

# Zero Voltage Switching Resonant Controller

## GENERAL DESCRIPTION

The ML4815 is designed to facilitate zero-voltage switched (ZVS) resonant converters requiring constant off-time and variable on-time control. Since the power MOSFET is turned on at zero voltage in ZVS resonant converters, power dissipation due to charge-dumping of the MOSFET drain-source capacitance is eliminated, allowing high frequency operation and power density to be maximized. MOSFET parasitic drain-source capacitance can also be used as part of the resonant circuit, minimizing component count.

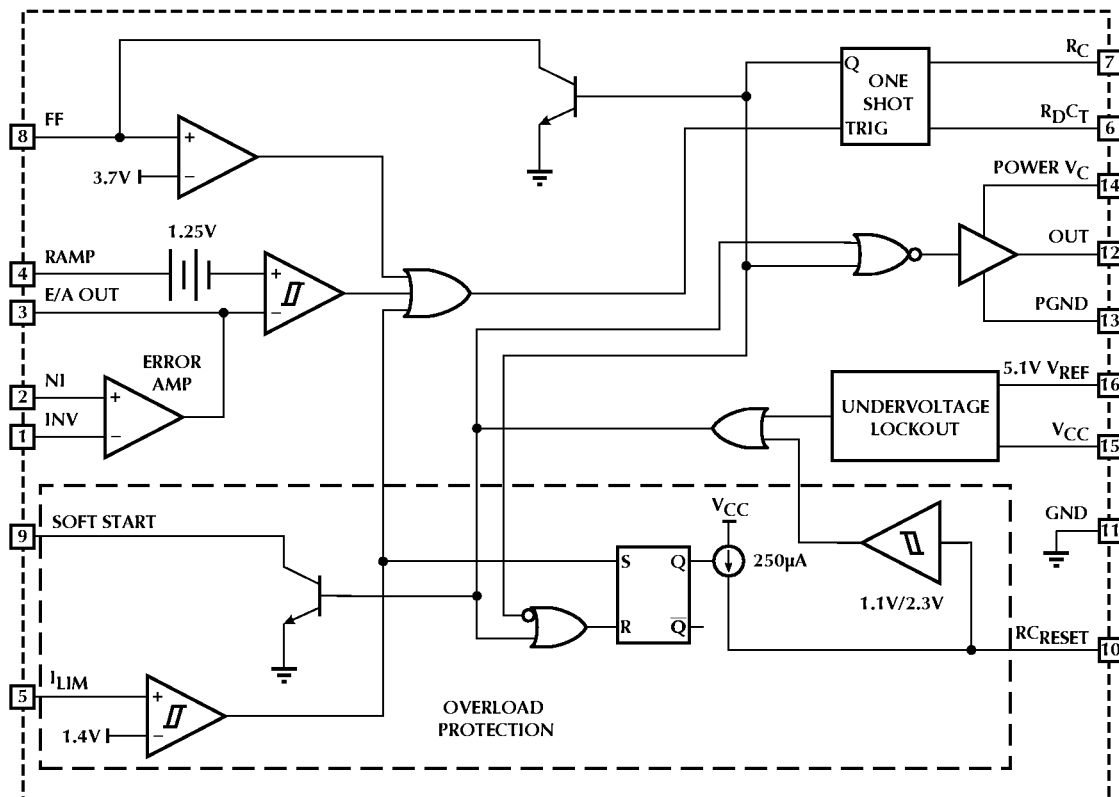
The ML4815 features a monostable multivibrator for precise off-time setting. The on-time is modulated through a ramp comparator in a manner similar to PWM converters. Either current mode control with maximum on-time clamp, or voltage mode control with input feedforward, can be selected.

ML4815 supports pulse-by-pulse (peak) current limiting as well as "hiccup" mode for fault protection. The controller is designed for operation up to 2MHz. The ML4815 also includes a wide band error amplifier, and a high peak current output driver which minimizes cross-conduction current.

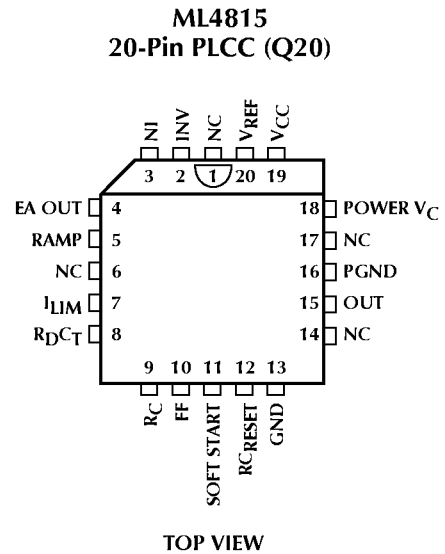
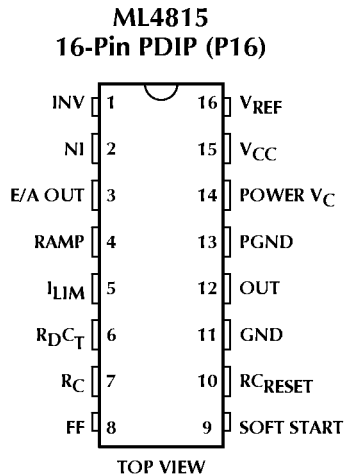
## FEATURES

- Supports single-switch ZVS resonant topology with minimal external components ideal for simple, high density DC to DC converters
- Small converter frequency variation from no-load to full-load
- High current (2A peak) totem-pole output drive with low cross conduction
- Precision buffered 5.1V reference ( $\pm 2\%$ )
- Wideband (5.5MHz), high slew rate ( $12\text{V}/\mu\text{s}$ ) error amp
- Undervoltage lockout with low current start-up
- Integrating fault detection/soft-start reset

## BLOCK DIAGRAM (Pin Configuration Shown is for DIP Version)



## PIN CONFIGURATION



## PIN DESCRIPTION (Pin Number in Parentheses is for PLCC Version)

PIN	NAME	FUNCTION	PIN	NAME	FUNCTION
1 (2)	INV	Inverting input to error amp	9 (11)	SOFT START	External RC network input for setting soft start time
2 (3)	NI	Non-inverting input to error amp	10 (12)	RC <sub>RESET</sub>	External RC network input for overcurrent integration and restart delay time
3 (4)	E/A OUT	Output of error amplifier and input to main comparator	11 (13)	GND	Analog signal ground
4 (5)	RAMP	Non-inverting input to main comparator. Connected to FF for feedforward voltage-mode control or to I <sub>LIM</sub> for current-mode control.	12 (15)	OUT	High current totem-pole output
5 (7)	I <sub>LIM</sub>	Current limit sense pin. Normally connected to current sense resistor.	13 (16)	PGND	Return path for OUT
6 (8)	R <sub>D C_T</sub>	External RC network input for setting one-shot off-time	14 (18)	POWER V <sub>C</sub>	Positive Supply for OUT
7 (9)	R <sub>C</sub>	External resistor input for modifying charge time of R <sub>D C_T</sub>	15 (19)	V <sub>C C</sub>	Positive supply input
8 (10)	FF	Capacitor to generate feedforward ramp	16 (20)	V <sub>R E F</sub>	Buffered output for the 5.1V reference

## 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.

$V_{CC}$ .....	30V
Output Current, Source or Sink	
DC .....	0.5A
Pulsed (0.5 $\mu$ s) .....	2A
Analog Inputs .....	-0.3V to 6V
Error Amplifier Output Current .....	-5 $\mu$ A
Soft Start Sink Current .....	100 $\mu$ A

Feedforward Sink Current .....	800mA
$C_T$ Charging Current .....	-50mA
Junction Temperature .....	125°C
Storage Temperature Range .....	-65°C to 150°C
Lead Temperature (Soldering, 10 sec) .....	260°C
Thermal Resistance ( $\theta_{JA}$ )	
Plastic DIP .....	65°C/W
Plastic Leaded Chip Carrier (PLCC) .....	60°C/W

## OPERATING CONDITIONS

Temperature Range .....	0°C to 70°C
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## ELECTRICAL CHARACTERISTICS

Unless otherwise specified,  $C_T = 330\text{pF}$ ,  $R_C = 100\Omega$ ,  $R_D = 2\text{k}\Omega$ ,  $V_{CC} = 15\text{V}$ ,  $T_A =$  Operating Temperature Range. (Note 1)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
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### REFERENCE

$V_{REF}$	Output Voltage	$T_A = 25^\circ\text{C}$ , $I_O = 1\text{mA}$	5.0	5.1	5.2	V
	Line Regulation	$T_A = 25^\circ\text{C}$ , $10\text{V} < V_{CC} < 30\text{V}$		2	20	mV/V
	Load Regulation	$T_A = 25^\circ\text{C}$ , $1\text{mA} < I_O < 10\text{mA}$		5	20	mV/V
	Temperature Stability	$-55^\circ\text{C} < T_J < 125^\circ\text{C}$ .		0.2	0.4	%
	Total Variation	Line, Load, Temp	4.94		5.25	V
	Output Noise Voltage	10Hz to 10kHz		50		$\mu\text{V}$
	Long Term Stability	1000 Hours		5	25	mV
$I_{SC}$	Short Circuit Current	$V_{REF} = 0\text{V}$	-15	-50	-100	mA

### ERROR AMPLIFIER

$V_{IO}$	Input Offset Voltage				20	mV
$I_{IB}$	Input Bias Current			0.6	3	$\mu\text{A}$
$I_{IO}$	Input Offset Current			0.1	1	$\mu\text{A}$
	Open Loop Gain	$1\text{V} < V_O < 4\text{V}$	60	96		dB
	CMRR	$1.5\text{V} < V_{CM} < 5.5\text{V}$	75	95		dB
	PSRR $12\text{V} < V_{CC} < 25\text{V}$	$12\text{V} < V_{CC} < 25\text{V}$	75	110		dB
$I_{SINK}$	Output Sink Current	E/A OUT = 1V	1	2.5		mA
$I_{SOURCE}$	Output Source Current	E/A OUT = 4V	-0.5	-1.3		mA
$V_{OH}$	Output High Voltage	E/A OUT = 1mA	0	0.5	1.0	V
$V_{OL}$	Output Low Voltage	E/A OUT = -0.5mA			0.8	V
	Unity Gain Bandwidth		3.0	5.5		MHz
	Slew Rate		6	12		V/ $\mu\text{s}$

### RAMP COMPARATOR

	RAMP Bias Current	$R_C = 0$		0.7		$\mu\text{A}$
	E/A OUT Zero DC Threshold	INV = E/A OUT (V), NI = FF = 2V, $I_{LIM} = 0\text{V}$ , $R_D C_T = 1.5\text{V}$	1.05	1.20	1.55	V
	Delay to Output	$C_L = 0$		55		ns

## ELECTRICAL CHARACTERISTICS (Continued)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>CURRENT LIMIT COMPARATOR</b>						
	$I_{LIM}$ Input Bias Current	$0 < V(I_{LIM}) < 4V$		2		$\mu A$
	Current Limit Threshold			1.41		V
	Hysteresis			30		mV
	Delay to Output	$R_{C_{RESET}} = 0, C_L = 0$		50		ns
<b>ONE-SHOT</b>						
	Off-Time Initial Accuracy	$T_A = 25^\circ C, C_L = 0$		0.45		$\mu s$
	Off-Time Voltage Stability	$C_L = 0, 12V < V_{CC} < 25V$		5		%
	Off-Time Temperature Stability	$C_L = 0$		5		%
$I_{SC}$	Off-Time Total Variation	$C_L = 0$		6		%
<b>FEEDFORWARD/MAXIMUM ON TIME CLAMP</b>						
	Discharge Current	$FF = 2.5V$		-250		mA
	Temperature Stability	$C_{FF} = 330pF, R_{FF} = 2.7k\Omega \text{ to } V_{REF}, C_L = 0$		1.0		$\mu s$
<b>SHUTDOWN/RESTART</b>						
	$R_{C_{RESET}}$ Charging Current			-250		$\mu A$
	Overload Shutdown Threshold			2.3		V
	Restart Threshold			1.1		V
<b>SOFT START</b>						
	Input Bias Current	$FF = 4V$		1		$\mu A$
	Discharge Current	$FF = 1V$		25		mA
<b>UNDER VOLTAGE LOCKOUT</b>						
	Start Threshold			13.4		V
	UVLO Hysteresis			3.6		V
<b>OUTPUT</b>						
	Output Low Level	$I_{OUT} = 20mA$		0.25	0.40	V
		$I_{OUT} = 200mA$		1.2	2.2	V
	Output High Level	$I_{OUT} = -20mA$		13.0		V
		$I_{OUT} = -200mA$		12.7		V
	Rise/Fall Time	$C_L = 1nF$		30		ns
<b>SUPPLY</b>						
	Short Circuit Current	$T_A = 25^\circ C, V_{OC} = 8V$		2	3	mA
	Operating $I_{CC}$			28	38	mA

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

## FUNCTIONAL DESCRIPTION

### ML4815 PRINTED CIRCUIT BOARD LAYOUT CONSIDERATIONS

High speed circuits demand careful attention to layout and component placement. To assure proper performance of the ML4815:

- 1) Use a ground plane
- 2) Damp or clamp parasitic inductive kick energy from the gate of any driven MOSFET. Don't allow the output pins to ring below ground. A series gate resistor or a shunt 1A Schottky diode at the output pin will serve this purpose.
- 3) Bypass  $V_{CC}$ ,  $V_C$  and  $V_{REF}$ . Use  $1\mu\text{F}$  monolithic ceramic capacitors with low equivalent series inductance for  $V_{CC}$  and  $V_C$ . Allow less than 1 cm of total lead length between the bypassed pin and the ground plane for each capacitor.
- 4) Treat the off-time setting capacitor,  $C_T$ , like a bypass capacitor.

### CONTROL METHODS

In current-mode control the current transformer output is fed into the RAMP comparator input. The current-sense waveform is used as the on-time modulating ramp. The on-time can be clamped to a maximum by using  $R_{FF}$  and  $C_{FF}$  as shown.

In feedforward voltage-mode control the on-time modulating ramp is generated with an external capacitor,  $C_{FF}$  from pin FF to ground.  $C_{FF}$  is charged through an external resistor,  $R_{FF}$ . The maximum on-time is the time taken to charge  $C_{FF}$  to 3.7V. Since the charging current depends on  $V_{IN}$  the resulting maximum on-time varies with  $V_{IN}$ .

### OUTPUT SECTION

When driving power MOSFETs with high equivalent gate capacitance ( $C_G > 3\text{nF}$ ) it is advisable to use an external 1N4148 diode between the  $V_{CC}$  and  $V_C$  pins (Figure 6) to reduce extra power dissipation caused by slow turn-off of Q7. In this case both  $V_{CC}$  and  $V_C$  pins should have bypass capacitors ( $C = 1\mu\text{F}$ ) as close as possible to the IC pins.

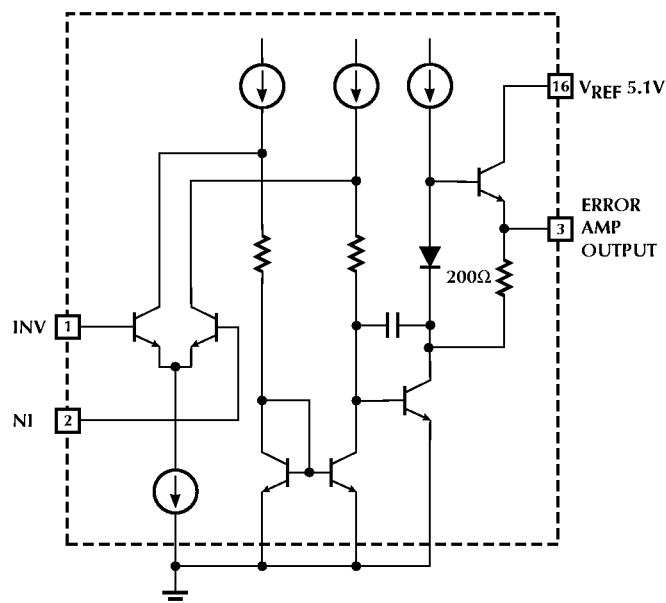


Figure 1. Simplified Schematic of Error Amplifier

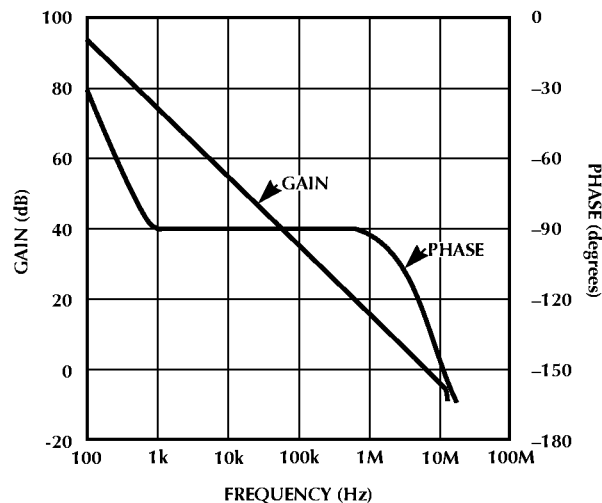


Figure 2. Open Loop Frequency Response

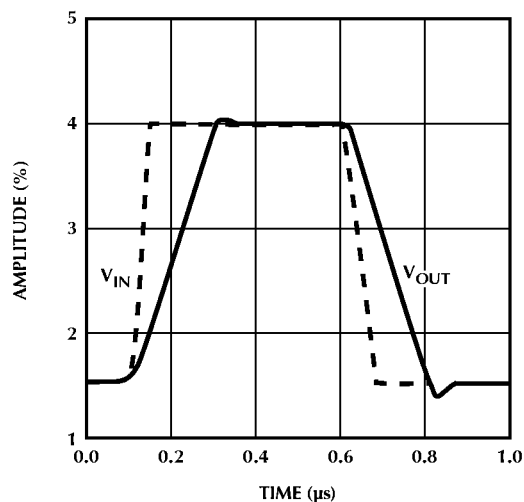


Figure 3. Unity Gain Slew Rate

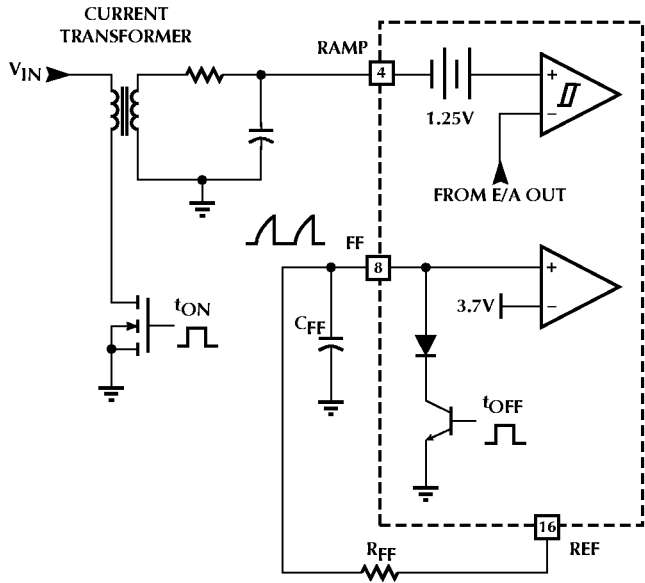


Figure 4. Current Mode Control with Maximum On-Time Clamp

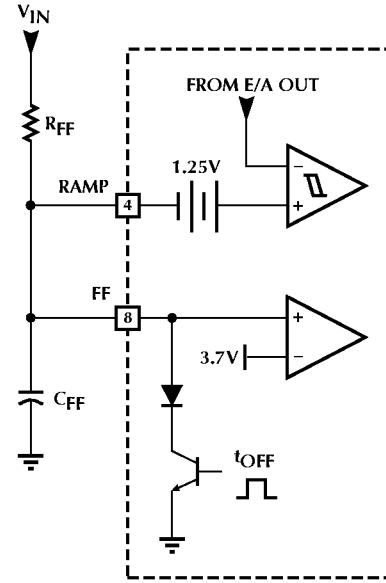


Figure 5. Feedforward Control

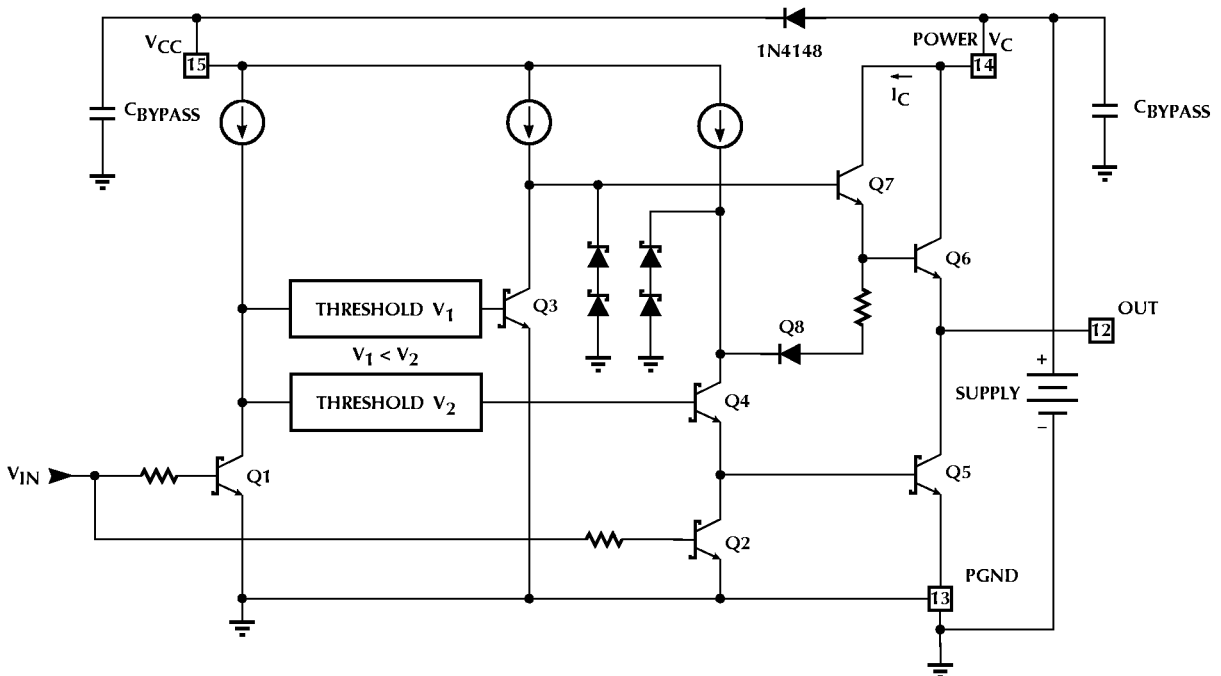


Figure 6. Totem Pole MOSFET Drive with Reduced Cross-Conduction

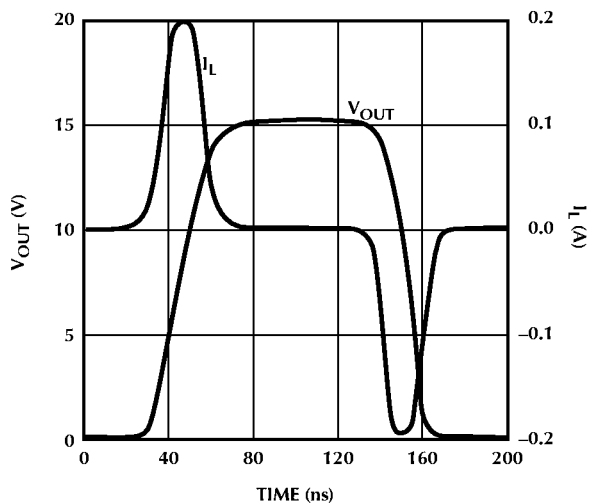


Figure 7. Rise and Fall Times when  $C_L = 1nF$

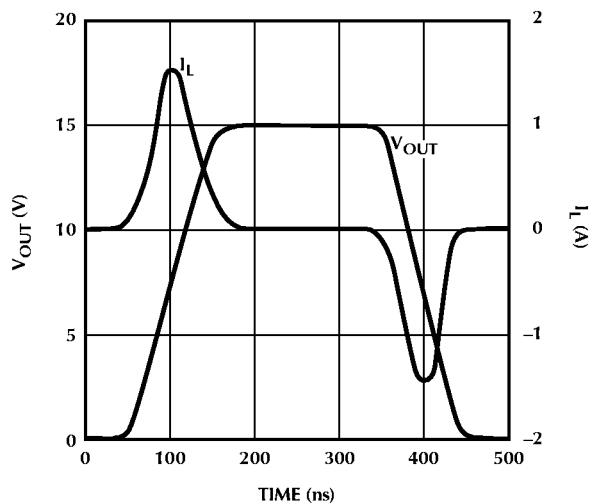


Figure 8. Rise and Fall Times when  $C_L = 10nF$

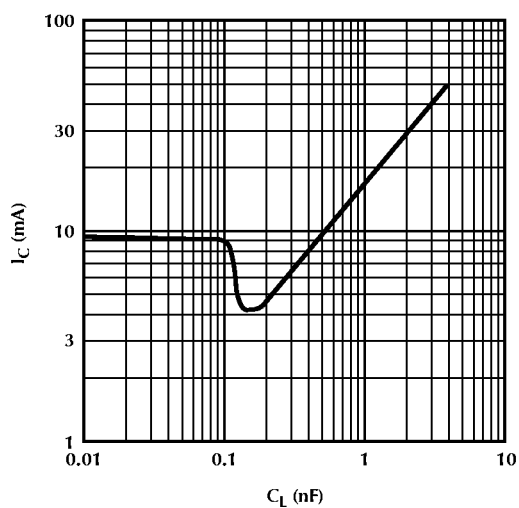


Figure 9.  $I_C$  vs  $C_L$

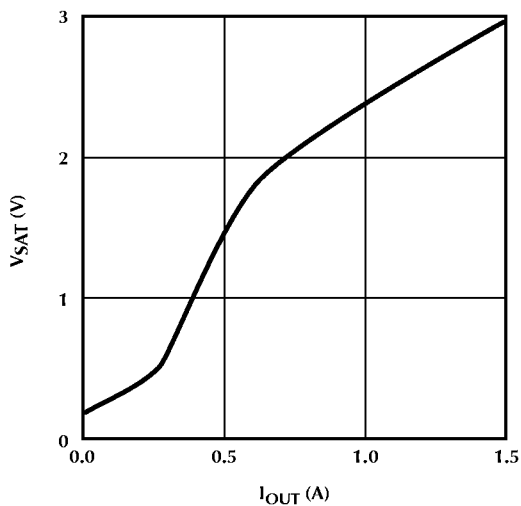


Figure 10.  $V_{OL}$  Curve

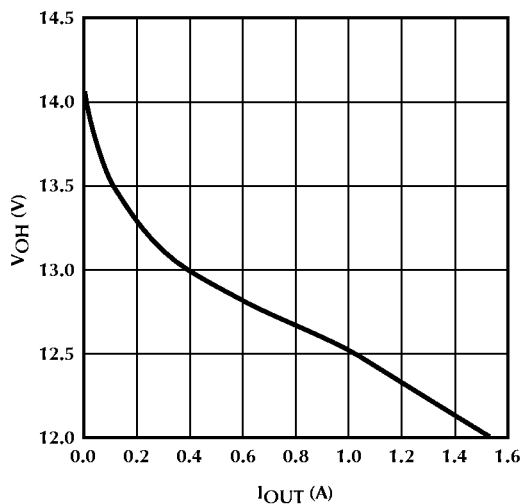


Figure 11.  $V_{OH}$  Curve

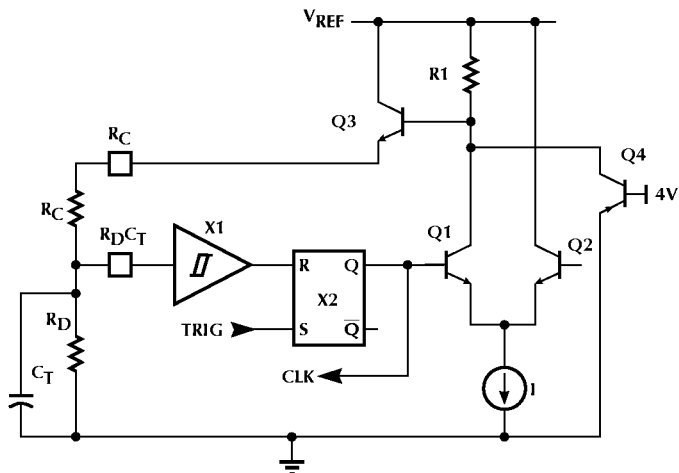


Figure 12. Block Diagram of the One-shot

## FUNCTIONAL DESCRIPTION (Continued)

### ONE-SHOT

Figure 12 shows the detailed block diagram of the one-shot circuitry. The one-shot is programmed with external resistors  $R_C$  &  $R_D$  and capacitor  $C_T$ . When CLK is low and Q2 conducts initially, the timing capacitor  $C_T$  is charged to 4V through  $R_C$  and Q3. This corresponds to the switch conduction cycle (on-time). When either the feedforward ramp or the sensed current signal exceeds the error amplifier output voltage a trigger pulse is sent to the one-shot which sets the R-S latch X2 and disables Q3.  $C_T$  voltage reaches the lower threshold (2V) of Schmitt-trigger X1. At this point the X1 output goes high, resetting X2, and Q1 turns off, allowing Q3 to recharge  $C_T$  to 4V. This time interval corresponds to the switch off-time. Since the off-time is simply the discharge time of  $C_T$ , one can express it this way:

$$t_{OFF} = 0.69 \times R_D C_T$$

The purpose of  $R_C$  is to slow the charging transient of  $C_T$  in order to widen the internal reset pulse.  $R_C$  is usually chosen such that the following inequality is satisfied:

$$\frac{R_C}{R_C + R_D} < 0.05$$

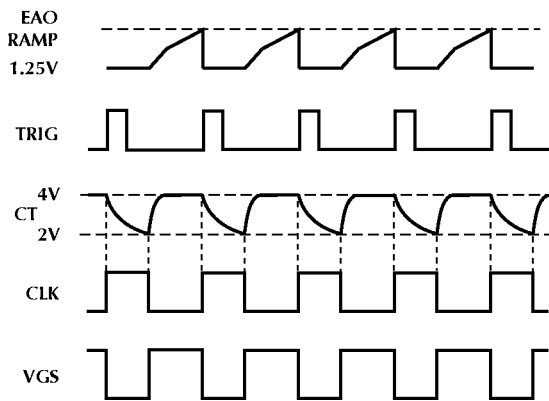


Figure 13. Timing Diagram of the One-shot

### CONSTANT ON-TIME CLAMP (In Current-Mode Only)

In current-mode control, the maximum on-time can be clamped by using the comparator X1 (Figure 15a).

The internal transistors Q1 & Q2 and diode D2 discharge  $C_{FF}$  to approximately  $V_{BE}$ . The time taken to charge  $C_{FF}$  from  $V_{BE}$  to  $V_{BIAS}$  sets the maximum on-time, as follows:

$$t_{ON(MAX)} = \frac{V_{REF} + 0.488 \times V_{BE}}{1.488}$$

The diode D1 compensates the  $V_{BE}$  dependent  $C_{FF}$  valley voltage. It can be shown that  $t_{ON(MAX)} \approx 1.115 \times R_{FF} \times C_{FF}$ , and  $t_{ON(MAX)}$  is relatively independent of temperature.

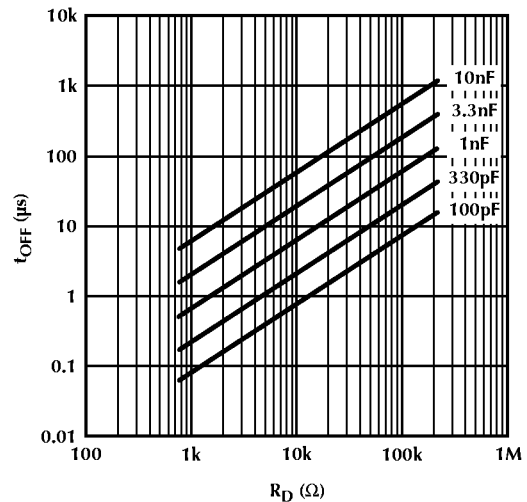


Figure 14.  $t_{OFF}$  vs  $R_D$



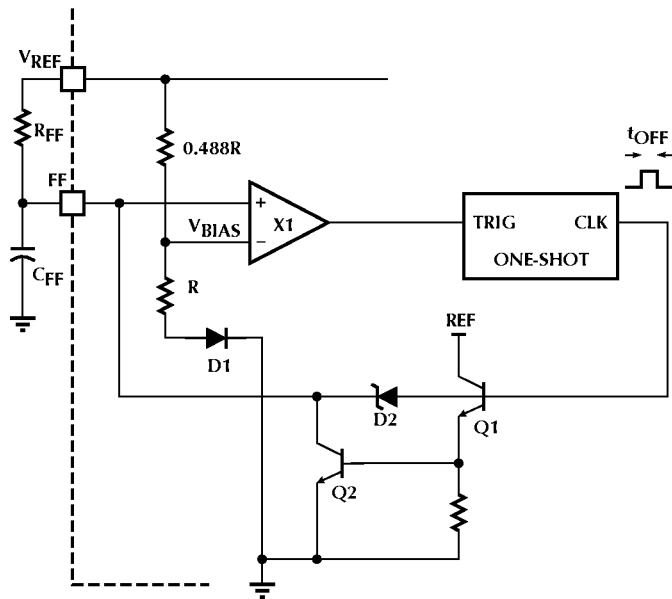


Figure 15a. Constant On-time Clamp Circuit

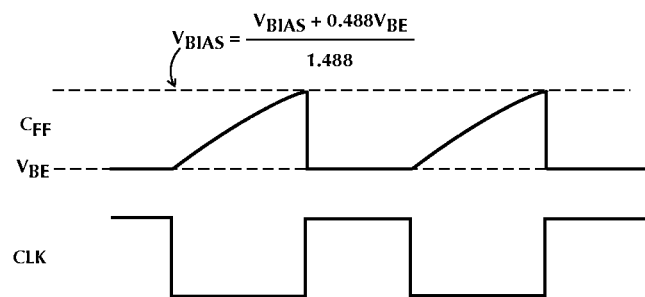


Figure 15b. Constant On-time Clamp Waveform

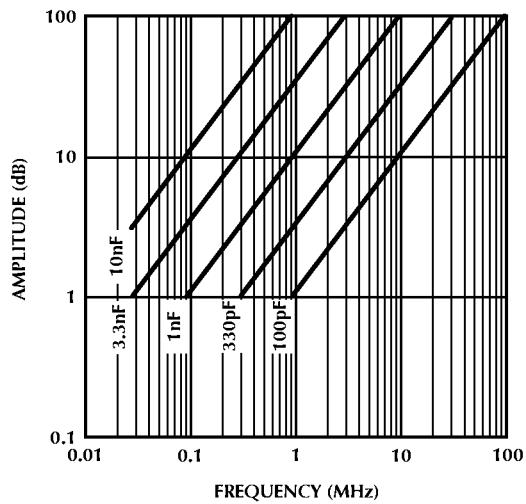


Figure 16.  $t_{OFF}$  vs  $R_{FF}$

## FUNCTIONAL DESCRIPTION (Continued)

### CURRENT LIMITING, OVERLOAD SHUTDOWN AND FAULT MANAGEMENT

The ML4815 features a unique overload protection scheme. See Figure 17. The power transistor current is compared with the current-limit threshold (1.4V) of X3. When the sensed current exceeds this threshold the one-shot is triggered and the R-S latch X4 is set. The one-shot blanks the gate drive and latch X4 turns on the current source  $I_F$ . The external capacitor  $C_{RD}$ , which is normally fully discharged, is charged towards an overload threshold of 2.3V. The packet of charge delivered to  $C_{RD}$  in each overcurrent cycle is  $I_F \times t_{OFF}$  (Figure 18). Latch X4 is reset after the off-time elapses. If the output short is removed before  $C_{RD}$  reaches the overload threshold,  $C_{RD}$  will be discharged through  $R_{RD}$  and normal operation will resume. However, under persistent output short circuit conditions  $C_{RD}$  is charged until it reaches 2.3V. Then the gate drive is immediately terminated, the soft-start capacitor is discharged (Figure 18), and  $C_{RD}$  discharges towards the restart threshold (1.1V) through  $R_{RD}$ . The gate drive remains off until  $C_{RD}$  is discharged below 1.1V. The time taken for  $C_{RD}$  to discharge to the restart threshold is the restart-delay time. This delay reduces the average power delivered to the load during overload conditions and protects both the load and the controller. If the overload condition persists the controller will continue to

hiccup until the cause of the overload is removed. The controller undergoes soft-start at each restart. The overload shutdown and restart sequence for a converter with a non-bootstrapped power supply  $V_{CC}$  is illustrated in Figure 19.

For a bootstrapped converter (where controller  $V_{CC}$  is obtained from an auxiliary winding of the main transformer), overload shutdown causes both the converter output and the controller  $V_{CC}$  to collapse. Undervoltage Lockout (UVLO) is activated and the onchip bandgap reference is disabled. ML4815 dissipates only 2mA of supply current during shutdown. Since  $I_{BLEED}$  is higher than the start-up current,  $C_S$  will be charged towards the UVLO start threshold. When this happens the entire controller becomes operational, except that the gate drive remains off.  $I_{CC}$  jumps to its full operational value. Since  $V_{CC}$  bootstrapping is not yet available  $I_{CC}$  will discharge  $C_S$  below the UVLO stop threshold. The onchip reference will again be disabled with the controller supply current reduced to 2mA.  $I_{BLEED}$  will again charge  $C_S$  towards the UVLO start threshold. The process repeats until  $C_{RD}$  is discharged below the restart threshold. The shutdown and restart sequence is illustrated with the timing diagram in Figure 20.

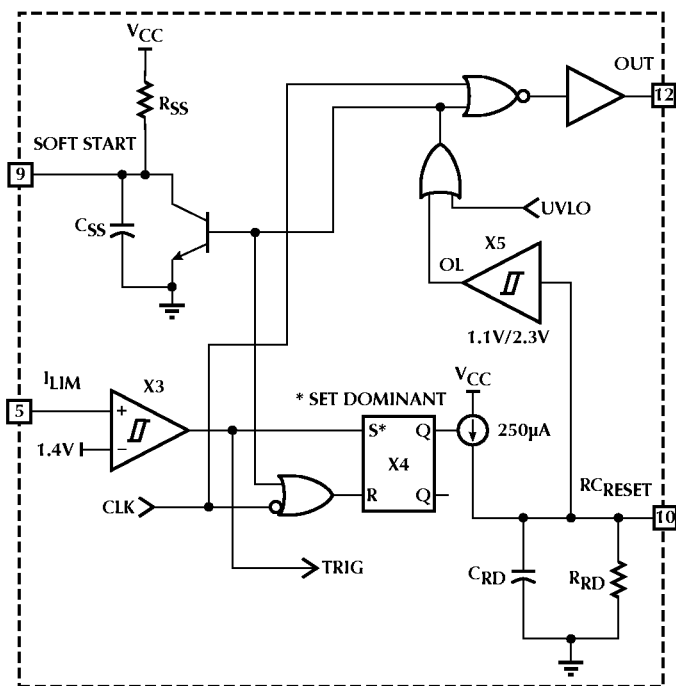


Figure 17. Overload Protection and Fault Management

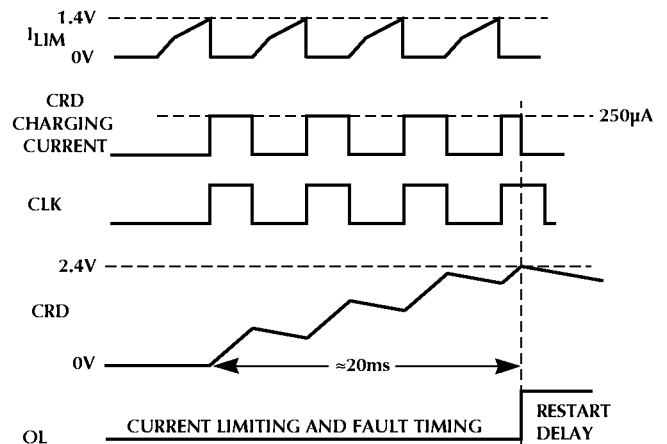


Figure 18. Current Limiting Overload Shutdown and Restart Sequence (Non-Bootstrapped Operation)

FUNCTIONAL DESCRIPTION (Continued)

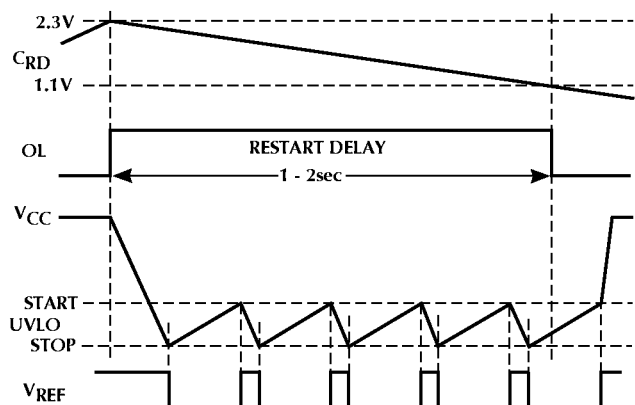


Figure 19. Overload Shutdown UVLO and Restart Sequence (Bootstrapped Operation)

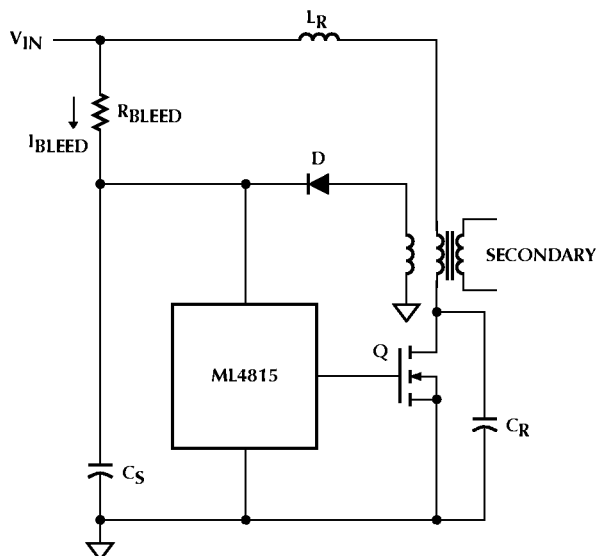


Figure 20. Simplified  $V_{CC}$  Bootstrapping Scheme

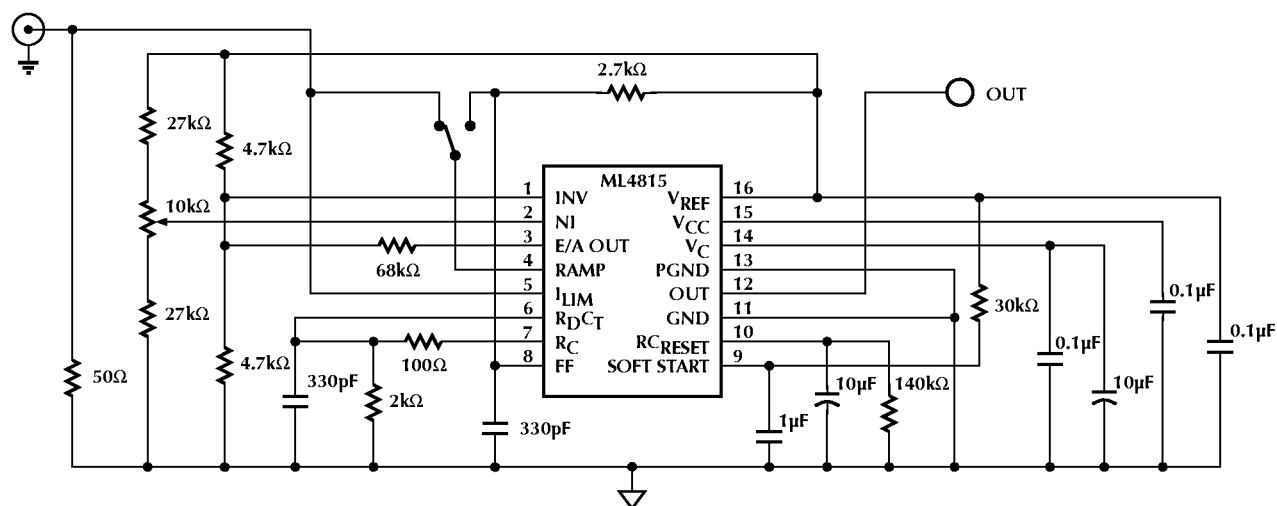


Figure 21. Open Loop Laboratory Test Fixture

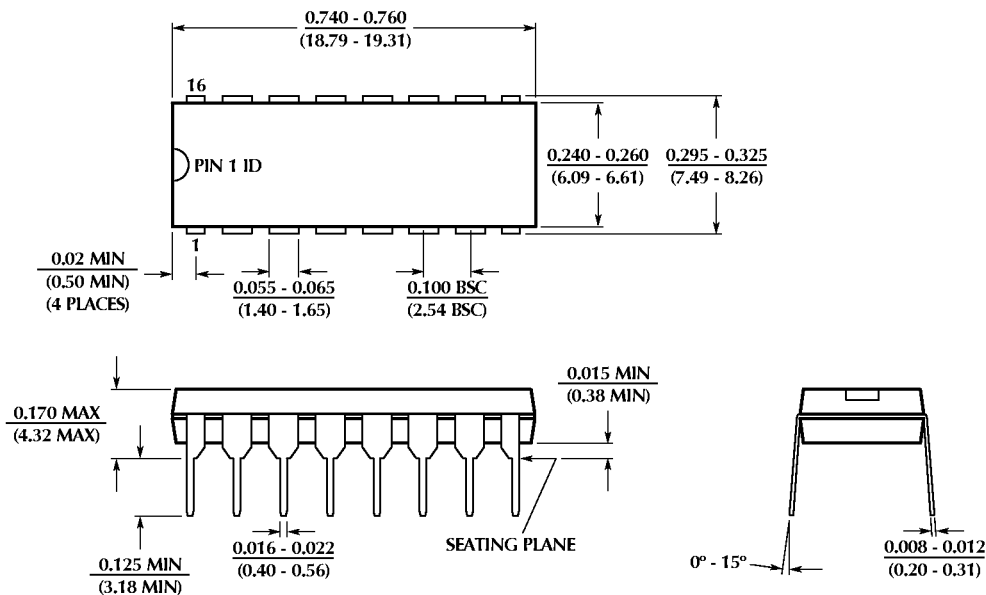




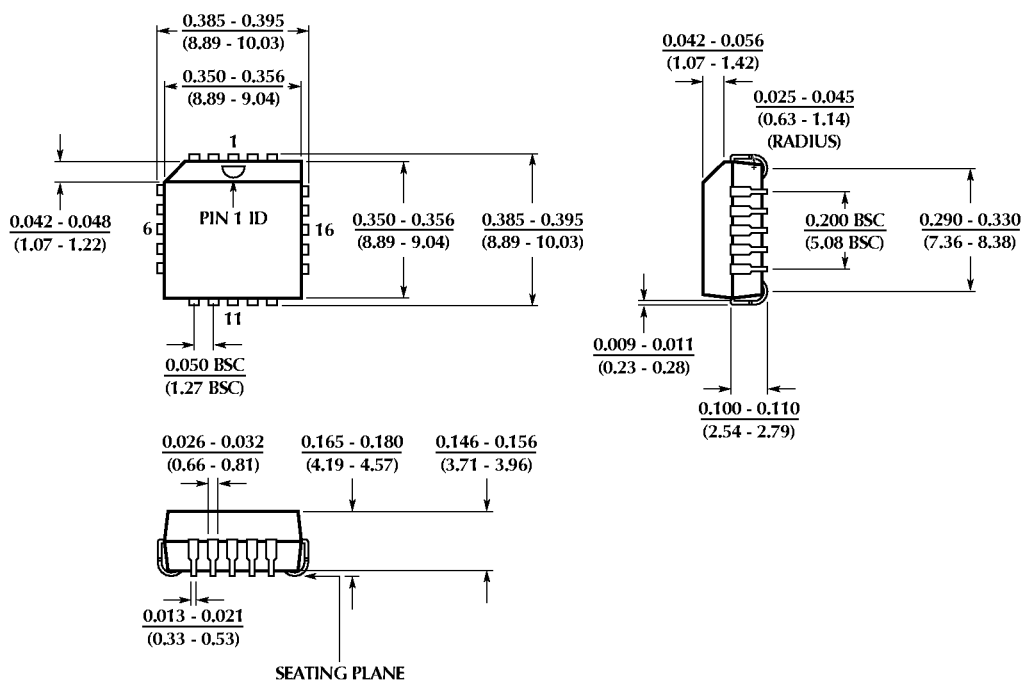


PHYSICAL DIMENSIONS inches (millimeters)

Package: P16  
16-Pin PDIP




Package: Q20  
20-Pin PLCC



## ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ML4815CP	0°C to 70°C	16-Pin PDIP (P16)
ML4815CQ	0°C to 70°C	20-Pin PLCC (Q20)

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