INTRODUCTORY

MAXIM

Low Voltage Step-Up Converters

MAX644/645/646/647

General Description

The MAX644, MAX645 and MAX646 are low power fixed +5V output step-up DC-DC converters designed for operation from very low input voltages. All control functions and a power FET are contained in the MAX644, MAX645 and MAX647, minimizing external components. The MAX646 contains an output pin to drive an external FET. A control pin changes between high power and low power standby modes. Standby mode allows operating for extended periods with minimum battery drain, and a power ready function is available for controlling external devices when the device is switched between standby and high power. In high power mode, the output current is approximately 40mA; in standby mode, it is about 500μA.

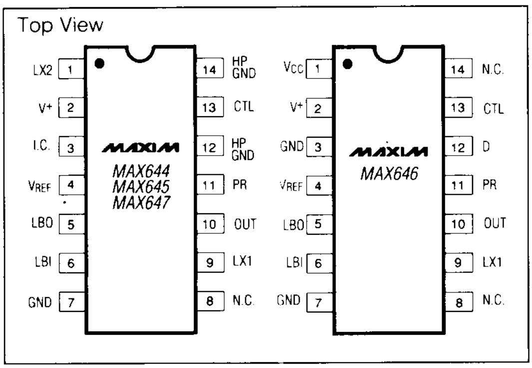
Minimum startup voltage is 1.15V, but once started the device will operate to lower voltages as the battery discharges. A separate low battery monitor is available; it can be used at its default value of 1.17V or may be adjusted by the designer to any higher voltage.

The MAX644, MAX646 and MAX647 are optimized for single cell (1.15V to 1.6V) battery operation; the MAX645 is designed for two cell (or single lithium cell) operation, with typical battery voltages of 2.0V to 3.6V. The MAX647 is identical to the MAX644 except its output voltage is preset to +3V.

Applications

- Battery Powered Devices
- Single Cell Instruments
- Solar Powered Systems
- Pagers and Radio Controlled Receivers
- Portable Instruments
- 4-20mA Loop Powered Instruments

Pin Configuration



Features

- ◆ +5V @ 40mA from a Single Cell Battery
- ◆ Guaranteed Start-up at 1.15V
- ◆ Minimum Component Count
- ◆ Shutdown Mode -- 80μA Quiescent Current
- ◆ Low Battery Indication
- ◆ Power Ready Function

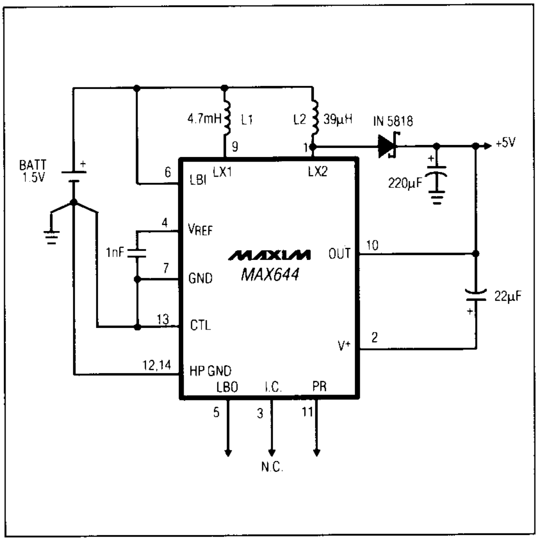
Ordering Information

PART	TEMP. RANGE	PACKAGE*
MAX644CPD	0°C to +70°C	Plastic DIP
MAX644CSD	0°C to +70°C	Small Outline
MAX644C/D	0°C to +70°C	Dice
MAX644EPD	-40°C to +85°C	Plastic DIP
MAX644ESD	-40°C to +85°C	Small Outline
MAX644MJD	-55°C to +125°C	CERDIP
MAX645CPD	0°C to +70°C	Plastic DIP
MAX645CSD	0°C to +70°C	Small Outline
MAX645C/D	0°C to +70°C	Dice
MAX645EPD	-40°C to +85°C	Plastic DIP
MAX645ESD	-40°C to +85°C	Small Outline
MAX645MJD	-55°C to +125°C	CERDIP

** All devices have 14 leads*

Ordering Information Continued on Last Page.

Typical Operating Circuit



Low Voltage Step-Up Converters

ABSOLUTE MAXIMUM RATINGS

Peak Voltage at LX1 Pin .... +16V
Peak Voltage at LX2 or V_{CC} Pin .... +6.6V
Supply Voltage to L1 .... +15V
Supply Voltage to L2, V_{CC} .... +5.6V
Peak Current, LX1 .... 50mA
Peak Current, LX2 .... 1.6A
LBO Output Current 50mA
Input Voltage, CTL, LBI (Note 1) .... -0.3V to (V^+ + 0.3V)

Note 1: V+ is generated at LX1. In low current mode, it is 4.5V to 5.6V (2.6V to 3.6V on MAX646); in high current mode, it is 10V to 15V.

Operating Temperature
MAX64XCXX .... 0°C to +70°C
MAX64XEXX .... -40°C to +85°C
MAX64XMXX .... -55°C to +125°C
Storage Temperature .... -65°C to +160°C
Lead Temperature (Soldering, 10 Sec) .... +300°C
Power Dissipation
Plastic DIP (derate 10mW/°C above 70°C) 800mW
SO (derate 8.7mW/°C above 70°C) 695mW
CERDIP (derate 9.5mW/°C above 70°C) 750mW

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS: MAX644, MAX646, MAX647

(GND = 0V, V_{BATT} = 1.2V, T_A = 25°C, unless otherwise noted.)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	MAX644, MAX646 T_A = Over Temp.	4.5	5.0	5.5	V
		MAX647 T_A = Over Temp.	2.7	3.0	3.3	
Output Curent	I_L			See Table 1		mA
Minimum Input Voltage to LX1	V_{LX1}	I_L = 0μA		0.9	1.0	V
Minimum Startup Voltage to LX1*	V_{LX1}	I_L = 0μA		1.1	1.15	V
Input Voltage to LX2	V_{LX2}		0.5		5.6	V
Peak LX2 Switch Current*	I_{LX2}	MAX644, MAX647			1.6	A
Standby Current	I_Q	I_L = 0μA, CTL = open		80		μA
Switching Frequency	f_0	V_{BATT} = 1.0 to 1.6V	15.5	18	24	kHz
		T_A = Over Temp.		18*		
LX2, D Switch Duty Cycle	%ON	MAX644, MAX646	66	75	80	%
		MAX647	50	66	75	
LX2, D Switch On Time*	t_{ON}	MAX644, MAX646	30	42	46	μs
		MAX647	23	37	44	
LX2 On Resistance*	R_{DSON}	MAX644, MAX647	0.40		0.67	Ω
D Output Saturation Current		MAX646 Source		-25		mA
		Sink		100		
Low Battery Input Threshold Voltage	V_{LBI}	T_A = Over Temp.	1.12		1.18	V
Low Battery Input Threshold Tempco				-0.5		mV/°C
Low Battery Input Bias Current	I_{LBI}			0.01	10	nA
Low Battery Output	V_{LBO}	V_{LBI} 1.12V, I_{LBO} = 1.6mA			0.4	V
		V_{LBI} 1.18V, I_{LBO} = -1μA	V^+-1			

*MIN, MAX and Over Temp. limits will be added to these TYP and 25°C specifications by August 1, 1989.

ELECTRICAL CHARACTERISTICS: MAX645

(GND = 0V, V_{BATT} = 2.4V, T_A = 25°C, unless otherwise noted.)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	T_A = Over Temp.	4.5	5.0	5.5	V
Output Current	I_L			See Table 1		mA
Minimum Input Voltage to LX1	V_{LX1}	I_L = 0μA		0.9	1.0	V
Minimum Startup Voltage to LX1*	V_{LX1}	I_L = 0μA		1.0	1.5	V
Input Voltage to LX2	V_{LX2}				5.6	V
Peak LX2 Switch Current*	I_{LX2}				1.6	A
Standby Current	I_Q	I_L = 0μA, CTL = Open		40		μA
Switching Frequency	f_0	V_{BATT} = 2.0V to 3.2V T_A = Over Temp.	15.5	18 18*	24	kHz
Switch Duty Cycle	%ON		40	50	60	%
Switch On Time*	t_{ON}		18	28	35	μs
LX2 On Resistance*	R_{DSON}		0.40		0.67	Ω
Low Battery Input Threshold Voltage	V_{LBI}	T_A = Over Temp.	1.12		1.18	V
Low Battery Input Threshold Tempco				-0.5		mV/°C
Low Battery Input Bias Current	I_{LBI}			0.01	10	nA
Low Battery Output	V_{LBO}	V_{LBI} < 1.12V, I_{LBO} = 1.6mA V_{LBI} > 1.18V, I_{LBO} = -1μA	 V^+-1		0.4	V

Low Voltage Step-Up Converters

Operating Principle

The MAX644, MAX645, MAX646 and MAX647 are flyback, or boost converters: energy from the battery is first stored in a coil and then discharged to the load. Essentially, the circuit consists of a battery in series with a coil, switch, rectifier, and filter, as shown in Figure 1. When the switch is closed, current builds up in the coil, creating a magnetic field. During the second half, or flyback part of the cycle, the switch opens, the magnetic field collapses and the voltage across the inductor reverses polarity, adding to the voltage of the battery and discharging through the rectifier into the load.

The switch is controlled by a constant frequency oscillator whose output is gated on and off by a comparator that monitors the output voltage. When the output voltage is above the comparator threshold, the switch skips an entire cycle of the oscillator. This pulse skipping technique varies the average duty cycle to achieve regulation, rather than varying the period or duty cycle of each cycle

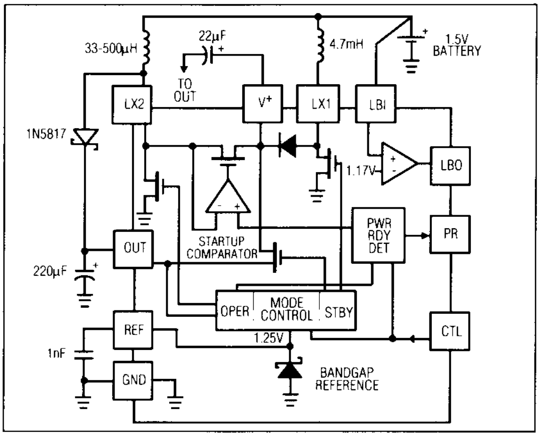


Figure 1. MAX644/45 Block Diagram

Pin Description

MAX646 PIN #	MAX644 MAX645 MAX647 PIN #	NAME	FUNCTION
–	1	LX2	Output (drain) of high power N-channel power MOS driver.
1	–	V_{CC}	Connect to battery positive terminal.
–	2	V^+	Output of low power up converter; 10 to 15V in high power mode, 4.5 to 5.6V in standby mode.
2	–	V^+	Output of low power up converter. 10 to 15V in high power mode, 2.6 to 3.6V in standby mode.
–	3	I/C	Internal Connection. Leave this pin unconnected. Do not ground.
3	7	GND	Low power ground.
4	4	V_{REF}	1.25V bandgap reference output; should be decoupled with a capacitor to pin 3. This terminal is high impedance and cannot source or sink current.
5	5	LBO	Low battery monitor output. Sinks 1.6mA when LBI is less than 1.17V, otherwise sources 1µA from V+.
6	6	LBI	Low battery monitor input. Very high input impedance.
8,14	8	NC	No connection.
9	9	LX1	Output (drain) of low power N-channel power driver.
10	10	OUT	+5V (+3V on MAX647). Feedback (input) pin for high power operation; output pin in standby mode.
11	11	PR	Power ready output; high (+5V on MAX644,645,646, +3V on MAX647) when high power converter is ready to supply power.
7	12,14	HP GND	High power ground.
13	13	CTL	Control mode switch input; open circuit or high for standby mode, ground for high power mode.
12	–	D	Driver output to external FET. Output voltage swings from GND to V_{OUT}.

of the switch; it eliminates a number of linear circuits that would otherwise add both circuit complexity and quiescent operating current.

The key to operating CMOS circuitry from a 1V supply depends on a technique called bootstrapping. A specially designed oscillator starts itself up on a very low voltage and builds up (or bootstraps) a higher voltage that in turn is used as the supply for further operation. This supply yields higher efficiency because the bootstrapped voltage drives the gate of the internal FET transistors to lower on resistance.

When power is first applied, the circuit is very inefficient (for the first cycle) until a higher voltage is generated on the flyback half of the first cycle. This higher voltage is rectified and filtered, and powers the whole IC (and thus the oscillator) for the next cycle. Since each cycle generates a higher voltage for the next cycle, the voltage builds up very rapidly. An internal regulator limits the voltage to about 12V. The load for this supply is only the CMOS chip itself, so the requirements for the components, particularly the external inductor L1, are very broad. This voltage is brought out to the V^+ pin and is connected to a tantalum capacitor for filtering.

This bootstrapped 12V drives an internal N-channel power FET that furnishes the switching power for the load. Since the gate of this FET is driven from a 12V supply, it has a very low on resistance and can efficiently switch high currents through a second inductor, L2. It is the power stored in this second inductor that is delivered to the 5V load via an external Schottky diode. The rectifiedand filtered 5V output is connected back to the OUT pin to provide feedback. The MAX644/45/46/47 thus has two separate switching circuits and uses two separate inductors.

Circuit Details

A typical application circuit is shown in Figure 2. The higher value inductor, L1, is typically 4.7mH, and may have fairly high losses. It is used for the low power section of the circuit and is rectified by an internal diode and routed to pin 2, V^+, where it is filtered by an external capacitor, C1. The second inductor, L2, varies from 39µH to 500µH, depending on input voltage and load current. It must have low series resistance and sufficient core material to handle the load power without saturating. The inductor is connected to pin 1 (LX2), the drain of the Low Power FET,and is rectified by an external Schottky diode, D1, and filtered by an external capacitor, C2. This is the main +5V output (+3V on the MAX647), and it is connected to OUT, pin 10, which is the feedback input in high power mode. Figure 3 shows a similar circuit for the MAX646 using an external FET for higher power output.

Low Power Standby Mode

A control pin (CTL) is available for putting the device into standby mode to conserve power. When this pin is held low, the IC operates normally, but if it is driven high or left open, the chip goes into standby. Several things happen: the POWER READY (PR) pin is driven low, the high power FET is gated off, the 12V (V^+) switching supply is reduced to 5V (+3V on the MAX647) and is connected to the V_{OUT} pin. By lowering the internal 12V supply to 5V, the leakage currents of the CMOS circuits and the losses associated with its voltage reference and oscillator are reduced to a minimum. The internal low power 5V supply can furnish up to 500µA, and it is connected to the normal 5V output pin (OUT) to supply current to the load, keeping alive standby circuits.

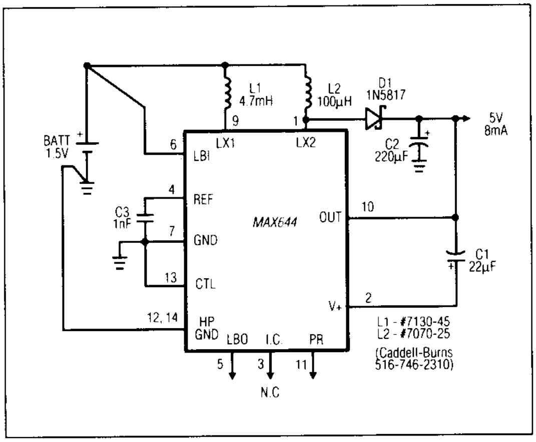


Figure 2. MAX644 Typical Application

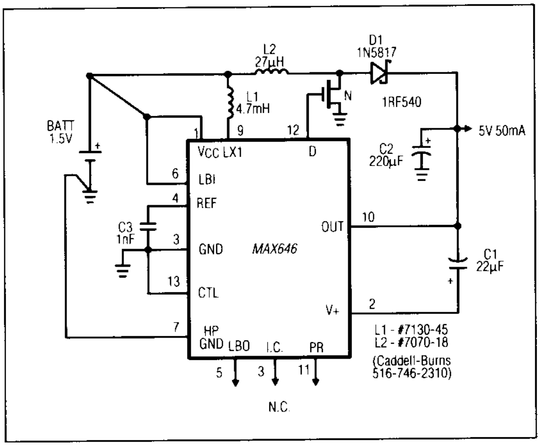


Figure 3. MAX646 Typical Application

Low Voltage Step-Up Converters

Power Ready Output Pin

During initial start up (and when placed in standby mode), the MAX644/45/46/47 internal voltages are too low to drive the power FET efficiently. A separate comparator determines when this voltage has reached a high enough value to drive the FET. The output of this comparator gates the FET drive voltage. This scheme extends battery life in standby mode and prevents the power FET from stalling when switching to high power mode. The comparator output is also brought out to the POWER READY (PR) pin and can be used to control external circuits, further reducing battery drain.

Start Up and Mode Considerations

The MAX644/45/46/47 may be started up in either the low power (standby) or high power mode. When starting in the high power mode, both the low power switch and the high power switch start immediately. Whether or not the load is connected, the output voltage will rise to 5V in the first few cycles. The OUT pin becomes an input for feedback to control regulation.

If the high power load (greater than about 500µA) is connected to the OUT pin and the device is placed in the low power mode by opening the CTL pin, the low power oscillator will have to furnish all of the 5V power via the OUT pin, and the low power oscillator will stall. It is, therefore, important to disconnect any load currents (greater than 500µA) whenever the low power or standby mode is selected. The power ready (PR) pin may be used to disconnect the load via an external transistor. This way the mode and connection of the high power load are both controlled through the CTL input.

Input Filtering

It is important to limit the rate of rise of the battery voltage when the circuit is first turned on with a mechanical switch or the installation of the battery(ies). A simple R-C network made up of the battery internal resistance and a 10µF tantalum capacitor placed at the battery side of L2 input is sufficient for this purpose. This capacitor also helps to absorb the (relatively) high peak currents that are drawn from the battery in the high power mode.

Output Filtering

It is also important to limit the speed at which V^+ decreases to 5V when the mode is switched from high power to standby. This is accomplished by putting a 22µF capacitor between the V^+ and OUT pins. Also, a 220µF capacitor placed on the OUT pin provides both filtering and serves to hold up the 5V during the switchover period. Without these capacitors, the 5V may spike negatively during the switchover.

Low Battery Function

A completely independent low battery monitor is built into the MAX644/45/46/47. Its input (LBI) is the + input of a CMOS comparator whose – input is connected to the internal 1.17V band-gap reference. This input can be connected directly to the battery in single cell circuits or connected to a high resistance voltage divider for higher voltage monitoring. The output (LBO) can sink 1.6mA or source several microamperes from V^+.

Inductor Selection

Low Power Coil

The choice of the low power inductor, L1, is not critical. A 4.7mH coil with a DC resistance of less than 40Ω is adequate for most applications. In general, higher inductance values allow lower start up voltages, while lower resistances yield lower quiescent current in standby mode. If the inductance is made too high, the low power (V^+) output voltage and current are reduced. This in turn reduces the efficiency of the power section, so the +5V output (in standby mode) supplies less current. Lower values of inductance raise the minimum start up voltage.

High Power Coil

The high power coil, L2, must store most of the energy that flows into the load. Accordingly, it should have a powdered iron or ferrite core and should have low resistance to minimize losses.

Calculating the worst case inductor for the high power section (LX2) of the MAX644/45/46/47 is a two step process:

1. Determine the smallest inductor value that will not cause the circuit to exceed the peak current rating of the MAX644/45/47 with the highest expected input voltage ($V_{IN(MAX)}$), the longest on time ($t_{ON(MAX)}$), and the lowest total resistance ($R_{(MIN)}$). $R_{(MIN)}$ is the sum of the minimum coil and FET resistances. Note that this peak current relates to the inductor and the FET switch and is several times the load current.

2. Determine the lowest average output current that this inductor will furnish to the load with the lowest input voltage ($V_{IN(MIN)}$), the shortest on time ($t_{ON(MIN)}$), and the highest total resistance ($R_{(MAX)}$).

From the Electrical Characteristics table:

I_{pk} LX2 = 1.5A
$R_{DSON(MIN)} = 0.4\Omega$
$f_{O(MIN)}$ = 15,500Hz
duty cycle maximum, $\%ON_{(MAX)} = 0.8$

then:

$$t_{ON(MAX)} = \%ON_{(MAX)}/f_{O(MIN)} = 0.8/15500 = 51.6\mu s$$

Assume that the minimum coil resistance, $R_{COIL(MIN)}$ is:

$$R_{COIL(MIN)} = 0.1\Omega$$

The minimum total resistance, $R_{(MIN)}$ is:

$$R_{(MIN)} = R_{DSON(MIN)} + R_{COIL(MIN)} = 0.4 + 0.1 = 0.5\Omega$$

Then:

$$I_{pk} = 1.5A = \frac{V_{IN(MAX)}}{R_{(MIN)}} \times \left[1 - e^{-R_{(MIN)} \times t_{ON(MAX)}/L_{(MIN)}}\right]$$

or:

$$L_{(MIN)}\,(\mu H) = \frac{-25.8\ (\mu s)}{ln(1 - R_{(MIN)} \times I_{pk} / V_{IN(MAX)})}$$

For a maximum input voltage of 1.56V (single alkaline cell), and a minimum coil resistance of 0.1Ω, the minimum permissible inductance for the MAX644/45/47 is 39.37µH.

Using this minimum inductance, the peak current, I_{pk}, is then calculated for the highest resistance ($R_{(MAX)}$) and the lowest input voltage ($V_{IN(MIN)}$). From this, the lowest output (DC) current is calculated.

From the Electrical Characteristics table:

$R_{DSON(MAX)} = 0.66\Omega$
$f_{O(MAX)} = 24{,}000Hz$
duty cycle minimum, $\%ON_{(MIN)} = 0.66$

then:

$$t_{ON(MIN)} = \%ON_{(MIN)}/f_{O(MAX)} = 0.66/24000 = 27.5\mu s$$

Assume that the maximum coil resistance, $R_{COIL(MAX)}$ is:

$$R_{COIL(MAX)} = 0.15\Omega$$

The maximum total charging resistance, $R_{(MAX)}$ is:

$$R_{(MAX)} = R_{DSON(MAX)} + R_{COIL(MAX)} = 0.81\Omega$$

At the end of the ON period:

$$I_{pk} = \frac{V_{IN(MIN)}}{R_{(MAX)}} \times \left[1 - e^{-R_{(MAX)} \times t_{ON(MIN)}/L_{(MIN)}}\right]$$

The energy stored in the coil is:

$$E_{COIL} = \frac{L_{(MIN)} \times I_{pk}^2}{2}$$

And the power put into the coil is:

$$P_{COIL} = f_{O(MIN)} \times E_{COIL} = \frac{L_{(MIN)} \times I_{pk}^2 \times f_{O(MAX)}}{2}$$

The minimum DC output current, I_{OUT}, is:

$$I_{OUT(MIN)} = \frac{P_{LOAD}}{V_{LOAD}} = \frac{P_{COIL} - P_{LOSS}}{V_{OUT(MAX)} + V_{DIODE} - V_{IN(MIN)}} = \frac{P_{COIL} - I_{pk}^2 \times R_{COIL(MAX)}/3 \times (1 - \%ON_{(MIN)})}{V_{OUT(MAX)} + V_{DIODE} - V_{IN(MIN)}}$$

Using a 47µH coil with a resistance of 0.15Ω and an input voltage of 1.1V, the worst case (minimum) 5V output current would be 19.4mA.

When selecting a coil, care should be exercised to insure that the minimum inductance value, including all the manufacturing tolerances, is never lower than the calculated inductance, or the peak current rating of LX2 may be exceeded. In addition, the current rating of the coil should be greater than the peak current used in the calculation (1.5A, normally), to avoid saturating the core.

If the worst case output current is too small, then either the minimum input voltage must be increased or the maximum input voltage should be decreased. It is always desireable to decrease the ratio between maximum and minimum input voltages. The coil resistance also has a significant effect on the output current, so selecting a lower coil resistance will increase the output current and increase the overall efficiency.

If no satisfactory value of inductance can be found for the desired current, the MAX646 may be used with an external FET whose peak current exceeds 1.5A. The calculations are similar for the MAX644 except the external FET's R_{DSON} and current rating should be substituted in the above equations.

If the worst case output current is significantly higher than the required load current, a higher inductance value may be used. This will tend to reduce the peak current and the ripple voltage. Be sure to adjust the coil resistance and recalculate all the values.

When the maximum battery voltage exceeds 1.65V, the MAX645 should be used. Calculations for the MAX645 are identical to the MAX644 calculations, except that different values must be used for the maximum and minimum duty cycles.

In general, if a choice of batteries is available, higher input voltages are preferred for two reasons. First, as the input voltage approaches 1V, the load on the battery increases while the losses increase. The losses become so dominant that efficiency suffers and little output current can be maintained. Second, certain losses, such as the coil resistance and the FET on resistance are less significant with higher input voltages. This means not only higher efficiency, but a greater range of input voltages are tolerable; this in turn means that more of the chemical energy can be converted into electricity. For example, three NiCd cells, with a fully charged voltage of 4.05V, may still be used down to 1.1V (with about 5mA of 5V output current), far beyond the normal life expectancy.

The inductance values for commonly encountered battery operated power supplies are tabulated in Table 1.

Low Voltage Step-Up Converters

Table 1. Minimum Inductance for Common Batteries

Battery Type	Battery MIN	Voltage MAX	I_{LOAD} mA	Coil(L2) µH	Caddell-Burns* P/N	Coil R ohms
1 NiCd (MAX644)	1.15	1.35	30	33	6860-07	0.04
1 Alk (MAX644)	1.2	1.55	30	30	6860-08	0.047
1 Alk (MAX647)	1.2	1.55	25 (at +3V)	47	6860-09	0.054
2 NiCd (MAX645)	2.3	2.7	47	56	6860-10	0.063
2 Alk (MAX645)	2.4	3.1	43	68	6860-11	0.068
1 Lith (MAX645)	2.6	3.6	46	82	6860-12	0.073

* Caddell-Burns, NY (516) 746-2310

Capacitor Selection

The high current fast rise-time pulses associated with switching power supplies demand good grounding and bypassing techniques. The MAX644/45/47 have 3 ground pins to improve grounding. In addition, the internal voltage reference is brought out for connection to an external 1nF capacitor, minimizing noise and modulation on the reference.

The two output voltages, V^+ and +5V, should be filtered with tantalum capacitors, or other capacitors with low effective series resistance, to minimize transients. If aluminum electrolytic capacitors are used, they should be paralleled with 0.1µF disc ceramics.

Selecting Low Power Switching Diodes

The MAX644/45/46/47 use one external diode, and this diode must be a Schottky. A common Schottky type that performs well is the 1N5818.

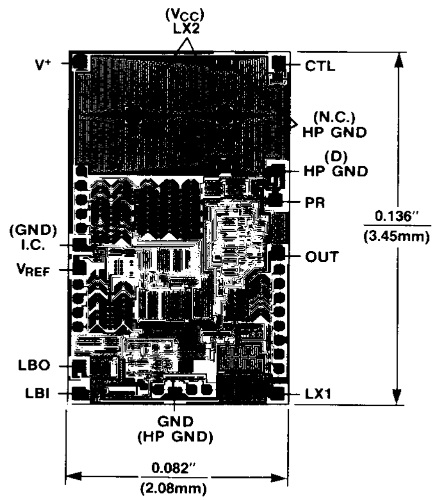
In applications where standby current must be minimized, the diode's reverse leakage characteristics are especially important. The MAX644/46/47 (40µA for the MAX645) standby current is typically 80µA, while the reverse current of some Schottky rectifiers can exceed this value, particularly at high temperatures. If necessary, diode leakage can be reduced with higher voltage Schottky types such as 1N5819. If standby mode is not used or is used only for short periods, then diode leakage is not a significant additional loss compared to the normal load current and need not be considered.

Ordering Information (continued)

PART	TEMP. RANGE	PACKAGE
MAX646CPD	0°C to +70°C	Plastic DIP
MAX646CSD	0°C to +70°C	Small Outline
MAX646C/D	0°C to +70°C	Dice
MAX646EPD	-40°C to +85°C	Plastic DIP
MAX646ESD	-40°C to +85°C	Small Outline
MAX646MJD	-55°C to +125°C	CERDIP
MAX647CPD	0°C to +70°C	Plastic Dip
MAX647CSD	0°C to +70°C	Small Outline
MAX647C/D	0°C to +70°C	Dice
MAX647EPD	-40°C to +85°C	Plastic DIP
MAX647ESD	-40°C to +85°C	Small Outline
MAX647MJD	-55°C to +125°C	CERDIP

** All devices have 14 leads*

Chip Topography



Note: Labels in ( ) are for MAX646 only

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