

MCP1601

500 mA Synchronous BUCK Regulator

Features

- Input Range of 2.7V to 5.5V
- 3 Operating Modes: PWM, PFM and LDO
- Integrated BUCK and Synchronous Switches
- Ceramic or Electrolytic Input/Output Filtering Capacitors
- 750 kHz Fixed Switching Frequency
- Oscillator Synchronization to 1 MHz PWM Mode
- Auto-Switching from PWM/PFM Operation
- 100% Duty Cycle Capable for Low Input Voltage
- 500 mA Continuous Output Current Capability
- Integrated Under-Voltage Lock-Out Protection
- Integrated Over-Temperature Protection
- Integrated Soft Start Circuitry
- Low Output Voltage Capability to 0.9V
- Temperature Range: -40°C to +85°C
- Small 8-Pin MSOP Package

Applications

- Low Power Handheld CPUs and DSPs
- Cellular Phones
- Organizers and PDAs
- Digital Cameras
- +5V or +3.3V Distributed Voltages
- USB Powered Devices

Package Type



Description

The MCP1601 is a fully integrated synchronous BUCK (step down) DC/DC converter for battery powered systems. With an input operating range of 2.7V to 5.5V, the MCP1601 is ideal for applications being powered by one single cell Li-Ion, 2 to 3 cell NiMH, NiCd or alkaline sources. Output voltages can range from 0.9V to V_{IN} to accommodate a wide range of applications. Efficiency can exceed 92% while operating at 750 kHz with load current capability up to 500 mA. The MCP1601 is used to minimize space, cost and wasted energy.

The PWM mode switching frequency is internally set to a fixed 750 kHz allowing the use of low profile, surface mount inductors and ceramic capacitors while maintaining a typical efficiency of 92%.

The MCP1601 is capable of three distinct operating modes: PWM, PFM and Low Drop Out.

When operating in PWM (pulse width modulation) mode, the DC/DC converter switches at a single high frequency determined by either the internal 750 kHz oscillator or external synchronization frequency.

For applications that operate at very light to no load for extended periods of time, the MCP1601 is capable of operating in PFM (pulse frequency modulation mode) to reduce the number of switching cycles/sec and consume less energy.

The third mode of operation (LDO mode) occurs when the input voltage approaches the output voltage and the BUCK duty cycle approaches 100%. The MCP1601 will enter a low drop out mode and the high-side P-Channel BUCK switch will saturate, providing the output with the maximum voltage possible.

The MCP1601 has integrated over-current protection, over-temperature protection and UVLO (Under Voltage Lockout) to provide for a fail safe solution with no external components.

The MCP1601 is available in the 8-pin MSOP package, with an operating temperature range of -40° C to $+85^{\circ}$ C.

Typical Application



Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V _{IN} - A _{GND}	6.0V
SHDN, FB, SYNC/PWM, VOUT (AGNE	-0.3V) to (V _{IN} +0.3V)
L _X to P _{GND}	0.3V to (V _{IN} +0.3V)
P _{GND} to A _{GND}	-0.3V to +0.3V
Output Short Circuit Current	continuous
Storage temperature	65°C to +150°C
Ambient Temp. with Power Applied	40°C to +85°C
Operating Junction Temperature	40°C to +125°C
ESD protection on all pins	> 4 kV

† Notice: Stresses above those listed under "Maximum ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

PIN FUNCTION TABLE

NAME	FUNCTION		
V _{IN}	Input Source Voltage		
SHDN	Device Shutdown Pin		
FB	Output Voltage Feedback Input		
A _{GND}	Analog Ground		
V _{OUT}	Sensed Output Voltage		
SYNC/PWM	Synchronous Clock input or PWM/ PFM select		
P _{GND}	Power Ground		
L _X	Output Inductor Node		

ELECTRICAL SPECIFICATIONS

Electrical Specifications: Unless otherwise indicated, V_{IN} =4.2V, V_{OUT} =1.8V, I_{LOAD} = 10 mA, T_A =-40°C to +85°C.								
Parameters	Sym	Min	Тур	Max	Units	Conditions		
Power Input Requirements								
Voltage	V _{IN}	2.7	_	5.5	V	$I_{LOAD} = 0$ mA to 500 mA		
Shutdown Current	I(V _{IN})	_	0.05	1.0	μA	Shutdown Mode (SHDN = GND)		
PFM Mode Current	I(V _{IN})		119	180	μA	SYNC/PWM = GND, PFM Mode (I _{LOAD} = 0 mA)		
Oscillator Section								
Internal Oscillator Frequency	F _{OSC}	650	750	850	kHz	SYNC/PWM = V_{IN}		
External Oscillator Capture Range	F _{SYNC}	850	—	1000	kHz	F _{SYNC} > F _{OSC}		
External Oscillator Duty Cycle	F _{SYN-FALL}	10	_	90	%	F _{SYNC} = 1 MHz		
Internal Power Switches								
R _{DSon} P-CHANNEL	R _{DSon-P}	_	500	_	mΩ	I _P =100 mA, T _A =+25°C, V _{IN} =4.2V		
R _{DSon} N-CHANNEL	R _{DSon-N}	_	500	_	mΩ	I _N =100 mA, T _A =+25°C, V _{IN} =4.2V		
Dropout Voltage	V _{DROPOUT}	_	250	_	mV	V _{OUT} = 2.7V, I _{LOAD} = 300 mA, T _A =+25°C, V _{DROPOUT} =97%V _{OUT}		
Pin Leakage Current	I _{LX}	-1.0	—	1.0	μA	$\overline{\text{SHDN}} = 0$ V, V _{IN} = 5.5V, L _X = 0V, L _X = 5.5V		
Output PWM Mode								
Peak Current Limit	I _{PEAK-PWM}	_	1.0	_	A	PWM Mode, SYNC/PWM = V_{IN} , T_A = +25°C		
Output Voltage								
Output Voltage Range	V _{OUT}	0.9	_	V _{IN}	V			
Reference Feedback Voltage	V _{FB}	0.78	0.8	0.82	V			
Feedback Input Bias Current	I _{VFB}		0.1		nA			
Line Regulation	V _{LINE-REG}	_	0.1	_	%/V	V_{IN} =2.7V to 5.5V, I_{LOAD} =10 mA		
Load Regulation	V _{LOAD-REG}	_	1.5	_	%	$V_{IN} = 3.6V,$ $I_{LOAD} = 0$ mA to 300 mA		
Start-Up Time	T _{START}	_	0.5	_	ms	PWM Mode, SYNC/PWM=V _{IN}		

ELECTRICAL SPECIFICATIONS (CONTINUED)

Electrical Specifications: Unless otherwise indicated, V _{IN} =4.2V, V _{OUT} =1.8V, I _{LOAD} = 10 mA, T _A =-40°C to +85°C.							
Parameters	Sym Min Typ Max Units Con		Conditions				
Protection Features	Protection Features						
Average Short Circuit Current			890	—	mA	R _{LOAD} < 1 ohm	
Under-Voltage Lockout	UVLO	2.4		2.7	V	For V _{IN} decreasing	
Under-Voltage Lockout Hysteresis	UVLO- _{HYS}		190	_	mV		
Thermal Shutdown	T _{SHD}		160	—	°C		
Thermal Shutdown Hysteresis	T _{SHD-HYS}		10	—	°C		
Interface Signals (SHDN, SYNC/PWM)							
Logic Low Input	V _{IN-HIGH}			15	% of		
					V _{IN}		
Logic High Input	V _{IN-HIGH}	45	—	—	% of		
					V _{IN}		
Input Leakage Current	I _{IN-LK}	_		0.1	μA		

TEMPERATURE SPECIFICATIONS

Electrical Specifications: Unless otherwise noted, all parameters apply at V _{DD} = 2.7V to 5.5V						
Parameters	Symbol	Min	Тур	Мах	Units	Conditions
Temperature Ranges						
Specified Temperature Range	T _A	-40	—	+85	°C	
Operating Junction Temperature Range	TJ	-40	_	+125	°C	
Storage Temperature Range	T _A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, 8 Pin MSOP	θ_{JA}	_	208	_	°C/W	Single-Layer SEMI G42-88 Board, Natural Convection

2.0 TYPICAL PERFORMANCE CURVES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise indicated, V_{IN} = 4.2V, V_{OUT} = 1.8V, L = 10 µH, C_{OUT} = 10 µF (X5R Ceramic), C_{IN} = 10 µF (X5R Ceramic), C_{IN} = 10 µF



FIGURE 2-1: Efficiency vs. Load Current $(V_{OUT} = 1.2V)$.



FIGURE 2-2: Efficiency vs. Load Current $(V_{OUT} = 1.8V)$.



FIGURE 2-3: Efficiency vs. Load Current $(V_{OUT} = 3.3V)$.



FIGURE 2-4: PFM Mode Quiescent Current vs. Input Voltage.



FIGURE 2-5: Input Voltage.

Oscillator Frequency vs.



FIGURE 2-6: Current.

Output Voltage vs. Load

Note: Unless otherwise indicated, V_{IN} = 4.2V, V_{OUT} = 1.8V, L = 10 µH, C_{OUT} = 10 µF (X5R Ceramic), C_{IN} = 10 µF (X5R Ceramic), C_{IN} Ceramic), SYNC/PWM=VIN.











FIGURE 2-8: Output Voltage vs. Load Current.



FIGURE 2-9: Input to Output Voltage Differential for 100% Duty Cycle vs. Load Current.



FIGURE 2-10: Switch Leakage vs. Temperature.



FIGURE 2-11: Typical PWM Mode of Operation Waveforms.



FIGURE 2-12: Typical PFM Mode of Operation Waveforms.

Note: Unless otherwise indicated, V_{IN} = 4.2V, V_{OUT} = 1.8V, L = 10 µH, C_{OUT} = 10 µF (X5R Ceramic), C_{IN} = 10 µF (X5R Ceramic), C_{IN} = 10 µF



FIGURE 2-13: Typical Startup From Shutdown Waveform.





FIGURE 2-15: (Forced PWM).



FIGURE 2-16: Load Step Response (PFM to PWM).



FIGURE 2-17: L (Forced PWM).

Line Step Response



Mode).

Note: Unless otherwise indicated, V_{IN} = 4.2V, V_{OUT} = 1.8V, L = 10 µH, C_{OUT} = 10 µF (X5R Ceramic), C_{IN} = 10 µF (X5R Ceramic), CIN = 10



FIGURE 2-19: Typical Output Ripple Voltage (Forced PWM Mode).



FIGURE 2-20: Typical Output Ripple Voltage (PFM Mode).



FIGURE 2-21: Synchronization.

External Oscillator

3.0 PIN FUNCTIONS

TABLE 3-1: PIN FUNCTION TABLE

Pin	Name	Function
1	V _{IN}	Input Voltage
2	SHDN	Shutdown Input
3	FB	Feedback Input
4	A _{GND}	Analog Ground Return
5	SYNC/ PWM	Oscillator Synchronization or PWM/ PFM Select Mode Input
6	V _{OUT}	Sensed Output Voltage Input
7	P _{GND}	Power Ground Return
8	L _X	BUCK Inductor Output

3.1 Input Voltage (V_{IN})

Connect the unregulated input voltage source to V_{IN} . If the input voltage source is located more than several inches away, or is a battery, a typical input capacitor of 10 μ F is recommended.

3.2 Shutdown Input (SHDN)

Connect SHDN to a logic low input to force the device into a shutdown low quiescent current mode. When in shutdown, both the P-Channel and N-Channel switches are turned off, in addition to the internal oscillator and other circuitry. When connected to a logic high input, the device will operate in the selected mode.

3.3 Feedback Input (FB)

Connect FB to an external resistor divider to set output voltage regulation. The feedback pin is typically equal to 0.8V. See Section 5.0, "Applications Information", for details in selecting feedback resistors.

3.4 Analog Ground Return (A_{GND})

Tie all small signal ground returns to A_{GND} . (See Section 5.6, "Printed Circuit Board Layout", for details).

3.5 Oscillator Synchronization or PWM/ PFM Select Mode Input (SYNC/PWM)

Connect an external oscillator to SYNC/PWM to synchronize. With an external oscillator present, the device is forced into a PWM-only mode of operation. For internal oscillator operation, the SYNC/PWM pin is tied high to operate in a forced PWM-only mode and low for a PWM/PFM mode of operation.

3.6 Output Voltage Sense (V_{OUT})

Connect the output voltage directly to V_{OUT} for sensing.

3.7 Power Ground Return (P_{GND})

Connect all large signal ground returns to $\mathsf{P}_{GND}.$ (See Section 5.6, "Printed Circuit Board Layout", for details).

3.8 BUCK Inductor Connection (L_X)

Connect L_X directly to the BUCK inductor. This pin carries large signal-level currents and all connections should be as short and wide as possible. (See Section 5.6, "Printed Circuit Board Layout", for details).

4.0 DEVICE OPERATION

The MCP1601 is a synchronous DC/DC converter with integrated switches. Developed to provide high efficiency across a wide line and load range, the MCP1601 integrates the three modes of operation described below. In addition to three operating modes, the MCP1601 also integrates many features that minimize external circuitry, saving board space and cost. With two external resistors used to set the output voltage, the MCP1601 output is adjustable from 0.9V to V_{IN} .

4.1 Operating Modes

The MCP1601 has three distinct modes of operation, with each one optimized for a specific operating condition commonly encountered in handheld portable power applications.

4.1.1 FEEDFORWARD VOLTAGE PULSE WIDTH MODULATION (PWM) MODE

The Pulse Width Modulation (PWM) mode of operation is desired when operating from typical to maximum output currents with the proper head room voltage at the input. This mode of operation optimizes efficiency and noise by switching at a fixed frequency. Typical output ripple voltage is less than 10 mV when using a 10 µH inductor and 10 µF ceramic capacitor. The internal operating frequency of the MCP1601 is 750 kHz, nominal. The duty cycle, or "ON" time, of the high-side, integrated, P-Channel MOSFET is determined by the continuous mode BUCK transfer function. For the continuous inductor current case, the duty cycle can be approximated by V_{OUT}/V_{IN}. The integrated high-side BUCK P-Channel switch will conduct for the "on" time. At the end of the "on" time, the high-side P-Channel switch is turned off and the integrated, low-side, N-Channel synchronous switch is turned on to freewheel the inductor current. The PWM mode architecture employed in the MCP1601 is a feedforward voltage mode control and feeds the input voltage into the PWM oscillator ramp. This information is used to quickly change the operating duty cycle in the event of a sudden input voltage change. The effects on the output voltage are minimized. To force the MCP1601 into PWM mode, the SYNC/PWM pin should be tied to a logic high. The forced PWM mode should be used for applications that require the fastest transient response from light load to heavy load or applications that require a single switching frequency independent of load.

An external oscillator between 850 kHz and 1 MHz can be connected to the SYNC/PWM pin for synchronization to an external clock source. The MCP1601 will always operate in the PWM mode when synchronized to an external oscillator.

4.1.2 PULSE FREQUENCY MODULATION (PFM) MODE

The MCP1601 is also capable of operating in a pulse frequency modulation mode. This mode of operation is desired for applications that have very long periods of inactivity and the output current requirement placed on the MCP1601 is very low. By entering the PFM mode of operation, the switching frequency becomes mainly a function of load current and will decrease as the load current decreases. By switching slower, the energy used turning "on" and "off" the high-side P-Channel and low-side N-Channel is reduced, making the PFM mode more efficient with light output load currents. When load activity is encountered, the MCP1601 will automatically switch from the PFM mode to the fixed frequency PWM mode by sensing the increase in load current. The auto PWM/PFM mode is selected by placing a logic low at the SYNC/PWM input pin. If an external clock is used to synchronize the MCP1601 switching frequency, the PFM mode is automatically disabled.

To enter the PFM mode of operation, the SYNC/PWM pin must be held to a logic low level and the peak inductor current, sensed internal to the MCP1601, is below the internal PFM threshold for more than 1024 clock cycles. If both of these conditions are met, the MCP1601 will enter the PFM mode. While in the PFM mode, the MCP1601 will disable the low-side N-Channel switch to optimize efficiency at low operating currents. A cycle will begin by turning on the high-side P-Channel switch and will end when the output voltage exceeds a predetermined voltage set point. If the peak inductor current exceeds the internal PFM mode current threshold prior to the output voltage exceeding the voltage set point, the load current has increased and the MCP1601 will automatically switch to PWM operation. The typical hysteresis on the PFM comparator is 6 mV. The typical output ripple voltage is below 40 mV when using a 10 μ H inductor and 10 μ F ceramic output capacitor when V_{IN} = 4.2V. For proper PFM mode operation, the value of the external inductor and the external capacitor should be the same. For example, when using a 10 µH inductor, a 10 µF capacitor should be used. When using a 22 µH inductor, a 22 µF capacitor should be used.

4.1.3 LOW DROP OUT (LDO) MODE

When the input voltage to the MCP1601 is decreasing and approaches the set output voltage level, the duty cycle increases to a maximum of 90% (typically). To continue to regulate the output to as high a voltage as possible, the MCP1601 enters the low drop out mode of operation. In this mode, the high-side P-Channel MOSFET acts like a saturated LDO. This mode allows the operation of the load circuitry down to the minimum input supply that is typical in battery-powered applications.

4.2 Cross-Conduction Timing

Proper timing between turning on the P-Channel, highside MOSFET and turning off the N-Channel, low-side MOSFET (and vice versa) is critical to obtaining high efficiency. This delay between transitions is what limits the maximum duty cycle obtainable by the MCP1601. The delay between transitions leads to more time when the external inductor current is freewheeling through the internal N-Channel body diode and leads to a decrease in efficiency. If the timing delay is too short and both the internal P-Channel MOSFET and N-Channel MOSFET conduct, high peak currents will be observed shooting through the device. This will also reduce the operating efficiency. The MCP1601 inset timing is integrated to optimize efficiency for the entire line and load operating range of the device.

4.3 Integrated Protection Features

4.3.1 SHUTDOWN

By placing a logic low on the \overline{SHDN} pin of the MCP1601, the device will enter a low quiescent current shutdown mode. This feature turns off all of the internal bias and drivers within the MCP1601 in an effort to minimize the quiescent current. This feature is popular for battery-operated, portable power applications. The shutdown low quiescent current is typically 1 μ A.

4.3.2 INTERNAL OSCILLATOR AND SYNCHRONIZATION CAPABILITY

The internal oscillator is completely integrated and requires no external components. The frequency is set nominally to 750 kHZ in an effort to minimize the external inductor and capacitor size needed for the BUCK topology. In addition to the internal 750 kHz oscillator, the MCP1601 is capable of being synchronized to an external oscillator. The external oscillator frequency must be greater than 850 kHz and less than 1 MHz. For proper synchronization, the duty cycle of the external synchronization clock must be between 10% and 90%. The minimum low voltage level should be below 15% of $V_{\mbox{\scriptsize IN}}$ and the high level of the clock should be above 45% of $V_{\mbox{IN}}.$ Rise and fall time requirements for the external synchronization clock must be faster than 100 ns from 10% to 90%. When synchronizing to an external clock, the MCP1601 will always operate in the PWM mode in an effort to eliminate multiple switching frequency's and their harmonics.

4.3.3 INTERNAL SOFT START

The MCP1601 completely integrates the soft start function and requires no external components. The soft start time is typically 0.5 ms and is reset during overcurrent and over-temperature shutdown.

4.3.4 OVER-TEMPERATURE PROTECTION

The MCP1601 protects the internal circuitry from overtemperature conditions by sensing the internal device temperature and shutting down when it reaches approximately 160°C. The device will shut down, the temperature will cool to approximately 150°C, soft start will be enabled and normal operation will resume with no external circuit intervention.

4.3.5 UNDER-VOLTAGE LOCKOUT

Protection from operating at sustained input voltages that are out of range is prevented with the integrated Under-Voltage Lockout feature. When the input voltage dips below 2.5V (typically), the MCP1601 will shutdown and the soft start circuit will be reset. Normal operation will resume when the input voltage is elevated above 2.7V, maximum. This hysteresis is provided to prevent the device from starting with too low of an input voltage.

5.0 APPLICATIONS INFORMATION



FIGURE 5-1: Typical Application Circuit.

5.1 Setting Output Voltage

The MCP1601 output voltage is set by using two external resistors for output voltages \geq 1.2V. For output voltages < 1.2V, a third 1 M Ω series resistor is necessary to compensate the control system. A 200 k Ω resistor is recommended for R₂, the lower end of the voltage divider. Using higher value resistors will make the circuit more susceptible to noise on the FB pin, causing unstable operation. Lower value resistors can be used down to 20 k Ω or below, if necessary.

The feedback reference voltage for the MCP1601 is typically 0.8V. The equation used to calculate the output voltage is shown below.

EQUATION

$$R_1 = R_2 \times [(V_{OUT}/V_{FB}) - 1]$$

Example:

Desired $V_{OUT} = 2.5V$ $V_{FB} = 0.8V$ $R_2 = 200 \text{ k}\Omega$ $R_1 = 425 \text{ k}\Omega$

5.1.1 LEAD CAPACITOR

Capacitor C_1 is used for applications that utilize ceramic output capacitors. To lower the PFM mode ripple voltage, a 47 pf capacitor for C_1 is used to couple the output AC ripple voltage to the internal PFM mode comparator. For PWM mode, only applications that use electrolytic capacitors that have 0.2Ω or greater of ESR (Equivalent Series Resistance), C_1 is not necessary.

5.2 Choosing External Components

5.2.1 CAPACITORS

The MCP1601 was developed to take full advantage of the latest ceramic capacitor technology, though electrolytic types can be used as well. When selecting the best capacitor for the application, the capacitance, physical size, ESR, temperature coefficient, ripple current ratings (electrolytic) and cost are considered in making the best choice.

When selecting ceramic capacitors for C_{OUT} , the temperature coefficient of the dielectric should be evaluated. Two dielectrics are recommended as they are stable over a wide temperature range (X5R and X7R). Other dielectrics can be used, but their capacitance should stay within the recommended range over the entire operating temperature range.

5.2.1.1 Input

For all BUCK-derived topologies, the input current is pulled from the source in pulses, placing some burden on the input capacitor. For most applications, a 10 μ F ceramic capacitor connected to the MCP1601 input is recommended to filter the current pulses. Less capacitance can be used for applications that have low source impedance. The ripple current ratings for ceramic capacitors are typically very high due to their low loss characteristics. Lower-cost electrolytic capacitors can be used, but ripple current ratings should not be exceeded.

5.2.1.2 Output

For BUCK-derived topologies, the output capacitor filters the continuous AC inductor ripple current while operating in the PWM mode. Typical inductor AC ripple current for the MCP1601 is 120 mA peak-to-peak with a 3.6V input, 10 μ H inductor for a 1.8V output application. Using an output capacitor with 0.3 Ω of ESR, the output ripple will be approximately 36 mV.

The recommended range for the output capacitor is from 10 μ F (±20%) to 47 μ F (±20%). Larger value capacitors can be used, but require evaluation of the control system stability.

EQUATION

$$V_{Ripple} = I_{LRipple} \times C_{OUTesr}$$

The above equation assumes that the output capacitance is large enough so that the ripple voltage (as a result of charging and discharging the capacitor) is negligible and can be used for applications that use electrolytic capacitors with esr > 0.3Ω .

When using a 10 μ F ceramic X5R dielectric capacitor, the output ripple voltage is typically less than 10 mV.

5.2.2 BUCK INDUCTOR

There are many suppliers and choices for selecting the BUCK inductor. The application, physical size requirements (height vs. area), current rating, resistance, mounting method, temperature range, minimum inductance and cost all need to be considered in making the best choice.

When choosing an inductor for the MCP1601 Synchronous BUCK, there are two primary electrical specifications to consider.

- 1. Current rating of the inductor.
- 2. Resistance of the inductor.

When selecting a BUCK inductor, many suppliers specify a maximum peak current.

The maximum peak inductor current is equal to the maximum DC output current plus 1/2 the peak-to-peak AC ripple current in the inductor. The AC ripple current in the inductor can be calculated using the following relationship.

EQUATION

$$V_L = L \times \frac{dI}{dt}$$

Solving for ΔI_L :

EQUATION

$$\Delta I_L = (V_L/L) \times \Delta t$$

Where: Δt is equal to the "on" time of the P-Channel switch and, V_L = the voltage across the inductor

(V_{IN} - V_{OUT})

Example:

V _{IN} =	3.6V
V _{OUT} =	1.8V
F _{SW} =	750 kHz
I _{OUT(MAX)} =	300 mA

The approximate "on" time is equal to the Duty Cycle $(V_{OUT}\,/\,V_{IN})$ x 1/F $_{SW}$

T _{ON} =	(1.8V/3.6V) x 1/(750 kHz)
T _{ON} =	667 ns
$V_L =$	3.6V - 1.8V = 1.8V
$\Delta I_L =$	(1.8V/10 µH) x 667 ns
$\Delta I_L =$	120 mA
I _{L(PEAK)} =	I _{OUTMAX} + 1/2 ∆I _L
I _{L(PEAK)} =	300 mA + (120 mA) / 2
I _{L(PEAK)} =	360 mA

Many suppliers of inductors rate the maximum RMS (Root Mean Square) current. The BUCK inductor RMS current is dependent on the output current, inductance, input voltage, output voltage and switching frequency. For the MCP1601, the inductor RMS current over the 2.7V to 5.5V input range, 0.9V to 5V output voltage range is no more than 15% higher than the average DC output current for the minimum recommended inductance of 10 μ H ±20%. When selecting an inductor that has a maximum RMS current rating, use a simple approximation that the RMS current is 1.2 times the maximum output current.

Example:

 $I_{OUT(MAX)}$ = 300 mA, the inductor should have an RMS rating > 360 mA (1.2 x $I_{OUT(MAX)}$).

DC resistance is another common inductor specification. The MCP1601 will work properly with inductor DC resistance down to 0Ω . The trade-off in selecting an inductor with low DC resistance is size and cost. To lower the resistance, larger wire is used to wind the inductor. The switch resistance in the MCP1601 is approximately 0.5Ω . Inductors with DC resistance lower than 0.1Ω will not have a significant impact on the efficiency of the converter.

5.3 L and C_{OUT} Combinations

When selecting the L-C_{OUT} output filter components, the inductor value range is limited from 10 μ H to 22 μ H. However, when using the larger inductor values, larger capacitor values should be used. The following table lists the recommended combinations of L and C_{OUT}.

TABLE 5-1:	L-COUT COMBINATIONS

L	C _{OUT}
10 µH	10 μF to 47 μF
15 µH	15 μF to 47 μF
22 µH	22µF to 47 µF

Note: For proper PFM mode operation, the value of the external inductor and the external capacitor should be the same. For example, when using a 10 μ H inductor, a 10 μ F capacitor should be used. When using a 22 μ H inductor, a 22 μ F capacitor should be used.

5.4 Passive Component Suppliers

TABLE 5-2:	CERAMIC CAPACITOR
	SUPPLIERS

Supplier	Туре	Description
Murata®	Ceramic	10 μF 0805 X5R 6.3V #GRM21BR60J106K
Murata [®]	Ceramic	10 μF 1206 X5R 6.3V #GRM319R60J106K
Taiyo Yuden™	Ceramic	10 μF 1210 X5R 6.3V JMK325BJ106MD
AVX™	Ceramic	10 μF 0805 X5R 6.3V #08056D106MAT4A
AVX™	Ceramic	10 μF 1206 X5R 6.3V #12066D106MAT4A
Kemet [®]	Ceramic	10 μf 1210 6.3V #C1210C106M9PAC
Murata®	Ceramic	22 μF 1206 X5R 6.3V GRM31CR60J226ME20B
Taiyo Yuden™	Ceramic	22 μF 1210 X5R 6.3V JMK325BJ226MY

Note: Taiyo Yuden 1210 is a low profile case (1.15 mm)

TABLE 5-3:	ELECTROLYTIC CAPACITOR
	SUPPLIERS

Supplier	Туре	Description
Kemet [®]	Tantalum	47 μF D Case 200 MΩ 10V #T495D476M010AS
AVX™	Tantalum	47 μF C Case 300 MΩ 6.3V #TPSC476M006S300
Sprague®	Tantalum	47 μF C Case 110 MΩ 16V 594D47X0016C2T
Sprague®	Tantalum	22 μF B Case 380 MΩ 6.3V 594D226X06R3B2T
Sprague®	Tantalum	15 μF B Case 500 MΩ 10V 594D156X0010B2T

Supplier	L	Туре	Area (mm)	Height (mm)	DC Resistance	Max. Current	Series
Sumida [®]	10 µH	Unshielded	4.1 mm x 3.8 mm	3.0 mm	230 MΩ	0.76A	C32
Sumida [®]	10 µH	Shielded	4.0 mm x 4.0 mm	1.8 mm	160 MΩ	0.66A	CDRH3D16
Sumida [®]	10 µH	Shielded	5.7 mm x 5.7 mm	3.0 mm	65 MΩ	1.3A	CDRH5D28
CT*	10 µH	Shielded	7.3 mm x 7.3 mm	3.5 mm	70 MΩ	1.7A	CTCDRH73
Coilcraft [®]	10 µH	Shielded	6.6 mm x 4.5 mm	3.0 mm	75 MΩ	1.0A	DS1608
Coilcraft®	15 µH	Shielded	6.6 mm x 4.5 mm	3.0 mm	90 MΩ	0.8A	DS1608
Coilcraft®	22 µH	Shielded	6.6 mm x 4.5 mm	3.0 mm	110 MΩ	0.7A	DS1608
Coilcraft [®]	10 µH	Unshielded Wafer	6.0 mm x 5.4 mm	1.3 mm	300 MΩ	0.60A	LPO6013
Coilcraft [®]	15 µH	Unshielded Wafer	6.0 mm x 5.4 mm	1.3 mm	380 MΩ	0.55A	LPO6013
Taiyo Yuden™	10 µH	Shielded	5.0 mm x 5.0 mm	2.0 mm	66 MΩ	0.7A	NP04SB100M

TABLE 5-4: INDUCTOR SUPPLIERS

Note: CT* = Central Technologies

5.5 Efficiency

Efficiency will be affected by the external component selection and the specific operating conditions for the application. In Section 2.0, "Typical Performance Curves", there are curves plotted using typical inductors that can be used to estimate the converter efficiency for 1.2V, 1.8V and 3.3V.

5.6 Printed Circuit Board Layout

The MCP1601 is capable of switching over 500 mA at 750 kHz. As with all high-frequency, switch mode, power supplies, a good board layout is essential to preventing the noise generated by the power train switching from interfering with the sensing circuitry. The MCP1601 has not demonstrated a sensitivity to layout, but good design practice will prevent undesired results.



FIGURE 5-2: Component Placement.

When designing a board layout for the MCP1601, the first thing to consider is the physical placement of the external components. In Figure 5-2, SM0805 10 μF ceramic capacitors are used for C_{IN} and C_{OUT}. The SM0603 package is used for R₁, R₂ and C₁. The inductor used is the Coilcraft[®] LPO2506 series low profile (0.047" high). The board outline in this example is 1" x 1". C_{IN}, L and C_{OUT} are positioned around the MCP1601 to make the high current paths as short as possible.



FIGURE 5-3: Top Layer.

The top layer of the board layout is shown in Figure 5-3. The power conversion process is made up of two types of circuits. One circuit carries changing large signals (current, voltage), like C_{IN} , C_{OUT} , L and the V_{IN} , L_X P_{GND} pins of the MCP1601. The other circuitry is much smaller in signal and is used to sense, regulate and control the high-power circuitry. These components are R_1 , R_2 , C_1 and pins FB, A_{GND} . The top layer is partitioned so that the larger signals connections are short and wide, while the smaller signals are routed away from the large signals.

The MCP1601 utilizes two ground pins to separate the large signal ground current from the small signal circuit ground. The large signal ("Power Ground") is labeled "P_{GND}". The small signal is labeled "Analog Ground" or "A_{GND}". In Figure 5-3, the P_{GND} and the A_{GND} are kept separate on the top layer.



FIGURE 5-4: Bottom Layer.

In Figure 5-4, the bottom layer is a partitioned ground plane that connects A_{GND} to P_{GND} near the input capacitor. The large signal current will circulate on the top P_{GND} partition. The lower partition is used for a "quiet" ground, where A_{GND} is connected.

6.0 PACKAGING INFORMATION

6.1 Package Marking Information

	ead MSOP		Example: 16011 344025 0
Legen	d: XXX Customer spec YY Year code (last WW Week code (W	ific information*	r year) week (01)

MCP1601

8-Lead Plastic Micro Small Outline Package (MS) (MSOP)









	Units	INCHES		MILLIMETERS*			
Dimension L	imits	MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		8				8
Pitch	р	.026		0.65			
Overall Height	А			.044			1.18
Molded Package Thickness	A2	.030	.034	.038	0.76	0.86	0.97
Standoff §	A1	.002		.006	0.05		0.15
Overall Width	Е	.184	.193	.200	4.67	4.90	.5.08
Molded Package Width	E1	.114	.118	.122	2.90	3.00	3.10
Overall Length	D	.114	.118	.122	2.90	3.00	3.10
Foot Length	L	.016	.022	.028	0.40	0.55	0.70
Footprint (Reference)	F	.035	.037	.039	0.90	0.95	1.00
Foot Angle	φ	0		6	0		6
Lead Thickness	С	.004	.006	.008	0.10	0.15	0.20
Lead Width	В	.010	.012	.016	0.25	0.30	0.40
Mold Draft Angle Top	α		7			7	
Mold Draft Angle Bottom	β		7			7	

*Controlling Parameter § Significant Characteristic

Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

Drawing No. C04-111

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

PART NO.	¥ <u>/xx</u>	Examples:
Device	Temperature Package Range	 a) MCP1601-I/MS: 8LD MSOP package. b) MCP1601T-I/MS: Tape and Reel, 8LD MSOP package.
Device:	MCP1601: 500 mA Synchronous BUCK Regulator MCP1601T: 500 mA Synchronous BUCK Regulator Tape and Reel	
Temperature Range:	$I = -40^{\circ}C \text{ to } +85^{\circ}C$	
Package:	MS = Plastic Micro Small Outline (MSOP), 8-lead	

Sales and Support

Data Sheets

Products supported by a preliminary Data Sheet may have an errata sheet describing minor operational differences and recommended workarounds. To determine if an errata sheet exists for a particular device, please contact one of the following:

- 1. Your local Microchip sales office
- 2. The Microchip Corporate Literature Center U.S. FAX: (480) 792-7277
- 3. The Microchip Worldwide Site (www.microchip.com)

Please specify which device, revision of silicon and Data Sheet (include Literature #) you are using.

Customer Notification System

Register on our web site (www.microchip.com/cn) to receive the most current information on our products.

MCP1601

NOTES:

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip's products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, KEELOQ, MPLAB, PIC, PICmicro, PICSTART, PRO MATE and PowerSmart are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, microID, MXDEV, MXLAB, PICMASTER, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Accuron, dsPIC, dsPICDEM.net, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, microPort, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICC, PICkit, PICDEM, PICDEM.net, PowerCal, PowerInfo, PowerTool, rfPIC, Select Mode, SmartSensor, SmartShunt, SmartTel and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2003, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.





Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999 and Mountain View, California in March 2002. The Company's quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEEL00® code hopping devices, Serial EEPROMs, microperipherals, non-volatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001 certified.



WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7200 Fax: 480-792-7277 Technical Support: 480-792-7627 Web Address: http://www.microchip.com

Rocky Mountain

2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7966 Fax: 480-792-4338

Atlanta

3780 Mansell Road, Suite 130 Alpharetta, GA 30022 Tel: 770-640-0034 Fax: 770-640-0307

Boston

2 Lan Drive, Suite 120 Westford, MA 01886 Tel: 978-692-3848 Fax: 978-692-3821

Chicago

333 Pierce Road, Suite 180 Itasca, IL 60143 Tel: 630-285-0071 Fax: 630-285-0075

Dallas

4570 Westgrove Drive, Suite 160 Addison, TX 75001 Tel: 972-818-7423 Fax: 972-818-2924

Detroit

Tri-Atria Office Building 32255 Northwestern Highway, Suite 190 Farmington Hills, MI 48334 Tel: 248-538-2250 Fax: 248-538-2260

Kokomo

2767 S. Albright Road Kokomo, Indiana 46902 Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles

18201 Von Karman, Suite 1090 Irvine, CA 92612 Tel: 949-263-1888 Fax: 949-263-1338

San Jose

Microchip Technology Inc. 2107 North First Street, Suite 590 San Jose, CA 95131 Tel: 408-436-7950 Fax: 408-436-7955

Toronto

6285 Northam Drive, Suite 108 Mississauga, Ontario L4V 1X5, Canada Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia

Microchip Technology Australia Pty Ltd Suite 22, 41 Rawson Street Epping 2121, NSW Australia

Tel: 61-2-9868-6733 Fax: 61-2-9868-6755 China - Beijing

Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office Unit 915 Bei Hai Wan Tai Bldg. No. 6 Chaoyangmen Beidajie Beijing, 100027, No. China Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu

Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office Rm. 2401-2402, 24th Floor, Ming Xing Financial Tower No. 88 TIDU Street Chengdu 610016, China Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou

Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office Unit 28F, World Trade Plaza No. 71 Wusi Road Fuzhou 350001, China Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR

Microchip Technology Hongkong Ltd. Unit 901-6, Tower 2, Metroplaza 223 Hing Fong Road Kwai Fong, N.T., Hong Kong Tel: 852-2401-1200 Fax: 852-2401-3431

China - Shanghai

Microchip Technology Consulting (Shanghai) Co., Ltd. Room 701, Bldg. B Far East International Plaza No. 317 Xian Xia Road Shanghai, 200051 Tel: 86-21-6275-5700 Fax: 86-21-6275-5060 China - Shenzhen

Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office Rm. 1812, 18/F, Building A, United Plaza No. 5022 Binhe Road, Futian District Shenzhen 518033, China Tel: 86-755-82901380 Fax: 86-755-82966626 China - Qingdao

Rm. B503, Fullhope Plaza, No. 12 Hong Kong Central Rd. Qingdao 266071, China Tel: 86-532-5027355 Fax: 86-532-5027205 India Microchip Technology Inc. India Liaison Office **Divyasree Chambers** 1 Floor, Wing A (A3/A4) No. 11, O'Shaugnessey Road Bangalore, 560 025, India Tel: 91-80-2290061 Fax: 91-80-2290062

Japan

Microchip Technology Japan K.K. Benex S-1 6F 3-18-20, Shinyokohama Kohoku-Ku, Yokohama-shi Kanagawa, 222-0033, Japan Tel: 81-45-471- 6166 Fax: 81-45-471-6122 Korea Microchip Technology Korea 168-1, Youngbo Bldg. 3 Floor Samsung-Dong, Kangnam-Ku Seoul, Korea 135-882 Tel: 82-2-554-7200 Fax: 82-2-558-5934 Singapore Microchip Technology Singapore Pte Ltd. 200 Middle Road #07-02 Prime Centre Singapore, 188980 Tel: 65-6334-8870 Fax: 65-6334-8850 Taiwan Microchip Technology (Barbados) Inc., Taiwan Branch 11F-3, No. 207 Tung Hua North Road Taipei, 105, Taiwan Tel: 886-2-2717-7175 Fax: 886-2-2545-0139 **EUROPE** Austria Microchip Technology Austria GmbH Durisolstrasse 2 A-4600 Wels Austria Tel: 43-7242-2244-399 Fax: 43-7242-2244-393 Denmark Microchip Technology Nordic ApS Regus Business Centre Lautrup hoj 1-3 Ballerup DK-2750 Denmark Tel: 45 4420 9895 Fax: 45 4420 9910 France Microchip Technology SARL Parc d'Activite du Moulin de Massy 43 Rue du Saule Trapu Batiment A - ler Etage 91300 Massy, France Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79 Germany Microchip Technology GmbH Steinheilstrasse 10 D-85737 Ismaning, Germany Tel: 49-89-627-144 0 Fax: 49-89-627-144-44 Italy Microchip Technology SRL Centro Direzionale Colleoni Palazzo Taurus 1 V. Le Colleoni 1 20041 Agrate Brianza Milan, Italy Tel: 39-039-65791-1 Fax: 39-039-6899883 United Kingdom Microchip Ltd. 505 Eskdale Road Winnersh Triangle

12/05/02

Wokingham

Berkshire, England RG41 5TU

Tel: 44 118 921 5869 Fax: 44-118 921-5820