

# ZVS Average Current PFC Controller

## GENERAL DESCRIPTION

The ML4822 is a PFC controller designed specifically for high power applications. The controller contains all of the functions necessary to implement an average current boost PFC converter, along with a Zero Voltage Switch (ZVS) controller to reduce diode recovery and MOSFET turn-on losses.

The average current boost PFC circuit provides high power factor (>98%) and low Total Harmonic Distortion (THD). Built-in safety features include undervoltage lockout, overvoltage protection, peak current limiting, and input voltage brownout protection.

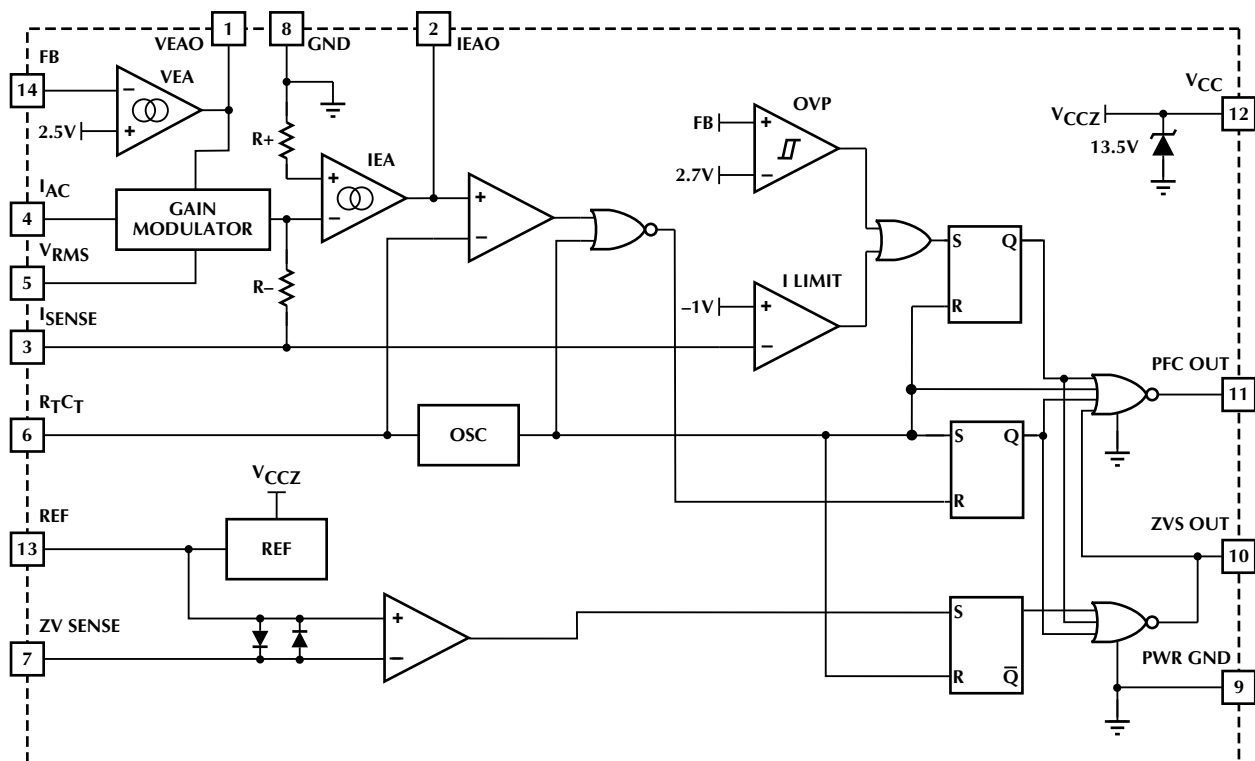
The ZVS control section drives an external ZVS MOSFET which, combined with a diode and inductor, soft switches the boost regulator. This technique reduces diode reverse recovery and MOSFET switching losses to reduce EMI and maximize efficiency.

## FEATURES

- Average current sensing, continuous boost, leading edge PFC for low total harmonic distortion and near unity power factor
- Built-in ZVS switch control with fast response for high efficiency at high power levels
- Average line voltage compensation with brownout control
- Current fed gain modulator improves noise immunity and provides universal input operation
- Overvoltage comparator eliminates output "runaway" due to load removal
- UVLO, current limit, and soft-start
- Precision 1% reference

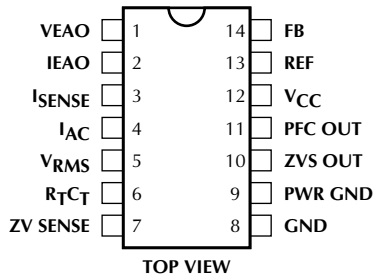
*\*This Part Is End Of Life As Of August 1, 2000*

## BLOCK DIAGRAM (Pin configuration shown for 14-pin package)

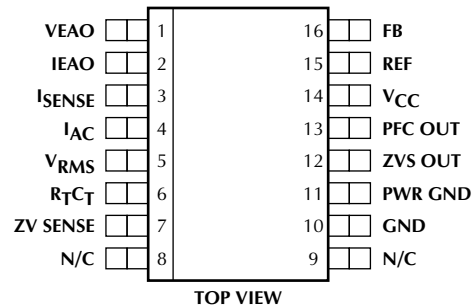


## PIN CONFIGURATION

**ML4822**  
14-Pin DIP (P14)



**ML4822**  
16-Pin SOIC (S16W)



## PIN DESCRIPTION (Pin number in parentheses is for 16-pin package)

PIN	NAME	FUNCTION	PIN	NAME	FUNCTION
1 (1)	VEAO	Transconductance voltage error amplifier output.	8 (10)	GND	Analog signal ground.
2 (2)	IEAO	Transconductance current error amplifier output.	9 (11)	PWR GND	Return for the PFC and ZVS driver outputs.
3 (3)	ISENSE	Current sense input to the PFC current limit comparator.	10 (12)	ZVS OUT	ZVS MOSFET driver output.
4 (4)	IAC	PFC gain modulator reference input.	11 (13)	PFC OUT	PFC MOSFET driver output.
5 (5)	VRMS	Input for RMS line voltage compensation.	12 (14)	VCC	Shunt-regulated supply voltage.
6 (6)	RTCT	Connection for oscillator frequency setting components.	13 (15)	REF	Buffered output for the internal 7.5V reference.
7 (7)	ZV SENSE	Input to the high speed zero voltage crossing comparator.	14 (16)	FB	Transconductance voltage error amplifier input.

## ABSOLUTE MAXIMUM RATINGS

Absolute maximum ratings are those values beyond which the device could be permanently damaged. Absolute maximum ratings are stress ratings only and functional device operation is not implied.

Shunt Regulator Current ( $I_{CC}$ ) .....	55mA
Peak Driver Output Current .....	$\pm 500$ mA
Analog Inputs .....	-0.3 to 7V
Junction Temperature .....	150°C
Storage Temperature Range .....	-65°C to 150°C

Lead Temperature (Soldering, 10 sec) .....	150°C
Thermal Resistance ( $\theta_{JA}$ )	
Plastic DIP .....	80°C/W
Plastic SOIC .....	110°C/W

## OPERATING CONDITIONS

Temperature Range	
ML4822CX .....	0°C to 70°C
ML4822IX .....	-40°C to 85°C

## ELECTRICAL CHARACTERISTICS

Unless otherwise specified,  $R_T = 52.3$ k $\Omega$ ,  $C_T = 470$ pF,  $T_A$  = Operating Temperature Range (Note 1)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>VOLTAGE ERROR AMPLIFIER</b>					
Input Voltage Range		0		7	V
Transconductance	$V_{NON-INV} = V_{INV}$ , $V_{EAO} = 3.75$ V	50	70	120	$\mu\text{S}$
Feedback Reference Voltage	$V_{EAO} = V_{FB}$	2.4	2.5	2.6	V
Open Loop Gain		60	75		dB
PSRR	$V_{CCZ} - 3\text{V} < V_{CC} < V_{CCZ} - 0.5\text{V}$	60	75		dB
Output Low			0.65	1	V
Output High		6.0	6.7		V
Source Current	$\Delta V_{IN} = \pm 0.5\text{V}$ , $V_{OUT} = 6\text{V}$	-40	-80		$\mu\text{A}$
Sink Current	$\Delta V_{IN} = \pm 0.5\text{V}$ , $V_{OUT} = 1.5\text{V}$	40	80		mA
<b>CURRENT ERROR AMPLIFIER</b>					
Input Voltage Range		-1.5		2	V
Transconductance	$V_{NON-INV} = V_{INV}$ , $I_{EAO} = 3.75$ V	130	195	310	$\mu\text{S}$
Input Offset Voltage			$\pm 3$	$\pm 15$	mV
Open Loop Gain		60	75		dB
PSRR	$V_{CCZ} - 3\text{V} < V_{CC} < V_{CCZ} - 0.5\text{V}$	60	75		dB
Output Low			0.65	1	V
Output High		6.0	6.7		V
Source Current	$\Delta V_{IN} = \pm 0.5\text{V}$ , $V_{OUT} = 6\text{V}$	-40	-80		$\mu\text{A}$
Sink Current	$\Delta V_{IN} = \pm 0.5\text{V}$ , $V_{OUT} = 1.5\text{V}$	40	80		$\mu\text{A}$
<b>OVP COMPARATOR</b>					
Threshold Voltage		2.6	2.7	2.8	V
Hysteresis		80	120	150	mV
<b>I<sub>SENSE</sub> COMPARATOR</b>					
Threshold Voltage		-0.8	-1.0	-1.15	V
Delay to Output			150	300	ns

## ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>ZV SENSE COMPARATOR</b>					
Propagation Delay	100mV Overdrive			50	ns
Threshold Voltage		7.35	7.5	7.65	V
Input Capacitance			6		pF
<b>GAIN MODULATOR</b>					
Gain (Note 2)	$I_{IAC} = 100\text{mA}$ , $V_{VRMS} = 0\text{V}$ , $V_{FB} = 0\text{V}$	0.36	0.51	0.66	
	$I_{IAC} = 50\text{mA}$ , $V_{VRMS} = 1.2\text{V}$ , $V_{FB} = 0\text{V}$	1.20	1.72	2.24	
	$I_{IAC} = 100\mu\text{A}$ , $V_{VRMS} = 1.8\text{V}$ , $V_{FB} = 0\text{V}$	0.55	0.78	1.01	
	$I_{IAC} = 100\mu\text{A}$ , $V_{VRMS} = 3.3\text{V}$ , $V_{FB} = 0\text{V}$	0.14	0.20	0.26	
Bandwidth	$I_{IAC} = 250\mu\text{A}$		10		MHz
Output Voltage	$V_{FB} = 0\text{V}$ , $V_{VRMS} = 1.15\text{V}$ , $I_{IAC} = 250\mu\text{A}$	0.72	0.8	0.9	V
<b>OSCILLATOR</b>					
Initial Accuracy	$T_A = 25^\circ\text{C}$	74	80	86	kHz
Voltage Stability	$V_{CCZ} - 3\text{V} < V_{CC} < V_{CCZ} - 0.5\text{V}$		1		%
Temperature Stability			2		%
Total Variation	Line, temperature	72		88	kHz
Ramp Valley to Peak Voltage			2.5		V
Dead Time		100	300	450	ns
$C_T$ Discharge Current		4.5	7.5	9.5	mA
<b>REFERENCE</b>					
Output Voltage	$T_A = 25^\circ\text{C}$ , $I_{REF} = 1\text{mA}$	7.425	7.5	7.575	V
Line Regulation	$V_{CCZ} - 3\text{V} < V_{CC} < V_{CCZ} - 0.5\text{V}$		2	10	mV
Load Regulation	$1\text{mA} < I_{REF} < 20\text{mA}$		2	15	mV
Temperature Stability			0.4		%
Total Variation	Line, load, and temperature	7.395		7.605	V
Long Term Stability	$T_j = 125^\circ\text{C}$ , 1000 hours		5	25	mV
Short Circuit Current	$V_{CC} < V_{CCZ} - 0.5\text{V}$ , $V_{REF} = 0\text{V}$	-15	-40	-100	mA
<b>PFC COMPARATOR</b>					
Minimum Duty Cycle	$V_{IEAO} > 6.7\text{V}$			0	%
Maximum Duty Cycle	$V_{IEAO} < 1.2\text{V}$	90	95		%

**ELECTRICAL CHARACTERISTICS** (Continued)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>MOSFET DRIVER OUTPUTS</b>					
Output Low Voltage	$I_{OUT} = -20\text{mA}$		0.3	0.8	V
	$I_{OUT} = -100\text{mA}$		0.6	3.0	V
	$I_{OUT} = -10\text{mA}, V_{CC} = 8\text{V}$		0.8	1.5	V
Output High Voltage	$I_{OUT} = 20\text{mA}$	9.5	10.3		V
	$I_{OUT} = 100\text{mA}$	9	10.3		V
Output Rise/Fall Time	$C_L = 1000\text{pF}$		40		ns
<b>UNDERVOLTAGE LOCKOUT</b>					
Threshold Voltage		$V_{CCZ} - 0.9$	$V_{CCZ} - 0.6$	$V_{CCZ} - 0.2$	V
Hysteresis		2.5	2.8	3.2	V
<b>SUPPLY</b>					
Shunt Voltage ( $V_{CCZ}$ )	$I_{CC} = 25\text{mA}$	12.8	13.5	14.2	V
Load Regulation	$25\text{mA} < I_{CC} < 55\text{mA}$		$\pm 150$	$\pm 300$	mV
Total Variation	Load and temperature	12.4		14.6	V
Start-up Current	$V_{CC} < 12.3\text{V}$		0.7	1.1	mA
Operating Current	$V_{CC} = V_{CCZ} - 0.5\text{V}$		22	28	mA

Note 1: Limits are guaranteed by 100% testing, sampling, or correlation with worst-case test conditions.

Note 2:  $\text{Gain} = K \times 5.3 \text{ V}$ ;  $K = (I_{\text{GAINMOD}} - I_{\text{OFFSET}}) \times I_{\text{AC}} \times (V_{\text{EAO}} - 1.5)^{-1}$ .

## FUNCTIONAL DESCRIPTION

Switching losses of wide input voltage range PFC boost converters increase dramatically as power levels increase above 200 watts. The use of zero-voltage switching (ZVS) techniques improves the efficiency of high power PFCs by significantly reducing the turn-on losses of the boost MOSFET. ZVS is accomplished by using a second, smaller MOSFET, together with a storage element (inductor) to convert the turn-on losses of the boost MOSFET into useful output power.

The basic function of the ML4822 is to provide a power factor corrected, regulated DC bus voltage using continuous, average current-mode control. Like Micro Linear's family of PFC/PWM controllers, the ML4822 employs leading-edge pulse width modulation to reduce system noise and permit frequency synchronization to a trailing edge PWM stage for the highest possible DC bus voltage bandwidth. For minimization of switching losses, circuitry has been incorporated to control the switching of the ZVS FET.

## THEORY OF OPERATION

Figure 1 shows a simplified schematic of the output and control sections of a high power PFC circuit. Figure 2 shows the relationship of various waveforms in the circuit. Q1 functions as the main switching FET and Q2 provides the ZVS action. During each cycle, Q2 turns on before Q1, diverting the current in L1 away from D1 into L2. The current in L2 increases linearly until at  $t_2$  it equals the current through L1. When these currents are equal, L1 ceases discharging current and is now charged through L2 and Q2. At time  $t_2$ , the drain voltage of Q1 begins to fall. The shape of the voltage waveform is sinusoidal due to the interaction of L2 and the combined parasitic

capacitance of D1 and Q1 (or optional ZVS capacitor  $C_{ZVS}$ ). At  $t_3$ , the voltage across Q1 is sufficiently low that the controller turns Q2 off and Q1 on. Q1 then behaves as an ordinary PFC switch, storing energy in the boost inductor L1. The energy stored in L2 is completely discharged into the boost capacitor via D2 during the Q1 off-time and the value of L2 must be selected for discontinuous-mode operation.

## COMPONENT SELECTION

### Q1 Turn-Off

Because the ML4822 uses leading edge modulation, the PFC MOSFET (Q1) is always turned off at the end of each oscillator ramp cycle. For proper operation, the internal ZVS flip-flop must be reset every cycle during the oscillator discharge time. This is done by automatically resetting the ZVS comparator a short time after the drain voltage of the main Q has reached zero (refer to Figure 1 sense circuit). This sense circuit terminates the ZVS on time by sensing the main Q drain voltage reaching zero. It is then reset by way of a resistor pull-up to  $V_{CC}$  (R6). The advantage of this circuit is that the ZVS comparator is not reset at the main Q turn off which occurs at the end of the clock cycle. This avoids the potential for improper reset of the internal ZVS flip-flop.

Another concern is the proper operation of the ZVS comparator during discontinuous mode operation (DCM), which will occur at the cusps of the rectified AC waveform and at light loads. Due to the nature of the voltage seen at the drain of the main boost Q during DCM operation, the ZVS comparator can be fooled into forcing the ZVS Q on for the entire period. By adding a circuit which limits the maximum on time of the ZVS Q, this problem can be avoided. Q3 in Figure 1 provides this function.

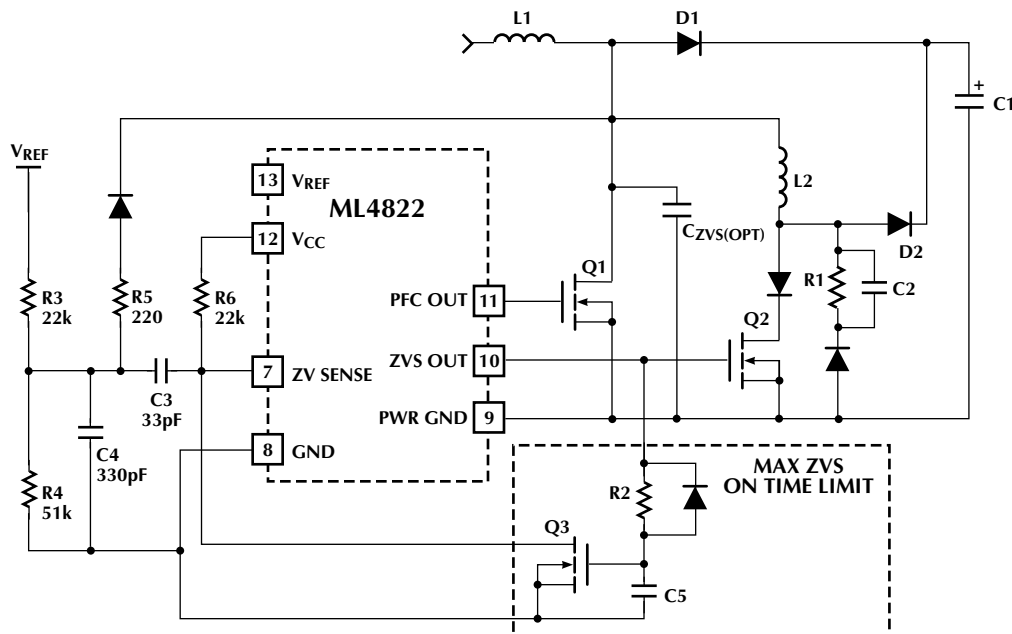


Figure 1. Simplified PFC/ZVS Schematic.

## Q1 Turn-On

The turn-on event consists of the time it takes for the current through L2 to ramp to the L1 current plus the resonant event of L2 and the ZVS capacitor. The total event should occur in a minimum of 350–450ns, but can be longer at the risk of increasing the total harmonic distortion. Setting these times equal should minimize conducted and radiated emissions.

$$t_{Q1(OFF)} = t_{IL2} + t_{RES} = 400\text{ns} \quad (1)$$

Where  $I_{L2}$  is equal to  $I_{L1}$ .

The value of L2 is calculated to remain in discontinuous-mode:

$$L2 = \frac{V_{BUS} \times V_{RMS(MIN)} \times t_{IL2}}{\sqrt{2} \times P_{OUT}} \quad (2)$$

The resonant event occurs in 1/4 of a full sinusoidal cycle. For example, when a 1/4 cycle occurs in 200ns, the frequency is 1.25MHz.

$$f_{RES} = \frac{1}{2\pi\sqrt{L2 \times C_{ZVS}}} = \frac{1}{4 \times t_{RES}} \quad (3)$$

Rearranging and solving for L2:

$$L2 = \frac{4 \times t_{RES}^2}{\pi^2 \times C_{ZVS}} \quad (4)$$

The resonant capacitor ( $C_{ZVS}$ ) value is found by setting equations 2 and 4 equal to each other and solving for  $C_{ZVS}$ .

$$C_{ZVS} = \frac{4 \times t_{RES}^2 \times \sqrt{2} \times P_{OUT}}{\pi^2 \times V_{BUS} \times V_{RMS(MIN)} \times t_{IL2}} \quad (5)$$

## APPLICATION

Figure 3 displays a typical application circuit for a 500W ZVS PFC supply. Full design details are covered in application note 33, ML4822 Power Factor Correction With Zero Voltage Resonant Switching.

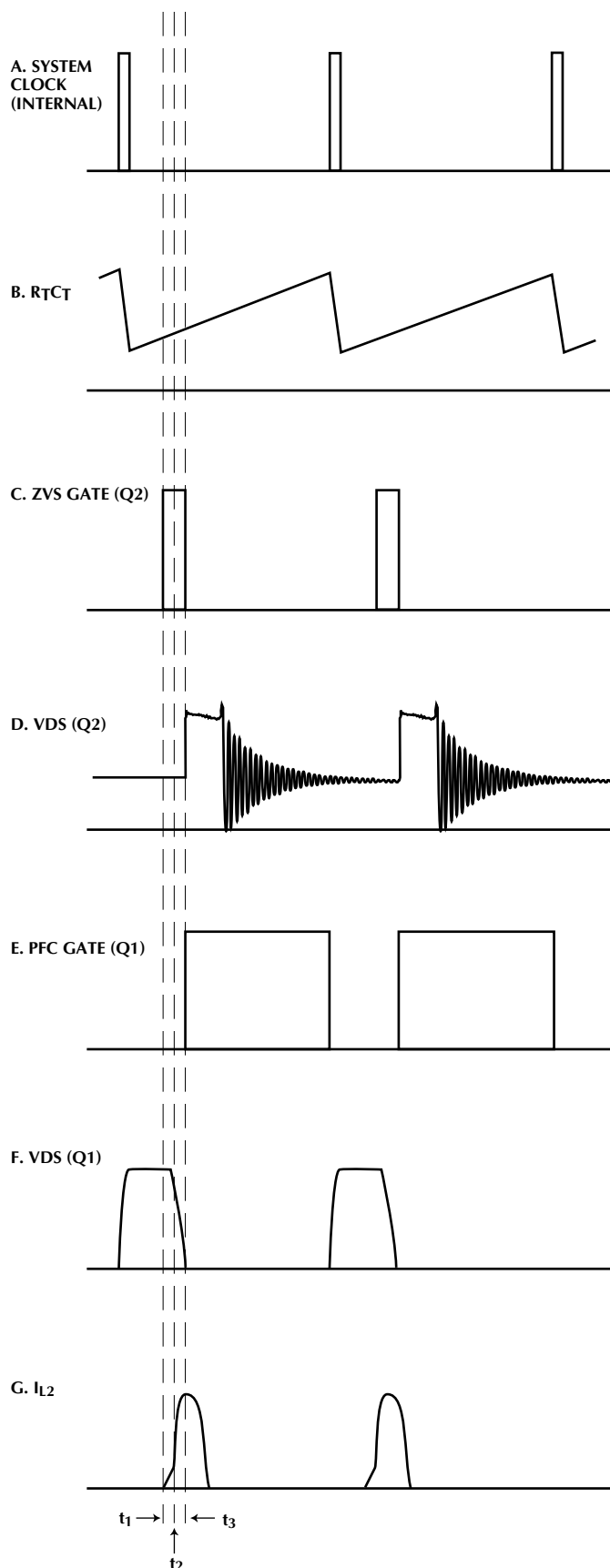


Figure 2. Timing Diagrams

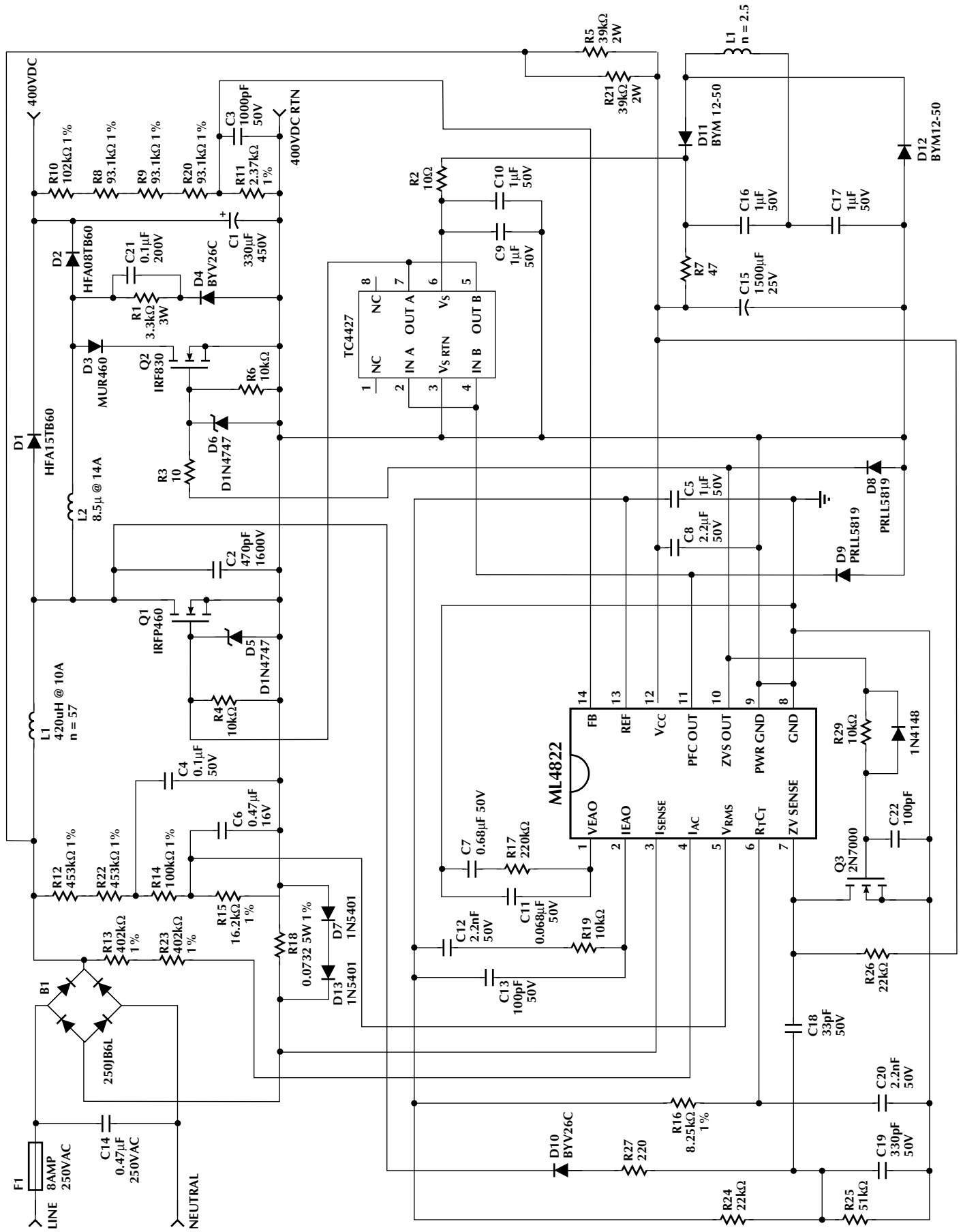
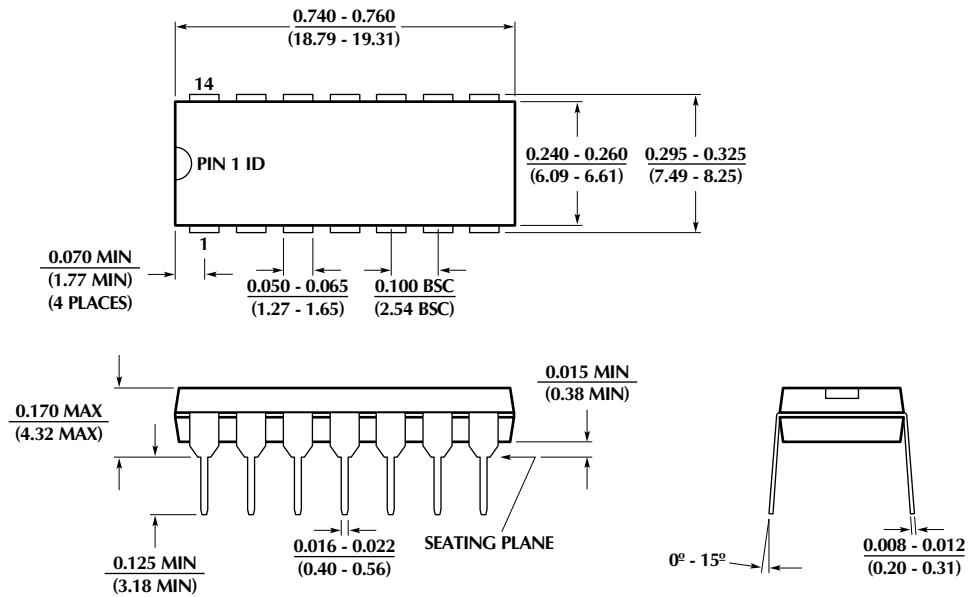


Figure 3. ML4822 Schematic

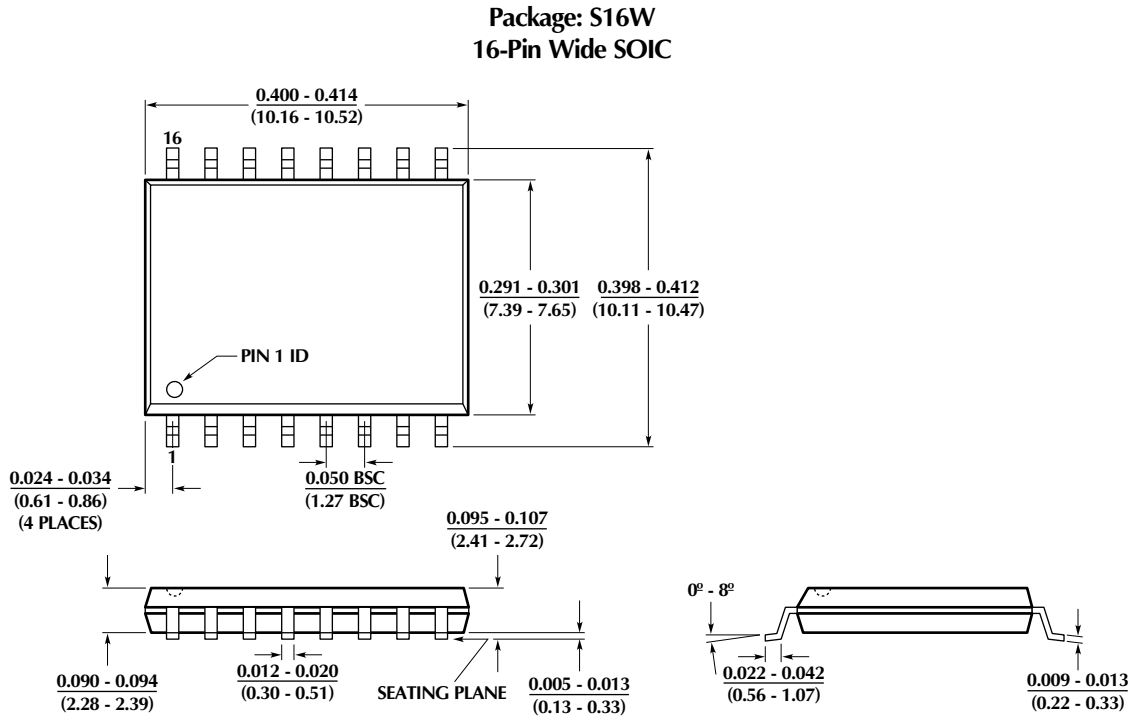


PHYSICAL DIMENSIONS inches (millimeters)

Package: P14  
14-Pin PDIP



## PHYSICAL DIMENSIONS inches (millimeters)



## ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ML4822CP ML4822CS	0°C to 70°C 0°C to 70°C	14-Pin PDIP (P14) (EOL) 16-Pin Wide SOIC (S16W) (EOL)
ML4822IP ML4822IS	-40°C to 85°C -40°C to 85°C	14-Pin PDIP (P14) (EOL) 16-Pin Wide SOIC (S16W) (EOL)

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2092 Concourse Drive  
San Jose, CA 95131  
Tel: 408/433-5200  
Fax: 408/432-0295