FAIRCHILD
SEMICONDUCTOR™

FEATURING
Extended Commercial Temperature Range
-20˚C to 70˚C
for Portable Handheld Equipment

July 2000

ML4872

High Current Boost Regulator with Shutdown

GENERAL DESCRIPTION

The ML4872 is a continuous conduction boost regulator designed for DC to DC conversion in multiple cell battery powered systems. Continuous conduction allows the regulator to maximize output current for a given inductor. The maximum switching frequency can exceed 200kHz, allowing the use of small, low cost inductors. The ML4872 is capable of start-up with input voltages as low as 1.8V and is available in 5V and 3.3V output versions with an output voltage accuracy of ±3%.

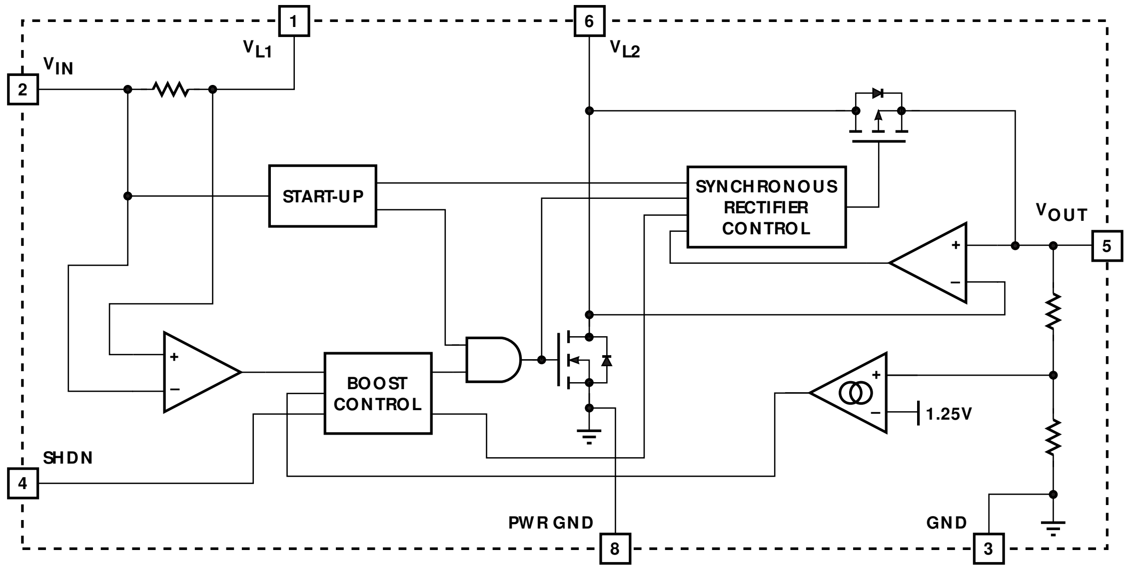
An integrated synchronous rectifier eliminates the need for an external Schottky diode and provides a lower forward voltage drop, resulting in higher conversion efficiency. In addition, low quiescent battery current and variable frequency operation result in high efficiency even at light loads. The ML4872 requires only one inductor and two capacitors to build a very small regulator circuit capable of achieving conversion efficiencies approaching 90%.

The SHDN input allows the user to stop the regulator from switching and powers down the control circuitry.

FEATURES

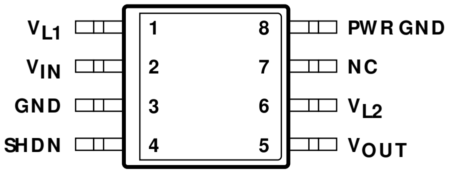
- Guaranteed full load start-up and operation at 1.8V Input
- Continuous conduction mode for high output current
- Very low supply current (20µA output referenced) for micropower operation
- Pulse frequency modulation and internal synchronous rectification for high efficiency
- Maximum switching frequency > 200kHz
- Minimum external components
- Low ON resistance internal switching FETs
- 5V and 3.3V output versions

BLOCK DIAGRAM



PIN CONFIGURATION

ML4872
8-Pin SOIC (S08)



TOP VIEW

PIN DESCRIPTION

PIN	NAME	FUNCTION
1	V_{L1}	Boost inductor connection
2	V_{IN}	Battery input voltage
3	GND	Ground
4	SHDN	Pulling this pin to V_{IN} causes the regulator to stop switching, and powers down the control circuitry

PIN	NAME	FUNCTION
5	V_{OUT}	Boost regulator output
6	V_{L2}	Boost inductor connection
7	NC	No connection
8	PWR GND	Return for the NMOS output transistor

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_{OUT}	7V
Voltage on any other pin	GND – 0.3V to V_{OUT} + 0.3V
Peak Switch Current (I_{PEAK})	2A
Average Switch Current (I_{AVG})	1A
Junction Temperature	150ºC
Storage Temperature Range	–65ºC to 150ºC
Lead Temperature (Soldering 10 sec)	260ºC
Thermal Resistance (θ_{JA})	160ºC/W

OPERATING CONDITIONS

Temperature Range	
ML4872CS-X	0ºC to 70ºC
ML4872ES-X	–20ºC to 70ºC
V_{IN} Operating Range	
ML4872CS-X	1.8V to V_{OUT} – 0.2V
ML4872ES-X	2.0V to V_{OUT} – 0.2V

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, V_{IN} = Operating Voltage Range, T_A = Operating Temperature Range (Note 1).

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
SUPPLY							
I_{IN}	V_{IN} Current	$V_{IN} = V_{OUT} - 0.2V$			2	5	µA
$I_{OUT(Q)}$	V_{OUT} Quiescent Current	SHDN = 0V			25	35	µA
		SHDN = V_{IN}			15	22	µA
$I_{L(Q)}$	V_L Quiescent Current					1	µA
PFM REGULATOR							
	I_L Peak Current			1.2	1.4	1.7	A
V_{OUT}	Output Voltage	$I_{L(PEAK)} = 0$	-3 Suffix	3.30	3.35	3.40	V
			-5 Suffix	4.95	5.05	5.15	V
	Load Regulation	See Figure 1, -3 Suffix V_{IN} = 2.4V, I_{OUT} = 400mA		3.20	3.25	3.40	V
		See Figure 1, -5 Suffix V_{IN} = 2.4V, I_{OUT} = 220mA		4.85	4.95	5.15	V
SHUTDOWN							
	Input Bias Current			–100		100	nA
	Shutdown Threshold	V_{SHDN} = high to low		0.4	0.6	1.1	V

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

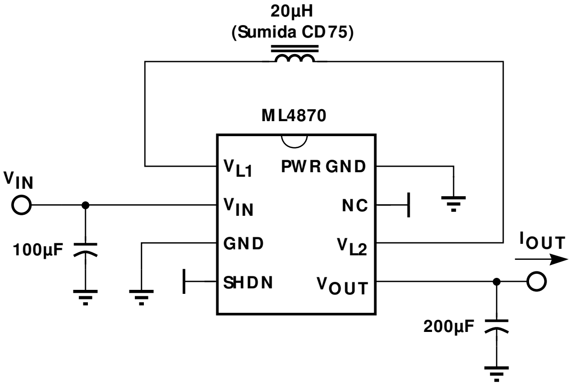


Figure 1. Application Test Circuit

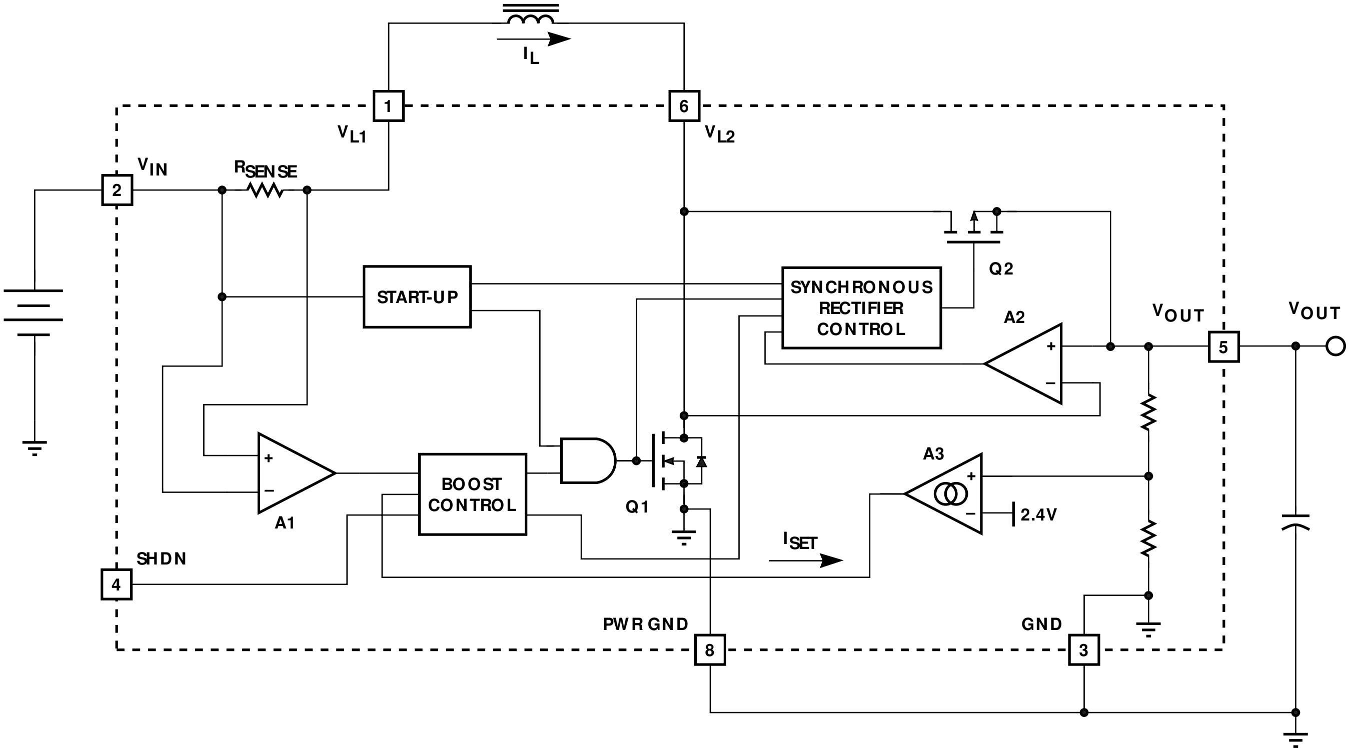


Figure 2. PFM Regulator Block Diagram

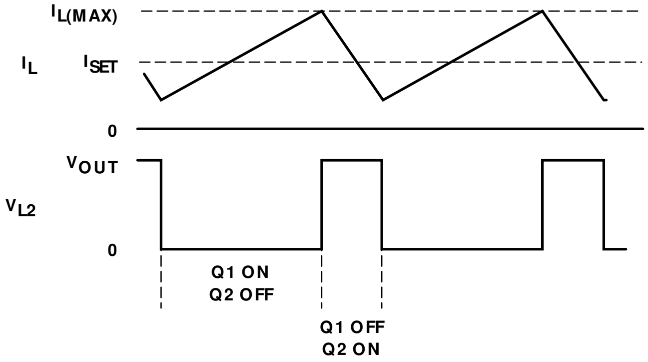


Figure 3. Inductor Current and Voltage Waveforms

FUNCTIONAL DESCRIPTION

The ML4872 combines a unique form of current mode control with a synchronous rectifier to create a boost converter that can deliver high currents while maintaining high efficiency. Current mode control allows the use of a very small, high frequency inductor and output capacitor. Synchronous rectification replaces the conventional external Schottky diode with an on-chip PMOS FET to reduce losses and eliminate an external component. Also included on-chip are an NMOS switch and current sense resistor, further reducing the number of external components, which makes the ML4872 very easy to use.

REGULATOR OPERATION

The ML4872 is a variable frequency, current mode switching regulator. Its unique control scheme converts efficiently over more than three decades of load current. A block diagram of the boost converter is shown in Figure 2.

Error amp A3 converts deviations in the desired output voltage to a small current, I_{SET}. The inductor current is measured through a 50mΩ resistor which is amplified by A1. The boost control block matches the average inductor current to a multiple of the I_{SET} current by switching Q1 on and off. The peak inductor current is limited by the controller to about 1.5A.

At light loads, I_{SET} will momentarily reach zero after an inductor discharge cycle , causing Q1 to stop switching. Depending on the load, this idle time can extend to tenths of seconds. While the circuit is not switching, only 20µA of supply current is drawn from the output. This allows the part to remain efficient even when the load current drops below 200µA.

Amplifier A2 and the PMOS transistor Q2 work together to form a low drop diode. When transistor Q1 turns off, the current flowing in the inductor causes pin 6 to go high. As the voltage on V_{L2} rises above V_{OUT}, amplifier A2 allows the PMOS transistor Q2 to turn on. In discontinuous operation, (where I_L always returns to zero), A2 uses the resistive drop across the PMOS switch Q2 to sense zero inductor current and turns the PMOS switch off. In continuous operation, the PMOS turn off is independent of A2, and is determined by the boost control circuitry.

Typical inductor current and voltage waveforms are shown in Figure 3.

SHUTDOWN

The SHDN pin should be held low for normal operation. Raising the shutdown voltage above the threshold level will disable the synchronous rectifier and force I_{SET} to zero. This prevents switching from occurring, and the output voltage becomes $V_{IN} - V_{DIODE}$.

DESIGN CONSIDERATIONS

OUTPUT CURRENT CAPABILITY

The maximum current available at the output of the regulator is related to the maximum inductor current by the ratio of the input to output voltage and the full load efficiency. The maximum inductor current is approximately 1.25A and the full load efficiency may be as low as 70%. The maximum output current can be determined by using the typical performance curves shown in Figures 4 and 5, or by calculation using the following equation:

$$I_{OUT(MAX)} = 1.25 \times \left(\frac{V_{IN(MIN)}}{V_{OUT}}\right) \times 0.7A \qquad (1)$$

INDUCTOR SELECTION

The ML4872 is able to operate over a wide range of inductor values. A value of 10µH is a good choice, but any value between 5µH and 33µH is acceptable. As the inductor value is changed the control circuitry will automatically adjust to keep the inductor current under control. Choosing an inductance value of less than 10µH will reduce the component's footprint, but the efficiency and maximum output current may drop.

It is important to use an inductor that is rated to handle 1.5A peak currents without saturating. Also look for an inductor with low winding resistance. A good rule of thumb is to allow 5 to 10mΩ of resistance for each µH of inductance.

The final selection of the inductor will be based on trade-offs between size, cost and efficiency. Inductor tolerance, core and copper loss will vary with the type of inductor selected and should be evaluated with a ML4872 under worst case conditions to determine its suitability.

Several manufacturers supply standard inductance values in surface mount packages:

Coilcraft	(847) 639-6400
Coiltronics	(561) 241-7876
Dale	(605) 665-9301
Sumida	(847) 956-0666

DESIGN CONSIDERATIONS (Continued)

OUTPUT CAPACITOR

The output capacitor filters the pulses of current from the switching regulator. Since the switching frequency will vary with inductance, the minimum output capacitance required to reduce the output ripple to an acceptable level will be a function of the inductor used. Therefore, to maintain an output voltage with less than 100mV of ripple at full load current, use the following equation:

$$C_{OUT} = \frac{44 \times L}{V_{OUT}} \tag{2}$$

The output capacitor's Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL), also contribute to the ripple. Just after the NMOS transistor, Q1, turns off, the current in the output capacitor ramps quickly to between 0.5A and 1.5A. This fast change in current through the capacitor's ESL causes a high frequency (5ns) spike to appear on the output. After the ESL spike settles, the output still has a ripple component equal to the inductor discharge current times the ESR. To minimize these effects, choose an output capacitor with less than 10nH of ESL and 100mΩ of ESR.

Suitable tantalum capacitors can be obtained from the following vendors:

AVX	(207) 282-5111
Kemet	(846) 963-6300
Sprague	(207) 324-4140

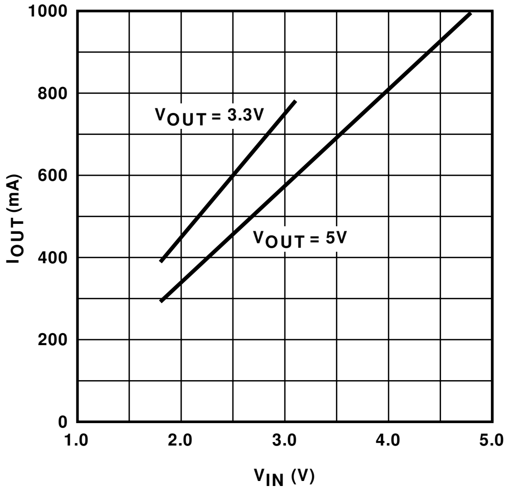


Figure 4. I_{OUT} vs. VIN Using the Circuit of Figure 8

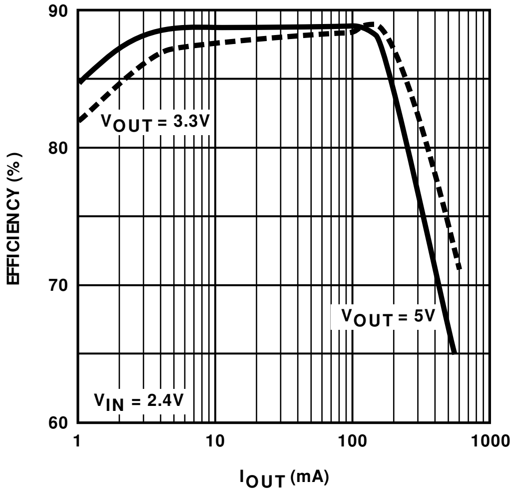


Figure 5. Efficiency vs. I_{OUT} Using the Circuit of Figure 8

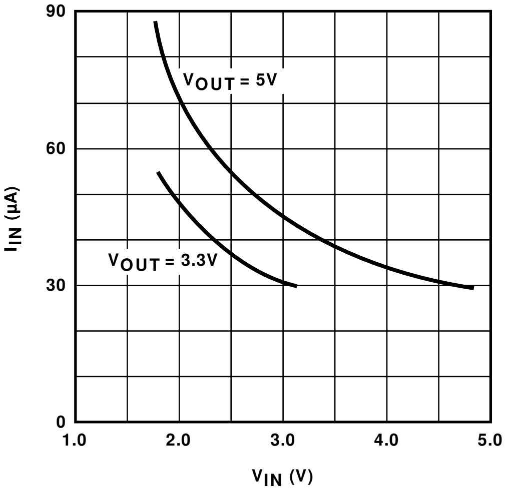


Figure 6. No Load Input Current vs. V_{IN}

DESIGN CONSIDERATIONS (Continued)

INPUT CAPACITOR

Due to the high input current drawn at startup and possibly during operation, it is recommended to decouple the input with a capacitor with a value of 47µF to 100µF. This filtering prevents the input ripple from affecting the ML4872 control circuitry, and also improves the efficiency by reducing the I squared R losses during the charge cycle of the inductor. Again, a low ESR capacitor (such as tantalum) is recommended.

It is also recommended that low source impedance batteries be used. Otherwise, the voltage drop across the source impedance during high input current situations will cause the ML4872 to fail to start-up or to operate unreliably. In general, for two cell applications the source impedance should be less than 200mΩ, which means that small alkaline cells should be avoided.

LAYOUT

Good layout practices will ensure the proper operation of the ML4872. Some layout guidelines follow:

- Use adequate ground and power traces or planes
- Keep components as close as possible to the ML4872
- Use short trace lengths from the inductor to the V_{L1} and V_{L2} pins and from the output capacitor to the V_{OUT} pin
- Use a single point ground for the ML4872 ground pin, and the input and output capacitors
- Separate the ground for the converter circuitry from the ground of the load circuitry and connect at a single point

A sample layout is shown in Figure 7.

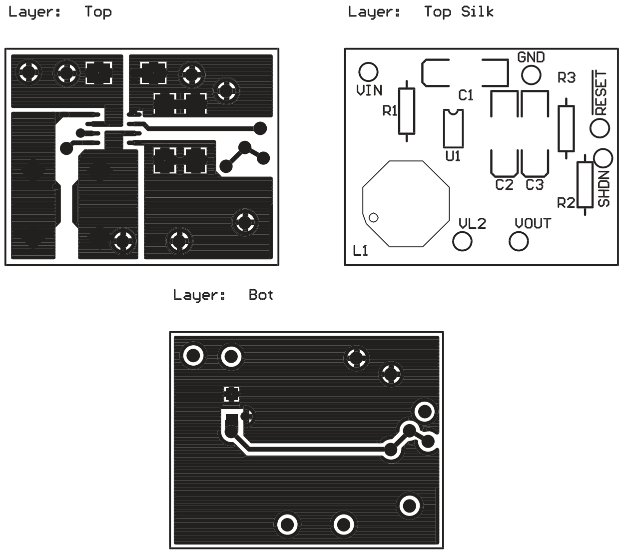


Figure 7. Sample PC Board Layout

DESIGN EXAMPLE

In order to design a boost converter using the ML4872, it is necessary to define a few parameters. For this example, assume that V_{IN} = 3.0V to 3.6V, V_{OUT} = 5.0V, and $I_{OUT(MAX)}$ = 500mA.

First, it must be determined whether the ML4871 is capable of delivering the output current. This is done using Equation 1:

$$I_{OUT(MAX)} = 1.25 \times \left(\frac{3.0V}{5.0V}\right) \times 0.7A = 0.53A$$

Next, select an inductor. As previously mentioned, the recommended inductance is 10µH. Make sure that the peak current rating of the inductor is at least 1.5A, and that the DC resistance of the inductor is in the range of 50 to 100mΩ.

Finally, the value of the output capacitor is determined using Equation 2:

$$C_{OUT} = \frac{44 \times 10\mu H}{5.0V} = 88\mu F$$

The closest standard value would be a 100µF capacitor with an ESR rating of 100mΩ. If such a low ESR value cannot be found, two 47µF capacitors in parallel could also be used.

The complete circuit is shown in Figure 8. As mentioned previously, the use of an input supply bypass capacitor is highly recommended.

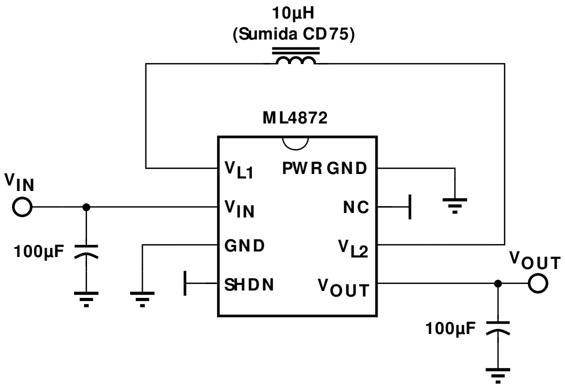


Figure 8. Typical Application Circuit

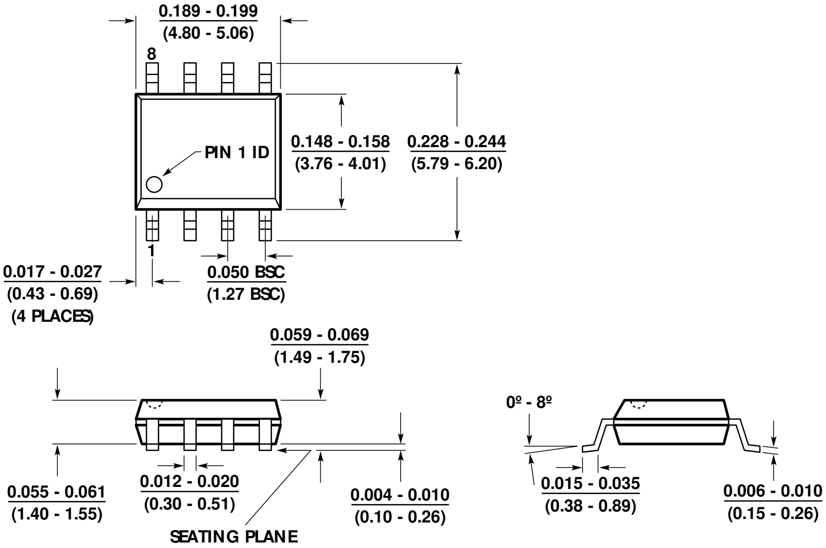
V_{IN} (V)	$I_{OUT(MAX)}$ (mA)	
	V_{OUT} = 3.3V	V_{OUT} = 5.0V
1.8	386.2	286.2
2.0	451.9	332.1
2.2	521.5	379.1
2.4	585.9	430.0
2.6	651.0	479.0
2.8	716.5	525.4
3.0	782.0	571.8
3.2		618.5
3.4		665.0
3.6		711.7
3.8		758.7
4.0		805.3
4.2		851.9
4.4		899.0
4.6		946.1
4.8		992.7

I_{OUT} (mA)	EFFICIENCY PERCENTAGE
V_{IN} = 2.4V, V_{OUT} = 3.3V	
1.0	82.0
2.0	84.4
5.0	87.0
10.0	87.6
20.0	87.9
50.0	88.3
100.0	88.6
200.0	88.2
586.0	65.1
V_{IN} = 2.4V, V_{OUT} = 5.0V	
1.0	84.4
2.0	87.0
5.0	87.7
10.0	88.4
20.0	88.9
50.0	89.1
100.0	88.9
200.0	87.5
485.0	71.6

Table 1. Typical I_{OUT} and Efficiency vs. V_{IN}

PHYSICAL DIMENSIONS inches (millimeters)

Package: S08
8-Pin SOIC



ORDERING INFORMATION

PART NUMBER	OUTPUT VOLTAGE	TEMPERATURE RANGE	PACKAGE
ML4872CS-3	3.3V	0ºC to 70ºC	8-Pin SOIC (S08)
ML4872CS-5	5.0V	0ºC to 70ºC	8-Pin SOIC (S08)
ML4872ES-3	3.3V	–20ºC to 70ºC	8-Pin SOIC (S08)
ML4872ES-5	5.0V	–20ºC to 70ºC	8-Pin SOIC (S08)

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