

3.3V Output DC-DC Step-Down Converter

GENERAL DESCRIPTION

The ML4866 is a high efficiency pulse width modulated (PWM) buck regulator designed for use in 5V systems or portable equipment that need a compact, efficient 3.3V supply. It has a switching frequency of 120kHz and uses synchronous rectification to optimize power conversion efficiency. Unlike other solutions, the ML4866 requires no external diodes or FETs.

The ML4866 can provide up to 500mA of output current, and operates over an input voltage range of 3.5V to 6.5V (3 to 4 cells or a 5 VDC supply). A complete switched mode power converter can be quickly and easily implemented with few external components. Thanks to a built-in autoburst mode, power conversion efficiency of this DC-DC converter can exceed 90% over more than 2 decades of output load current.

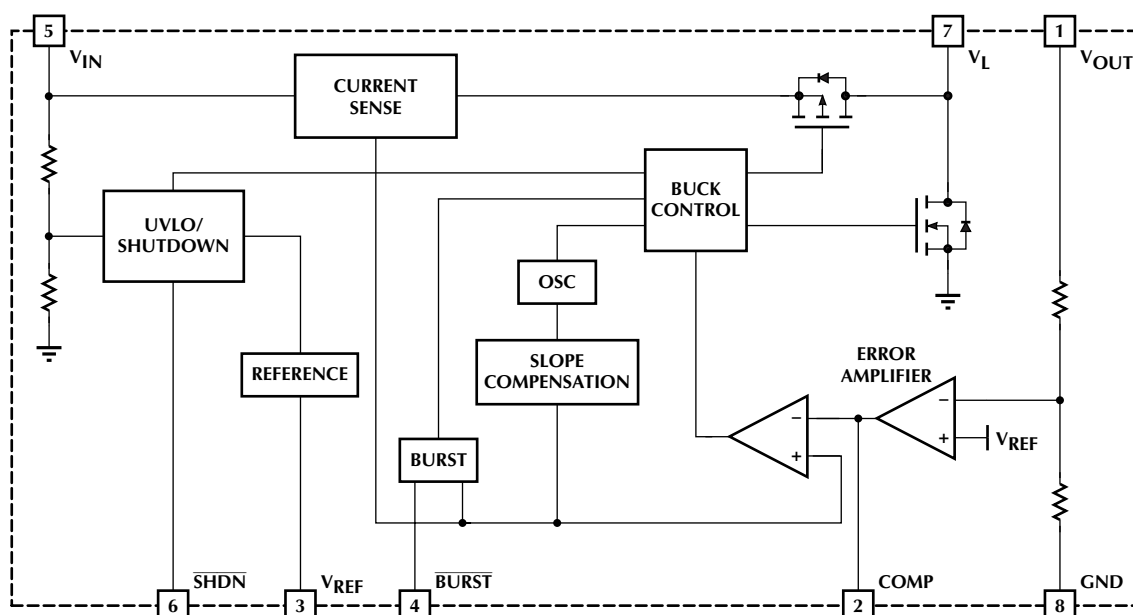
Stability and fast loop response are provided by current programming and a current sense circuit. The ML4866 also has a $\overline{\text{SHDN}}$ pin for use in systems which have power management control. Undervoltage lockout and soft start are also built in.

FEATURES

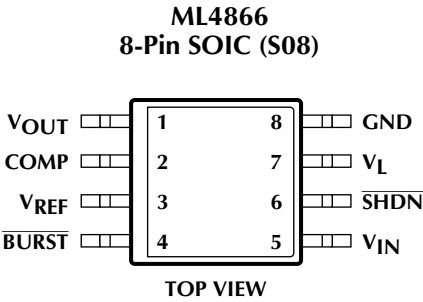
- High power conversion efficiency over 2 decades of load current
- No external FETs or diodes; minimum external components
- 3.5V to 6.5V input voltage range
- Significantly extends battery life over linear regulator based solutions
- Micropower operation
- Low shutdown mode quiescent current

(* Indicates Part is End Of Life as of July 1, 2000)

BLOCK DIAGRAM



PIN CONFIGURATION



PIN DESCRIPTION

PIN	NAME	FUNCTION	PIN	NAME	FUNCTION
1	V _{OUT}	Regulated 3.3V output	5	V _{IN}	Input voltage
2	COMP	Connection point for an external compensation network	6	SHDN	Pulling this pin low shuts down the regulator
3	V _{REF}	1.25V reference output	7	V _L	Buck inductor connection
4	BURST	This pin controls when the control circuit switches between PWM and PFM modes of operation	8	GND	Ground

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

OPERATING CONDITIONS

Temperature Range

ML4866CS	0°C to 70°C
ML4866ES	-20°C to 70°C
ML4866IS	-40°C to 85°C
V_{IN} Operating Range	3.5V to 6.5V

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, $V_{IN} = 5V$, $L = 50\mu H$, $C_{OUT} = 100\mu F$, $R_{COMP} = 390k\Omega$, $C_{COMP} = 15nF$, T_A = Operating Temperature Range (Note 1)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
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REFERENCE

V_{REF}	Output Voltage	$0 < I(V_{REF}) < -5\mu A$, $I_{OUT} = 0mA$	1.22	1.25	1.27	V
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PWM REGULATOR

f_{OSC}	Oscillator Initial Accuracy	$I_{OUT} = 200mA$, $T_A = 25^\circ C$	100	115	165	kHz
	Oscillator Total Variation	Line and Temp	90	130	185	kHz
	Soft Start V_{IN} to V_{OUT} Delay			3	5	ms
	BURST Burst Mode Threshold		250	400		mV
	BURST PWM Mode Threshold			500	850	mV
	BURST Bias Current				35	μA
	Output Voltage	$I_{OUT} = 200mA$	3.2	3.3	3.4	V
		$I_{OUT} = 20mA$, $\overline{BURST} = 0V$	3.28	3.38	3.48	V
	Line Regulation	$V_{IN} = 4V$ to $6.5V$, $T_A = 25^\circ C$			± 2	%
	Load Regulation	$I_{OUT} = 100mA$ to $500mA$, $T_A = 25^\circ C$			± 2.5	%
		$I_{OUT} = 5mA$ to $100mA$, $\overline{BURST} = 0V$, $T_A = 25^\circ C$			± 2.5	%
	Temperature Stability	$T_A = -40^\circ C$ to $85^\circ C$			± 1	%
	Total Variation	Line, Load, Temp			± 5	%

SHUTDOWN

	UVLO Startup Threshold		3.2		3.5	V
	UVLO Shutdown Threshold		2.9		3.1	V
	\overline{SHDN} Threshold			2		V
	\overline{SHDN} Bias Current				-5	μA

ELECTRICAL CHARACTERISTICS (Continued)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
SUPPLY						
I_{IN}	V_{IN} Current	$I_{OUT} = 0\text{mA}$, $\overline{BURST} = 5\text{V}$		400	500	μA
		$I_{OUT} = 0\text{mA}$, $\overline{BURST} = 0\text{V}$		120	220	μA
		$\overline{SHDN} = 0\text{V}$		20	35	μA

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

FUNCTIONAL DESCRIPTION

The ML4866 is a current-mode, step-down (buck) converter designed to keep the buck inductor current in the continuous conduction mode (CCM). Current-mode operation provides faster output response to input voltage and output current changes along with cycle-by-cycle current limiting. CCM inductor current is preferred when the highest conversion efficiencies are required.

For high efficiencies at low output current, the ML4866 contains an autoburst function which automatically switches from pulse width modulation (PWM) to pulsed frequency modulation (PFM) operation when the output current drops below 100mA. Selection of either mode is possible by applying the correct logic level signal to the \overline{BURST} pin. When operating in PWM mode, loop compensation of the ML4866 is simplified due to its transconductance type error amplifier.

An under voltage lockout (UVLO) circuit within the ML4866 enables the converter when the input voltage is greater than 3.25V and disables it when the input voltage is below 3.10V. The IC can also be disabled externally by applying a logic low signal to the \overline{SHDN} pin. When disabled, the ML4866 draws less than 20 μA of current.

The internal 1.25V bandgap reference is made available via the V_{REF} pin, and may be used for general applications requiring less than 10 μA of current. For proper operation, this pin must always be bypassed to GND with a 100nF capacitor.

BURST MODE

Burst (PFM) mode is a method of regulating the output voltage by applying a variable frequency modulation technique to the buck inductor. This method maintains higher efficiencies at light loads than if PWM were used.

If \overline{BURST} is left open, the ML4866 switches from PWM mode to PFM mode when the output current falls below 100mA. When the output voltage falls out of regulation while in PFM mode, the internal buck switch turns on and ramps the inductor current up to 300mA. The buck switch then turns off and the synchronous switch turns on,

ramping the inductor current down to 0mA. This action is repeated until the output voltage returns to its nominal setting and begins again when the output drops below its nominal setting. The rate or frequency at which this "bursting" occurs is directly proportional to the output current. When the average output current rises above 130mA, the ML4866 returns to PWM operation.

For applications having a load current range of less than 100mA and greater than 130mA, the \overline{BURST} pin should be left open and bypassed to ground with a 15nF or larger capacitor. It is possible to tailor an application for the highest possible efficiency by externally forcing the ML4866 into either control mode. Applying a logic low level to \overline{BURST} forces the IC into PFM mode. Conversely, a logic high places it in PWM mode. Care should be taken to avoid reducing the efficiency by placing the controller in the least efficient mode for a given output current.

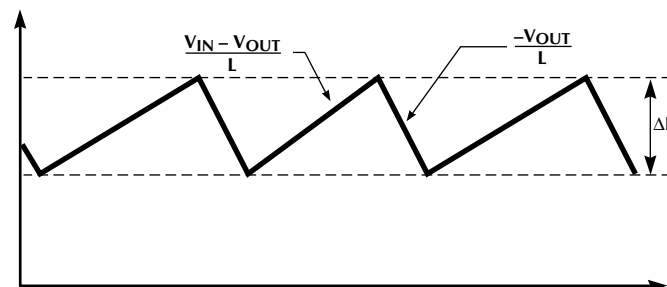


Figure 1. Inductor Current

DESIGN CONSIDERATIONS

INDUCTOR SELECTION

Figure 1 shows the inductor current in a step-down converter operating in CCM. Note that the inductor current does not reach zero during each switching cycle. This is unlike discontinuous conduction mode (DCM) where the inductor current is allowed to reach zero. CCM operation generally results in lower peak to peak output ripple voltage and higher circuit efficiencies because of lower peak and RMS currents in the switching FETs and buck inductor. The minimum value of inductance required for CCM operation with a 6.5V input and a load range of 100mA to 500mA is:

$$L > \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{2 \times V_{IN(MAX)} \times I_{OUT(MIN)} \times f_{SW}} \quad (1)$$

$$L > \frac{3.3V \times (6.5V - 3.3V)}{2 \times 6.5V \times 100mA \times 120kHz} > 68\mu H$$

To guarantee reliable operation, the peak inductor current must be between 80% and 85% of its maximum rated value. This value is the sum of the inductor peak to peak current and the maximum output current:

$$I_{L(P-P)} = \frac{2 \times V_{OUT(MAX)} \times (V_{IN(MIN)} - V_{OUT(MAX)})}{V_{IN(MIN)} \times f_{SW(MIN)} \times L} \quad (2)$$

$$I_{L(P-P)} = \frac{2 \times 3.465V \times (4.0V - 3.465V)}{4.0V \times 90kHz \times 100\mu H} = 103mA$$

$$I_{L(PEAK)} = I_{OUT(MAX)} + \frac{V_{OUT(MAX)} \times (V_{IN(MIN)} - V_{OUT(MAX)})}{V_{IN(MIN)} \times f_{SW} \times L} \quad (3)$$

$$I_{L(PEAK)} = I_{OUT(MAX)} + \frac{3.465V \times (4.0V - 3.465V)}{4.0V \times 120kHz \times 100\mu H} = 550mA$$

For the highest efficiency, inductor core and copper losses must be minimized. Good high frequency core material such as Kool-Mu, ferrite or Molyperm are popular choices for this converter. Disregarding physical size requirements, the lowest loss inductor will generally be the one with the highest peak current rating.

Figure 2 displays the efficiency of the ML4866 under various input voltage and output current conditions. These results were obtained using a Coiltronics CTX100-4 inductor having the following specifications:

Nominal Inductance - 100μH

Peak Current Rating - 950mA

DC Resistance - 175mΩ

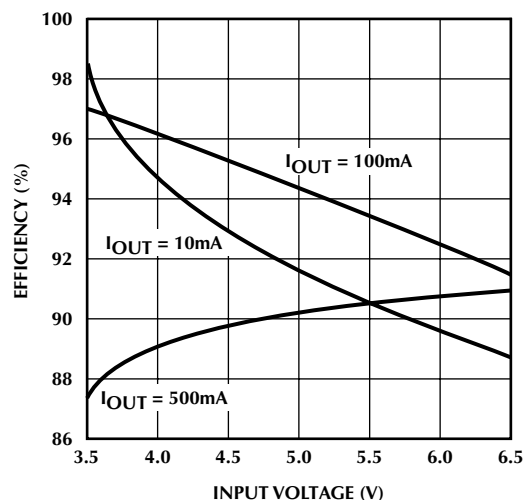


Figure 2. Efficiency vs. Input Voltage

A partial listing of inductor manufacturers with standard parts which meet the criteria for use with the ML4866 is given below.

Coiltronics	(561) 241-7876
Dale	(605) 665-9301
Coilcraft	(847) 639-6400
XFMRS, Inc	(317) 834-1066
Sumida	(847) 956-0666

CAPACITOR SELECTION

A typical digital system requires a peak to peak output ripple voltage of no greater than 1% to 3% of the nominal output voltage. In a step-down converter, the largest contributor to ripple voltage is almost always the product of the inductor peak-to-peak current times the output capacitor's equivalent series resistance. To select the correct capacitor, first calculate the minimum capacitance value required:

$$C_{OUT} > \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{8 \times V_{P-P(MAX)} \times V_{IN(MAX)} \times L \times f_{SW}^2} \quad (4)$$

$$C_{OUT} > \frac{3.3 \times (6.5V - 3.3V)}{8 \times 33mV \times 6.5V \times 100\mu H \times 120kHz^2} > 4.27\mu F$$

Next, calculate the maximum permissible ESR of the output capacitor:

$$ESR < \frac{(0.033)}{(0.1)} < 0.33\Omega \quad (5)$$

When limited space is available, tantalum capacitors are the best choice. Electrolytic capacitors can be used and will be less expensive, but the ESR for low capacitance values as needed here will be much higher than for the same value tantalum. Table 2 lists the ESR values for a number of general purpose tantalum capacitors which are widely available from a number of sources. A 47μF capacitor was chosen for the design example.

DESIGN CONSIDERATIONS (Continued)

FREQUENCY COMPENSATION

Frequency compensation of the ML4866 is required when the converter is operating in PWM mode. Two simple methods are provided to ensure the converter is frequency stable. Both these methods will work only if the inductor current is selected to be in CCM at the maximum load current (see Inductor Selection). The first, called dominant pole compensation, is used when non-varying loads are expected. This method requires a single capacitor connected from the error amplifier output (COMP Pin) to ground.

For loads which change suddenly, the transient response (or bandwidth) of the circuit must be increased to prevent the output voltage from going outside of the regulation band. The method used to accomplish this is called zero/pole compensation and requires a series resistor capacitor network from COMP to ground.

To determine which method works best for a given application, apply the components found from the zero/pole compensation method to an actual circuit and examine the output voltage variation. If the voltage variation is acceptable, connect the simpler, single capacitor and re-check the output voltage for acceptable load transient response.

NON-VARYING LOAD CURRENT

For the best possible response to load transients using only a single capacitor, dominant pole compensation is implemented with a single capacitor value of:

$$C_{\text{COMP}} = \frac{g_m}{2 \times f_{\text{COMP}}} \quad (6)$$

Where f_{COMP} is the unity gain crossover point (640Hz), $g_m = 62.5\mu\text{mho}$, and $C_{\text{COMP}} > 15.5\text{nF}$ (choose a standard 18nF or 22nF capacitor). The value of C_{COMP} can be increased but at the risk of increased output voltage variations with transient loads.

CAPACITANCE	VOLTAGE RATING	SIZE	ESR @ 100kHz
4.7 μF	16V	3216	0.490 Ω
10 μF	6.3V	3216	0.368 Ω
22 μF	16V	7343	0.149 Ω
33 μF	6.3V	6032	0.291 Ω
47 μF	10V	7343	0.144 Ω
100 μF	6.3V	7343	0.088 Ω

Table 2. ESR Values for Low Cost Tantalum Capacitors

VARYING LOAD CURRENT

To minimize output voltage variations due to rapidly changing load currents, use the series RC zero compensation method to find the compensation network component values that will improve the output voltage response to load transients.

The unity gain bandwidth of the converter is extended to 15kHz using an RC network determined by:

$$R_{\text{COMP}} > \frac{G}{g_m}, \text{ where } G = \frac{f_o}{f_{\text{COMP}}} \quad (7)$$

$$C_{\text{COMP}} = \frac{1}{50\pi \times R_{\text{COMP}}} \quad (8)$$

Where $f_o = 15\text{kHz}$, $f_{\text{COMP}} = 640\text{Hz}$, $R_{\text{COMP}} > 375\text{k}\Omega$ (use 390k Ω , 5%), and $C_{\text{COMP}} = 16\text{nF}$ (use 15nF).

Either method of compensation for CCM mode with result in continued stability as the ML4866 changes to DCM mode at lighter load currents. Figure 3 shows a typical application circuit for the ML4866.

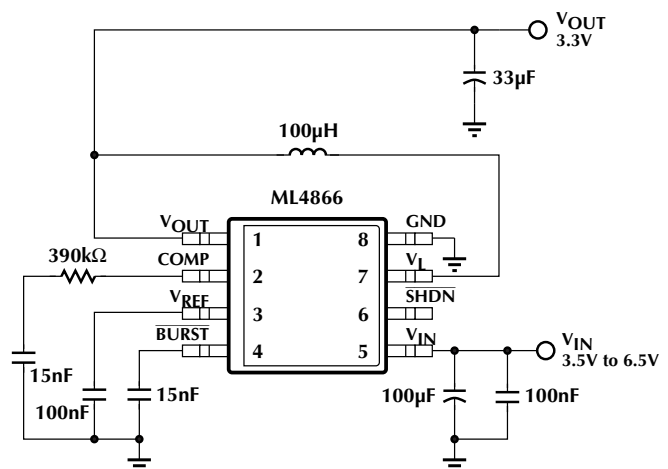


Figure 3. Typical Application Circuit

LAYOUT

For proper performance, all components should be placed as close to the ML4866 as possible. Particular attention should be paid to minimize the length of the connections between the COMP and V_{REF} pins to GND. Also avoid bringing these traces and the associated components close to V_L .

It is always recommended that a $10\mu\text{F}$ or greater capacitor be connected to V_{IN} of the ML4866. A $33\mu\text{F}$ tantalum capacitor and 100nF film or ceramic capacitor is recommended when powering the ML4866 from Lithium or Alkaline cells.

Ground and power planes must be large enough to carry the current the converter has been designed to supply.

A sample PC board layout is shown in Figure 4.

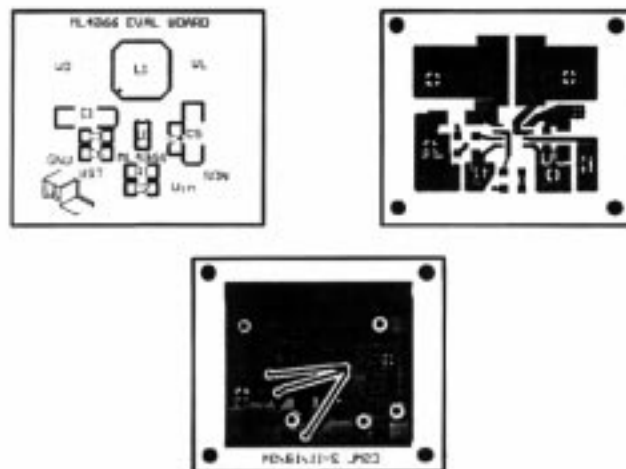
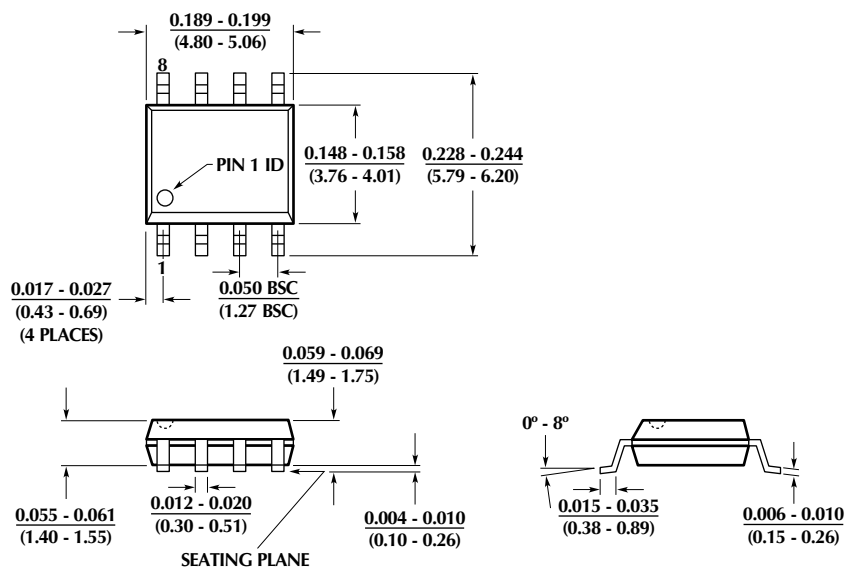


Figure 4. Sample PC Board Layout

PHYSICAL DIMENSIONS inches (millimeters)

Package: S08
8-Pin SOIC



ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ML4866CS (End Of Life)	0°C to 70°C	8-Pin SOIC (S08)
ML4866ES (EOL)	-20°C to 70°C	8-Pin SOIC (S08)
ML4866IS (Obsolete)	-40°C to 85°C	8-Pin SOIC (S08)

DS4866-01

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