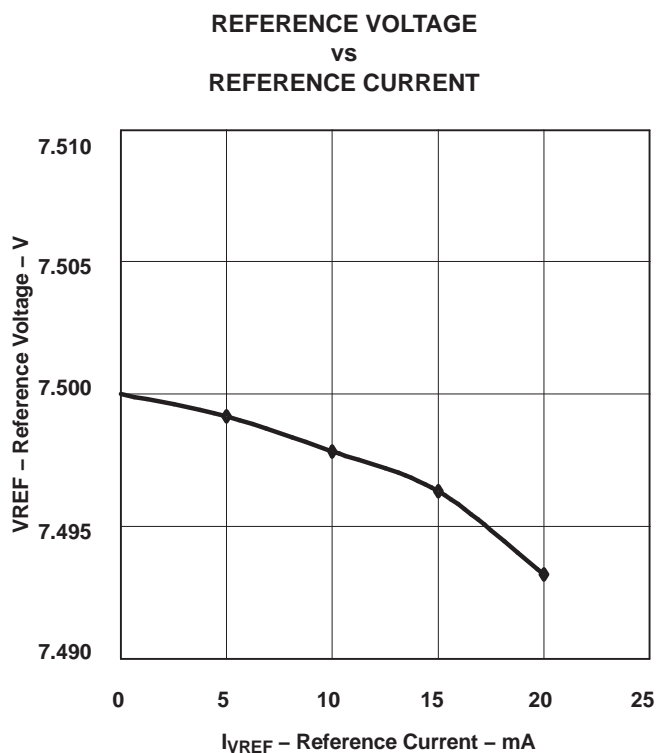


Figure 9.

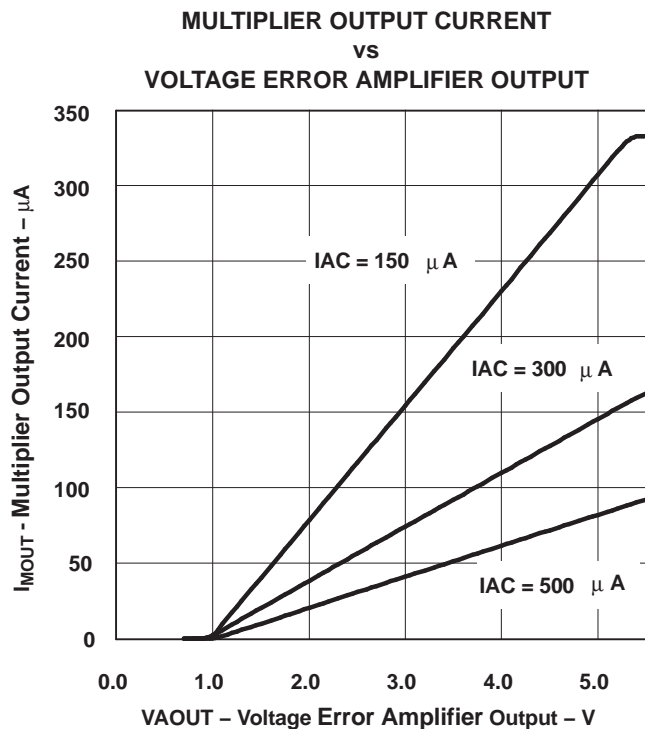


Figure 10.

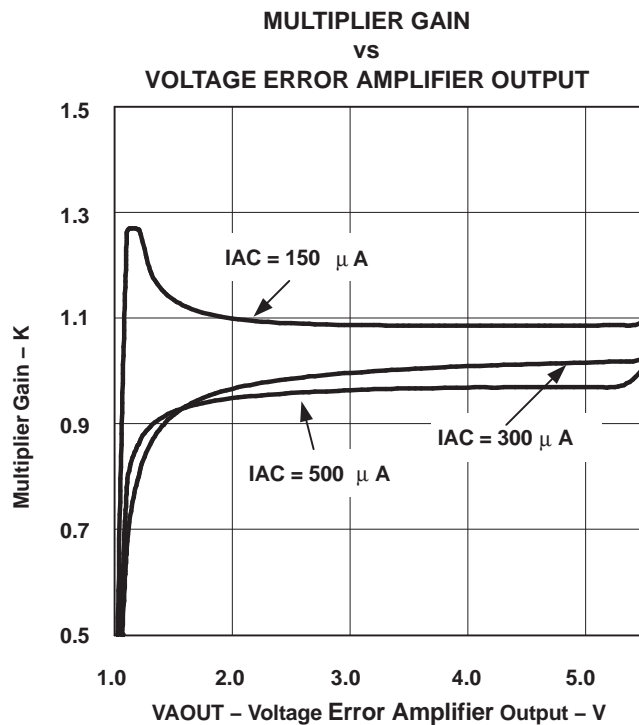


Figure 11.

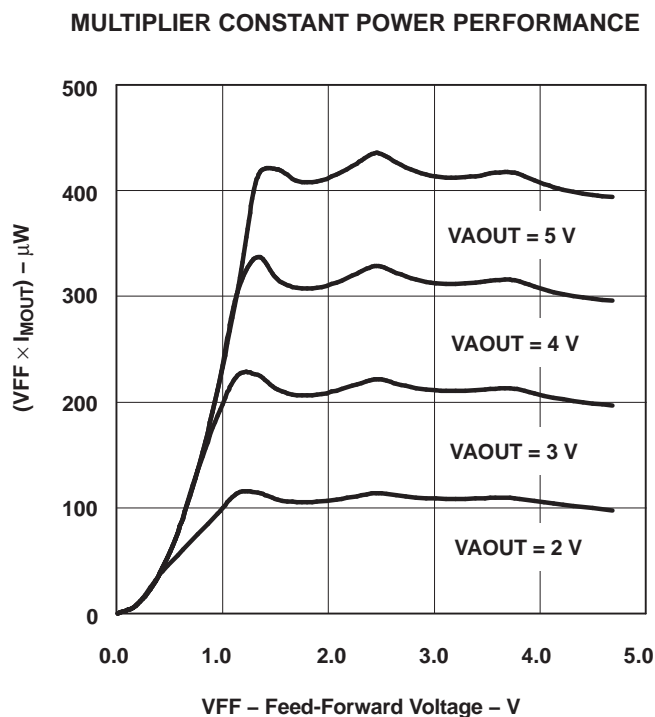


Figure 12.

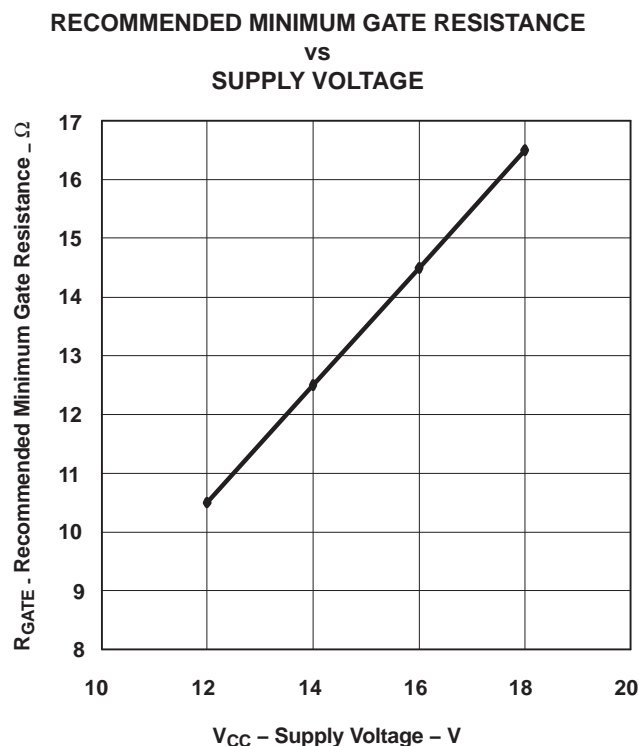


Figure 13.



## References and Resources

Application Note, Differences Between UCC3817A/18A/19A and UCC3817/18/19, Texas Instruments Literature Number SLUA294

Evaluation Module, UCC3817EVM, 385V, 250W PFC Boost Converter

User's Guide, UCC3817 BiCMOS Power Factor Preregulator Evaluation Board, Texas Instruments Literature Number SLUU077

Application Note, Synchronizing a PFC Controller from a Down Stream Controller Gate Drive, Texas Instruments Literature Number SLUA245

Seminar topic, High Power Factor Switching Preregulator Design Optimization, L.H. Dixon, SEM-700, 1990.

Seminar topic, High Power Factor Preregulator for Off-line Supplies, L.H. Dixon, SEM-600, 1988.

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
UCC2818AQDRQ1	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

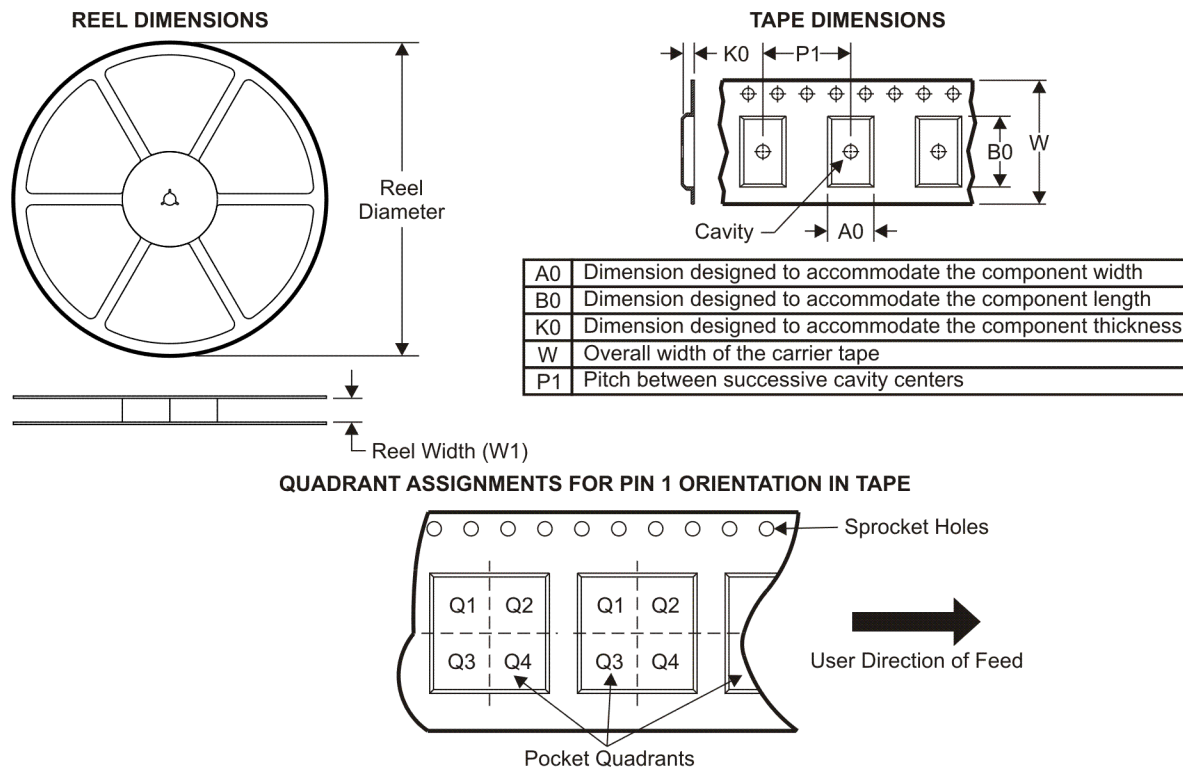
**OTHER QUALIFIED VERSIONS OF UCC2818A-Q1 :**

- Catalog: [UCC2818A](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

**TAPE AND REEL INFORMATION**



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
UCC2818AQDRQ1	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1

## TAPE AND REEL BOX DIMENSIONS

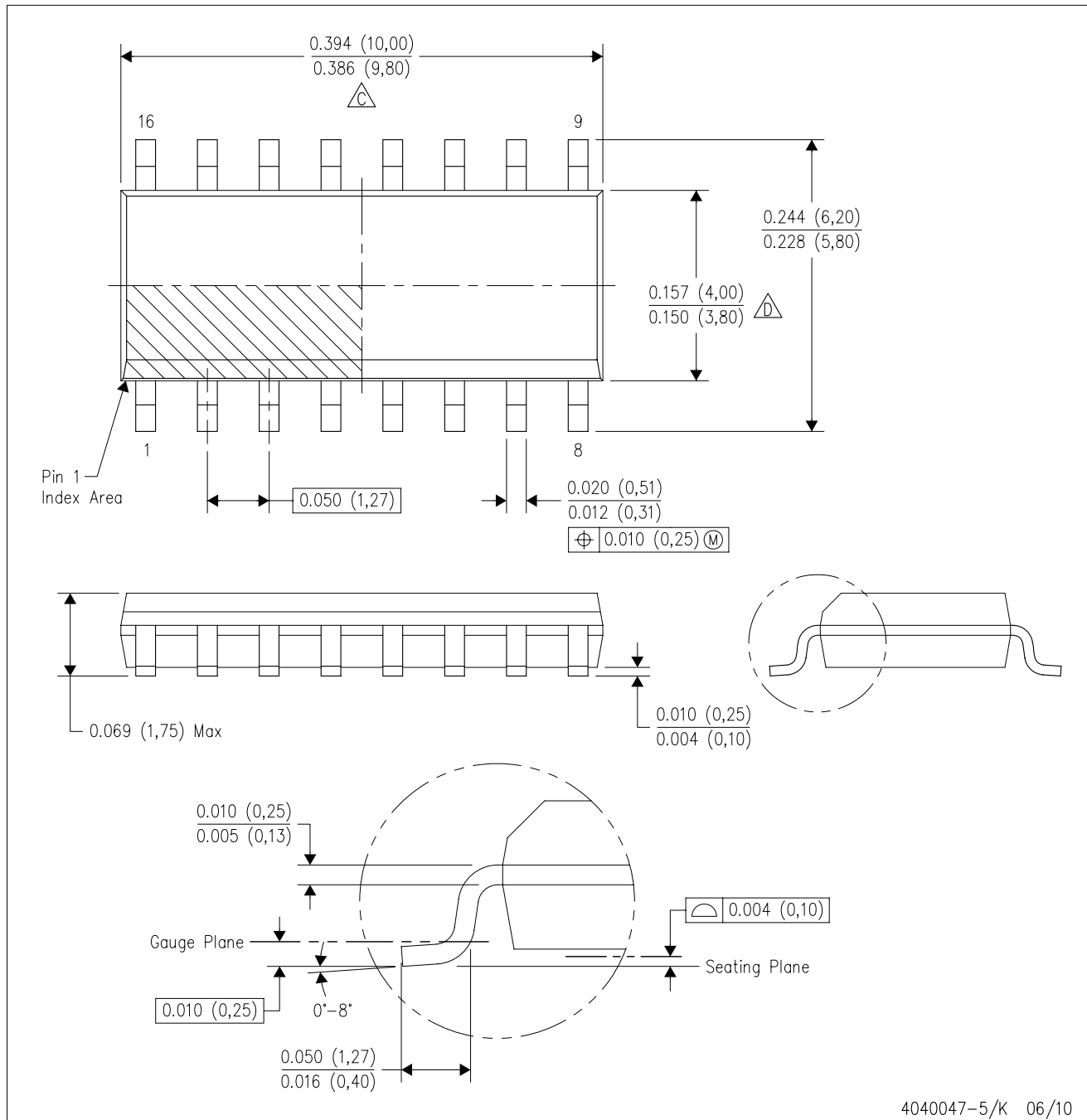


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
UCC2818AQDRQ1	SOIC	D	16	2500	333.2	345.9	28.6

D (R-PDSO-G16)

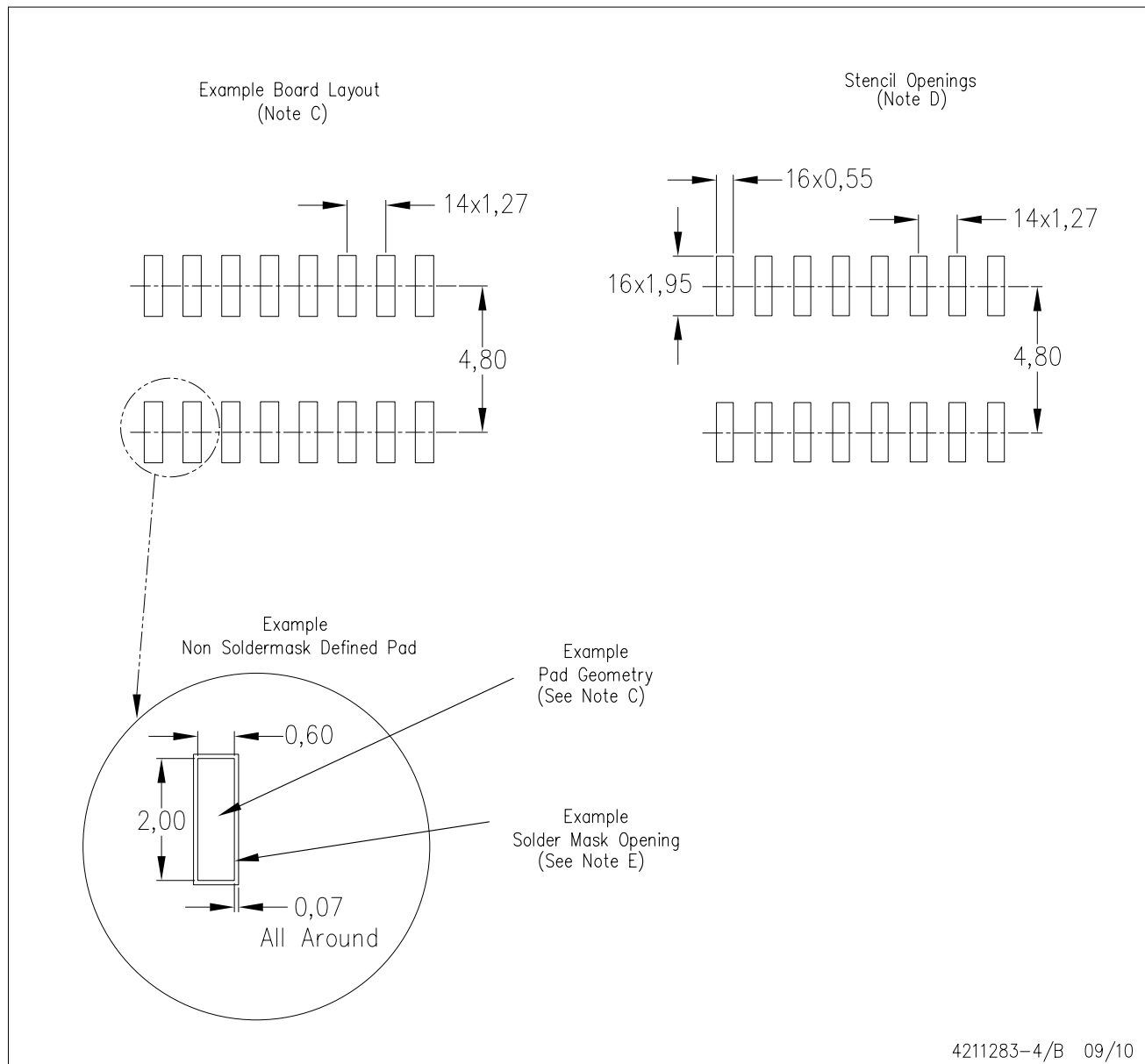
PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 (0,15) per end.
  - D. Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
  - E. Reference JEDEC MS-012 variation AC.

D (R-PDSO-G16)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		Applications	
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>	Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>	Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>	Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>	Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>	Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>	Energy	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>	Space, Avionics & Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
RF/IF and ZigBee® Solutions	<a href="http://www.ti.com/lprf">www.ti.com/lprf</a>	Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
		Wireless	<a href="http://www.ti.com/wireless-apps">www.ti.com/wireless-apps</a>