Battery Management and DC-DC Converter Circuit Collection

A Power-Supply Applications Guide for Portable Equipment

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MAXIM

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How to Read the Circuit Descriptions

This collection contains circuits running the gamut of power requirements, from tiny hand-held devices consuming only microwatts to large equipment like portable workstations that consume over 30W. However, all of these portable systems share the common requirements of high efficiency and miniaturization. The circuits contained in this collection were designed with these two important goals in mind.

Efficiency *should be viewed as more than just a snapshot of P_{OUT}/P_{IN} at some fixed load; it should be viewed from the perspective of increasing useful battery life. This can be accomplished by choosing the correct type of regulator, minimizing the power losses in external components, operating with ultra-low quiescent supply currents, and intelligently managing the power via logic-controlled shutdown modes.*

All efficiency data was taken with low-cost, real-world components, usually tantalum SMT capacitors and small SMT inductors. Solid gold wires, superconductors, and magnetic cores made from "unobtainium" are strictly disallowed.

Miniaturization *is addressed through high operating frequency and surface-mount construction. Almost every circuit in this collection is constructed entirely from surface-mount components, and every description provides part numbers for off-the-shelf magnetic components. In many cases, evaluation kits and/or printed circuit board layouts are available (as noted under Application Parameters).*

The specifications listed for each circuit are typical values at $T_A = +25°C$, except for the following:

Input Voltage Range: *These are min/max values generated after engineering review and lab experimentation. At the lower end of this input range, load current capability is usually reduced from that given in the Max Load Current Capability specification.*

Battery Voltages: *The term "cell" as used in the circuit description titles refers to the input voltage, with each cell having a maximum voltage of 2V or less (NiCd, NiMH, or alkaline). For example, a 2-cell circuit might have an input range of 1.8V to 4V, which accommodates a depleted alkaline battery (0.9/cell) but can also withstand the worst-case voltage of a NiCd being fast-charged (1.8V/cell). All DC-DC converter circuits are presented in order of increasing battery voltage.*

Max Load Current Capability: *This is also a guaranteed value, derated by at least 25% from the actual load capability to allow margin for process variations and component tolerances.*

Shutdown Logic Thresholds: *The shutdown control logic input thresholds are TTL compatible ($V_{IL} < 0.8V$, $V_{IH} > 2.0V$) unless noted. Detailed min/max specifications for all parameters can be found in the device data sheets.*

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Section 1
Fast Battery Chargers

Battery charger circuits encompass a wide range of design approaches, depending on the battery chemistry, source voltage, and power level. For example, a charger for two AA-size cells in a palmtop computer that is supplied from a 9V DC wall-cube adapter must necessarily be quite different from the charger for a 10-cell laptop computer connected directly to the AC main power. The following battery-charger collection covers fast charging of nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH) batteries from 5V to 40V DC sources.

Battery Charger Application Chart

Chemistry	Recommended Charging Method
Lead-Acid	Float voltage source with current-limited output. The float voltage should be set at 2.35V to 2.45V per cell (consult manufacturer). Many of the buck regulators and linear regulators in the **Main Power Supplies from High-Voltage Batteries (5 cells and above)** section can be adapted to this task.
NiCd and NiMH	Fast-charge: current source into battery with redundant charge-termination methods. Trickle-charge: current source at C/10 or less. This can be as simple as a resistor in series with a voltage source.
Lithium-Ion	Float voltage source similar to lead-acid charger. The float voltage should be set at 4.1V to 4.2V per cell (consult manufacturer).

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Simple Fast Charger with Linear Regulator Current Source

Application Parameters

Input Voltage Range ....(BATT + 1V) to 20V
5V Min

Max Charging Current Capability ......Limited only by Max PD

Supply Current (not charging) ....5µA Max

Efficiency ....Approximately Equal to
V_{BATT}/V_{SOURCE} x 100%

♦ Powers load and charges battery simultaneously—
   eliminates battery switchover circuitry

♦ Small and low cost —16-pin SO package

♦ Charges 1 to 16 series cells

♦ Evaluation kit available

Related Data Sheet

♦ MAX713 Battery Charger

Application Discussion

Two closely related problems found in powering small portable systems are charging the battery and switching over from battery power to AC power when an external AC-DC adapter is plugged in. The following circuit solves both problems at once with a low-cost linear regulator approach that simultaneously supplies both battery and load.

The fast-charge controller IC used here can supply the system load current while the battery is being charged by sensing and dynamically regulating the battery current. The MAX713 terminates the fast-charge cycle upon one (or all) of the following conditions: negative delta-V sensing, thermistor temperature, clocked time-out, or voltage ceiling. The MAX713 can be configured to drive a linear regulator, as in this example, or it can gate an external switching-regulator current source as in the following examples. The sister part, MAX712, is identical except that it terminates the fast charge at zero delta-V slope, which may be appropriate for certain NiMH batteries.

Employing a linear regulator instead of a switching regulator as the charger's current-source section is an excellent approach for small systems such as palmtop computers having low-voltage AC-DC adapters (5V-, 9V, and 12V-output are common examples) and low-wattage battery packs. The linear regulator approach is also effective for battery-backup in non-portable systems (such as large file servers).

The decision to use a linear or a switcher usually hinges on the level of acceptable power dissipation in the linear regulator pass element. For example, fast-charging three
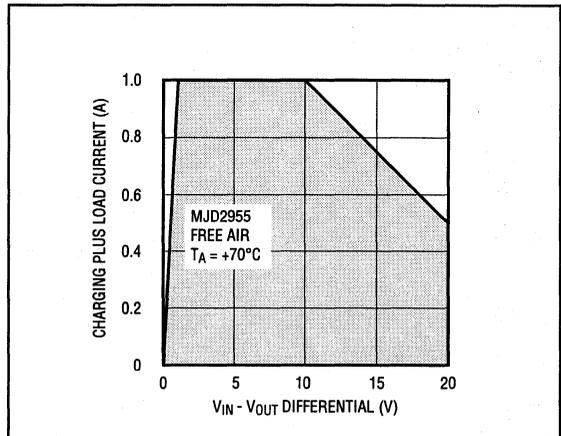
Figure 1. MAX713/MJD2955 Operating Area

Note: See the MAX712/MAX713 data sheet for additional pin-strap connections to program the number of cells and the timer (PG0-PG3).
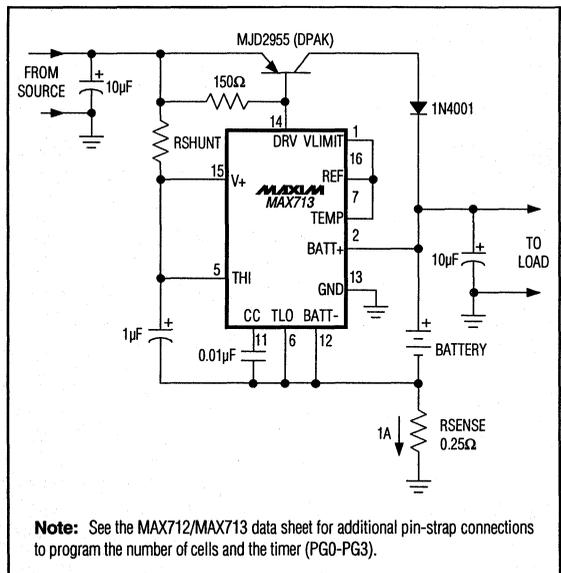
Figure 2. NiCd/NiMH Charger with Linear Regulator

750mA/hour NiCd cells from 9V DC at a 1C rate results in a worst-case dissipation of about five watts— a little too toasty for some hand-held applications. However, keep in mind that the output impedance of most wall-cube AC adapters will cause their output voltage to fall under heavy load, thus reducing the load power; often, this means that a wall cube that at first glance appears to have too high an output voltage for the linear regulator approach may actually be acceptable.

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Simple Fast Charger with Buck Switch-Mode Current Source

Application Parameters

Input Voltage Range ....(BATT + 1.5V) to 20V

7V Min.

Max Charging Current Capability ....3A as shown

Efficiency (V_{IN} = 12V, 2 cells, 1A).............................80%

♦ Includes step-down switch-mode current source

♦ Charges 1 to 8 series cells

♦ Configurable Output Current

Related Data Sheet

♦ MAX713 Battery Charger

Application Discussion

Fast-charging large batteries in compact enclosures—where heatsinking is impractical—raises the issue of temperature rise. The battery-charger current source must have high enough efficiency to prevent excess temperature rise. However, cost is also important, so drastic measures to improve efficiency (such as a synchronous rectifier) usually aren't needed.

The current-source buck regulator shown here consists of the buck switcher components (PFET, inductor, and rectifier), the error amplifier within the MAX713, and the resistor-capacitor network attached to CC. Other than improved efficiency, the main difference between this circuit and the linear regulator approach is that the linear approach can service the load while simultaneously charging the battery.

The control loop is a variable-frequency, hysteretic type that senses and regulates the current through the battery. Battery current is measured by the 0.08Ω sense resistor. This sense signal is compared to an internally generated 250mV threshold; the difference is gained up by a factor of eight, and the resultant error signal appears at the current-sense amplifier output (CC pin). A second high-gain stage between CC and DRV compares the error signal to the MAX713's +2.00V reference and turns the PFET switch either on or off in order to regulate the battery current. The circuit operates as a switcher rather than a linear regulator due to hysteresis introduced by the feedback divider and 33pF capacitor connected to CC. The capacitor injects charge into the CC node each time the PFET turns on or off, which kicks the error signal slightly above or below the +2.00V reference. This action overdrives the second gain stage and ensures a fast-switching drive signal to the PFET.

The circuit as shown is good for 3A charging currents. Lower currents allow smaller external components; for example, for a 1A charger, 1N5818s (1A Schottky) can be substituted for the 1N5821s, and a Sumida CD75-470 (47µH at 1A) SMT inductor can be substituted for the Gowanda part. Also, higher input voltages can be
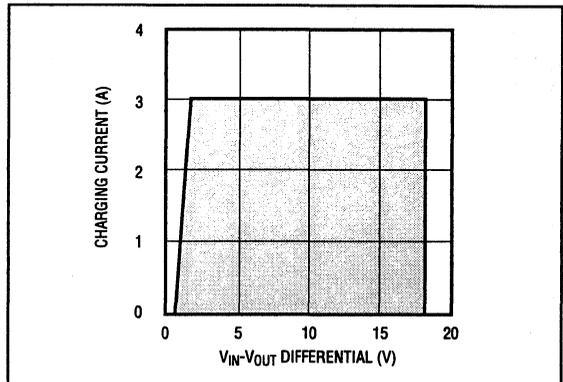
Figure 3.   MAX713 Buck Operating Area
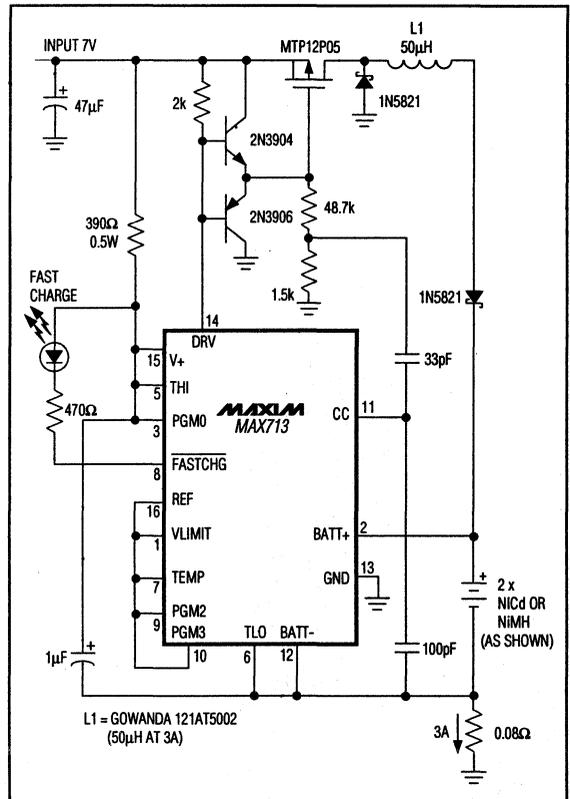
Figure 4.   NiCd/NiMH Charger with Buck Regulator

accommodated by adding a level-shifter between DRV and the PFET driver transistors, and changing the 390Ω shunt regulator resistor value.

Microprocessor-Controlled Switch-Mode Current Source: A System Solution

Input Voltage Range......................................5V to 18V

Quiescent Supply Current (V_{IN} = 5V)..........................1mA

Max Load Current Capability (V_{IN} = 5V)....1.5A (configurable)

♦ 3.3V current-mode PWM buck controller

♦ 15V (12V) flyback controller

♦ Battery charger current source (buck SMPS)

♦ Dual PCMCIA V_{PP} outputs (0V/V_{CC}/12V)

♦ 300kHz fixed-frequency oscillator

♦ 10µA shutdown mode

♦ 2.5V 1.5% reference output

♦ 5V low-dropout linear regulator output

♦ Analog multiplexer

♦ Five level translators for high-side switching

♦ SPI-compatible serial interface

♦ Evaluation kit available

Related Data Sheet

♦ MAX781 Subnotebook SMPS

Application Discussion

One effective scheme for fast-charging batteries is to employ a microcontroller with on-board ADC as the charger intelligence. This approach allows the charging algorithm to be changed easily through software. In this situation, a "dumb" switching regulator current source is needed, preferably one that has a digitally adjustable charging rate (to accommodate different battery packs). The circuit shown here integrates a switching regulator current source with several other power-supply functions. The current source output is programmed through a 3-wire SPI-type serial interface. See page 34 for further discussion.

A stand-alone buck regulator current source can be fashioned from the MAX724 circuitry used in the following application (*High-Voltage Buck Switch-Mode Charger*).
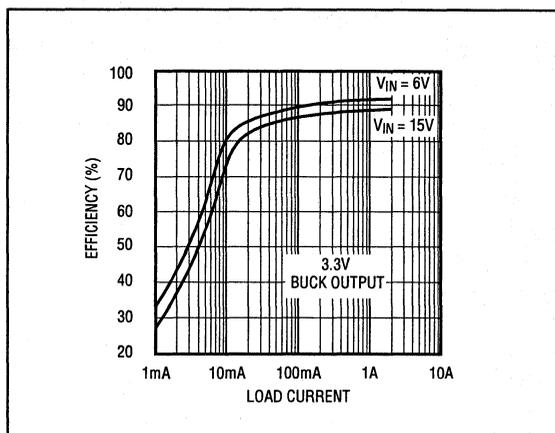
Figure 5. Efficiency vs. Load Current

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Microprocessor-Controlled Switch-Mode
Current Source: A System Solution
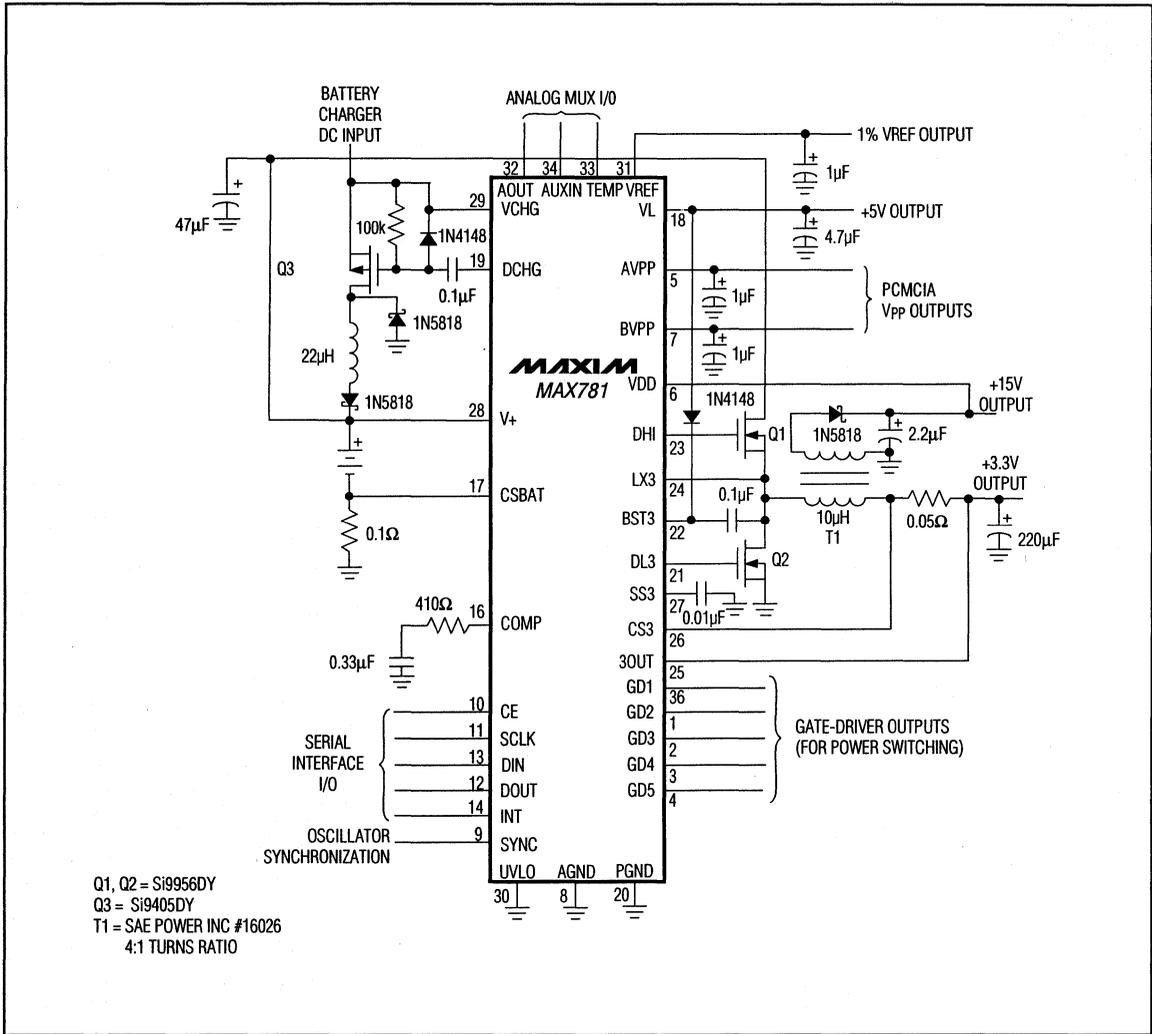
Figure 6. Single-Chip Subnotebook Computer Power Supply

High-Voltage Buck Switch-Mode Charger

Application Parameters

Input Voltage Range ....(BATT + 2.5V) to 40V
                                                    15V Min

Max Charging Current Capability 5A

Supply Current (not charging) 10μA

Efficiency (V$_{IN}$ = 20V, 1A, 6 cells)............................80%

♦ **Charges high-cell-count battery packs**

♦ **Powers load and charges battery simultaneously—**
  eliminates battery switchover circuitry

♦ **Charges 1 to 12 series cells**

Related Data Sheets

♦ **MAX713 Battery Charger**

♦ **MAX724 Buck Regulator**

Application Discussion

At high input voltages (15V and above), buck switching regulators with internal bipolar NPN switches such as the MAX724 become economical and relatively efficient, since the large VCE (sat) voltage of the switch becomes small relative to the input voltage. This circuit employs a robust 5A bipolar switching regulator IC that is configured for current-source output. Maximum input voltage is 40V.

The compensation (VC) pin of the MAX724, which is at the internal junction of the error-amplifier output and the PWM comparator input, is overdriven by an external op amp that allows the MAX713 DRV pin to control duty cycle. The MAX713 senses the battery charging current and modulates the duty cycle in order to regulate the charging current. The dominant pole for loop stability is set at the compensation pin of the MAX713 (CC), so do not increase the value of the battery filter capacitor without also increasing the CC capacitor. Lower values for both capacitors are preferred in order to maintain good transient response characteristics.

This circuit is configured to supply a load while simultaneously charging the battery. If the drop across the sense resistor during discharge is undesirable, the resistor can be shorted out temporarily with an optional low on-resistance (r$_{DS (on)}$) N-channel MOSFET. If load transients are expected during the fast-charge cycle, check the worst-case load step response. The battery voltage must settle to 5mV x N (where N is the number of cells) in less than 2msec for the MAX713's internal analog-to-digital converter to terminate the cycle properly.

For applications needing 2A or less, using a MAX726 instead of the MAX724 provides somewhat better efficiency due to its low-saturation, non-darlington switch.
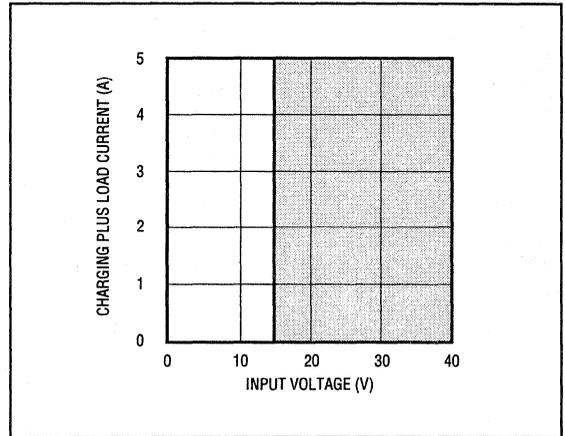
Figure 7. MAX713/MAX724 Operating Area
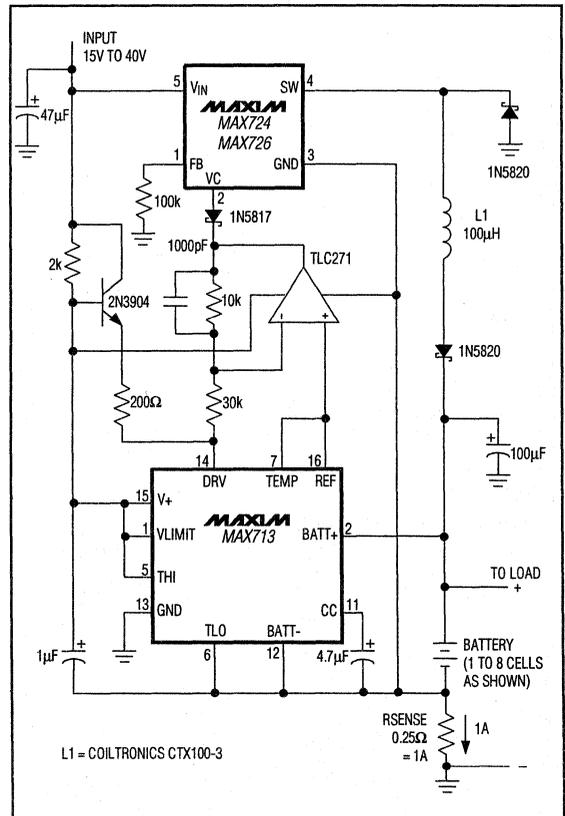
Figure 8. High-Voltage, High-Power DC Input Charger

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Section 2
Main Power Supplies for Low Voltage Batteries
(4 cells and below)

The following circuits are DC-DC converters intended to generate the main system supply voltage in battery-powered systems (usually 3.3V or 5V). The circuits are presented in order of increasing battery voltage. Often, there will be more than one solution presented for each application niche, providing alternate solutions that have unique performance advantages.

Most of the circuits in this first section covering low-voltage batteries are by necessity the simple boost (step-up) topology in one form or another, although there are two 4-cell buck regulators at the end. The next section deals with 4-cell to 5V converters, which are hybridized step-up and step-down converters. The third section on main power supplies covers high-voltage circuits and contains mostly buck (step-down) switching regulators plus a couple of low-dropout linear regulators.

Control Schemes

There are three basic control schemes found in the DC-DC switching-regulator ICs in this collection:

- Current-mode Pulse-Width Modulation (PWM)

- Fixed-time Pulse-Frequency Modulation (PFM)

- Current-limited Pulse-Frequency Modulation (PFM)

Design equations for each of the control schemes are found in Appendix A. Generally speaking, the PWM ICs have higher quiescent supply current than the PFM ICs. In return, the PWM ICs provide superior noise characteristics (usually important only in noise-sensitive applications such as radios and cellular phones).

1-4 Cells to 3.3V/5V via
Low-Power Boost Regulator

Application Parameters

Input Voltage Range......................................1V to 6.2V

Start-Up Supply Voltage ($I_{LOAD} = 0$)..........................0.9V

Quiescent Supply Current ($V_{IN} = 2.5V$).....................220µA

Max Load Current Capability ($V_{IN} = 1V$)..................100mA

($V_{IN} = 1.8V$) 240mA

♦ Internal low VF rectifier

♦ Continues to regulate with $V_{IN} > V_{OUT}$

♦ Rectifier can be turned off—blocks inductor-diode leakage path and completely disconnects load from battery

♦ Withstands output short-circuit to ground

♦ Pulse-skipping PFM

♦ 20µA shutdown mode

♦ Adjustable switch current limit

♦ Adjustable output version

♦ Evaluation kit available

Related Data Sheet

♦ MAX778 Boost Regulator

Application Discussion

A single-cell battery, especially near end-of-life, barely provides adequate gate-drive voltage to start up a MOSFET-based switching regulator. If a single-cell system must start up under load, a bipolar switching transistor is a good alternative to MOSFETs, especially to discrete power MOSFETs, the best of which today have a very high 2V worst-case gate threshold voltage specification.The MAX777 overcomes this problem by employing an internal NPN bipolar switch.

The MAX777/MAX778/MAX779 are micropower step-up converters built with a high-speed (200kHz) pulse-skipping PFM controller. High operating frequency allows the inductor to be made very small (10µH or less), reducing the needed energy storage and core size.

These ICs accept 1V to 6.2V (1-cell to 4-cell) inputs and generate fixed 3V, 3.3V, 5V, or adjustable outputs. Each replaces the usual external Schottky rectifier with an internal active rectifier that completely turns off in shutdown mode, entirely disconnecting the load from the source, overcoming a fundamental problem of the boost topology.
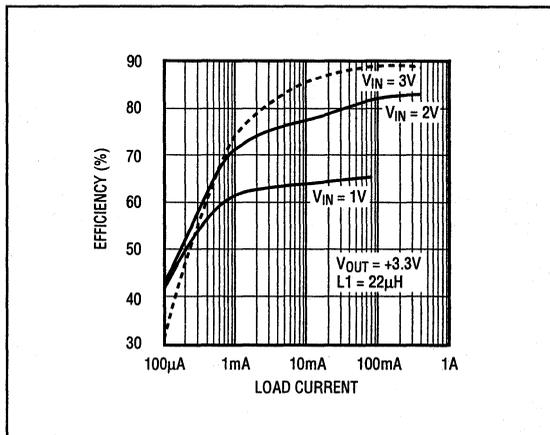
Figure 9. Efficiency vs. Load Current
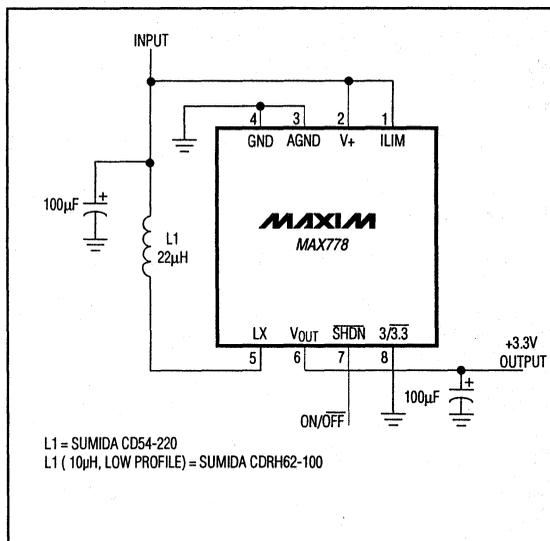
Figure 10. Single-Cell Boost Regulator with Synchronous Rectifier

The internal synchronous rectifier can also act like a low-dropout linear regulator. This switched linear mode occurs automatically as the input voltage exceeds the programmed output voltage, thus allowing for wider input voltage ranges than are normally possible with a simple boost regulator (for example, 4 cells in, +5V out).

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2-3 Cells to 5V at High Power:
Parallel-Connected Dual Boost Controller

Application Parameters

Input Voltage Range ....0.9V to 5.5V

Start-Up Supply Voltage (I_{LOAD} = 0) 1.4V

Quiescent Supply Current (V_{IN} = 3V)
             Low-Power Mode 170µA
             High-Power Mode 240µA

Max Load Current Capability (V_{IN} = 3V).....................1.5A

♦ Low-power/high-power mode switch

♦ All surface-mount components

♦ Pulse-skipping PFM

♦ 1.5% reference output

♦ Power-fail detection output

Related Data Sheet

MAX718 Palmtop SMPS

Application Discussion

"High power" in the world of small 2-cell boost regulators translates to a 5V at 1A output, which is just 5W. But getting even 5W from a 2-cell or 3-cell battery is a non-trivial design problem. Peak currents will be higher than 2A, which means that even small voltage drops in the power devices, battery, capacitors, and PC board wiring can result in grossly poor efficiency and outright failure. For example, an AA alkaline battery pack can't support a 5W load at all, except in short surges, due to high internal battery impedance. However, NiMH and NiCd battery packs offer the low output impedance needed for continuous heavy load drains.

This circuit connects two boost regulators from a MAX718 in parallel, and is intended to provide surge-current capability for small systems with occasional heavy loads (such as disc-drive motor spin-up or radio transmission). The main regulator contributes its good light-load efficiency during normal system operation and guarantees low-voltage start-up (its power MOSFET has a 0.8V gate threshold voltage). The auxiliary regulator with external MOSFET is not limited to 5W output; it can be tailored to heavier loads with bigger inductors and capacitors.

Normally, paralleling unsynchronized switching regulator outputs like this is a bad idea, due to possible beat frequency problems between two close oscillator frequencies and current "hogging." In this case, it works because of the widely differing current capabilities and totally asynchronous switching of the two regulator sections. Light-load efficiency improves 10% when
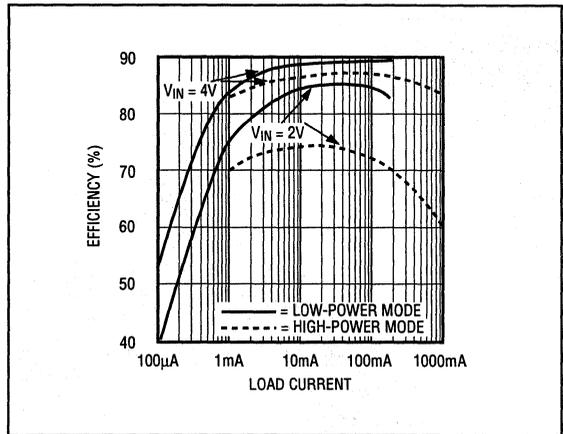
Figure 11. Efficiency vs. Load Current

Q1 = MTD3055EL OR SILICONIX Si9410DY
C1, C2 = 330µF, 6.3V SPRAGUE 595D SMT TANTALUM
L1 = SUMIDA CD54-220 (22µH)
L2 = SUMIDA CD105-100 (10µH)
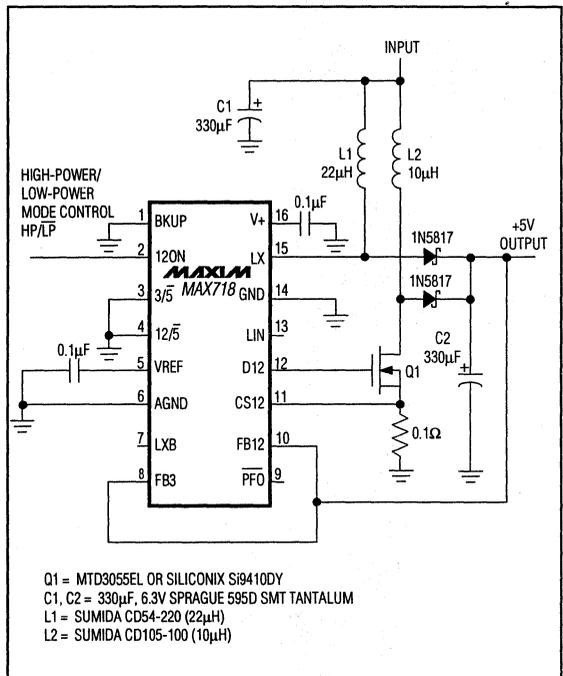
Figure 12. High-Power, Low-Voltage Boost Regulator

operating in low-power mode (200mA max load current) instead of high-power mode, due to the reduced peak-current level.

2-3 Cells to 3.3V/5V at Medium Power

Application Parameters

Input Voltage Range.................................0.9V to V_{OUT}

Start-Up Supply Voltage 1.4V

Quiescent Supply Current (V_{IN} = 3V)

          3.3V Mode 60μA

          5V Mode 140μA

Max Load Current Capability (V_{IN} = 3V, 5V mode).......400mA

♦ 0.5MHz switching frequency

♦ Pulse-skipping PFM

♦ 1.5% reference output (alive in shutdown)

♦ Power-fail detection

♦ 20μA shutdown mode

♦ Adjustable-output version available (MAX757)

♦ Evaluation kit available

Related Data Sheet

♦ MAX756 Boost Regulator

Application Discussion

Palmtop computers place tough design requirements on the power supply: On one hand, they must be ultra-small to fit into compact enclosures; on the other hand, they must be efficient and have ultra-low standby currents to provide battery life measured in days and weeks. Small size means high frequencies for tiny inductor cores, but high frequencies imply high switching losses and poor efficiency. This circuit strikes a balance between size and efficiency by using a fast MOSFET switch coupled with a PFM control loop that has judiciously chosen ON-time and OFF-time values.

This circuit and the two that follow are building blocks for all kinds of medium-power palmtop applications. The MAX756 shown here contains a 0.4Ω N-channel MOSFET switch that has a very low 0.8V gate threshold voltage — a feature that allows it to start up under heavy load and low input voltage conditions. Other nice details include a low-quiescent 1.5% accurate voltage reference output and accurate low-battery detection.

Inductor values can be less than 10μH with little effect on supply current, making the MAX756 shine in size-constrained applications such as PCMCIA memory cards. Miniature (3mm diameter) inductors are made possible by a relatively high 0.5MHz maximum switching frequency. While one might expect to pay the penalty of increased supply current for 0.5MHz operation, the
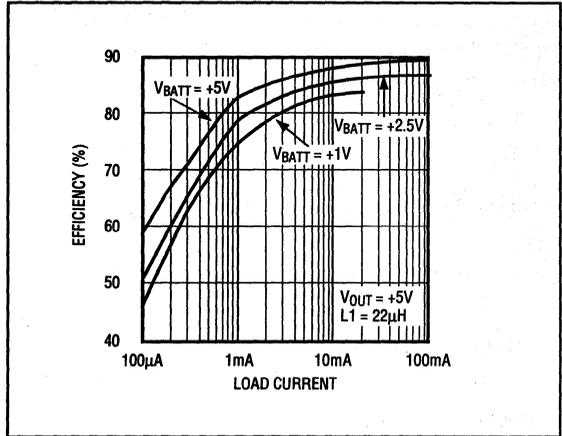
Figure 13. Efficiency vs. Load Current
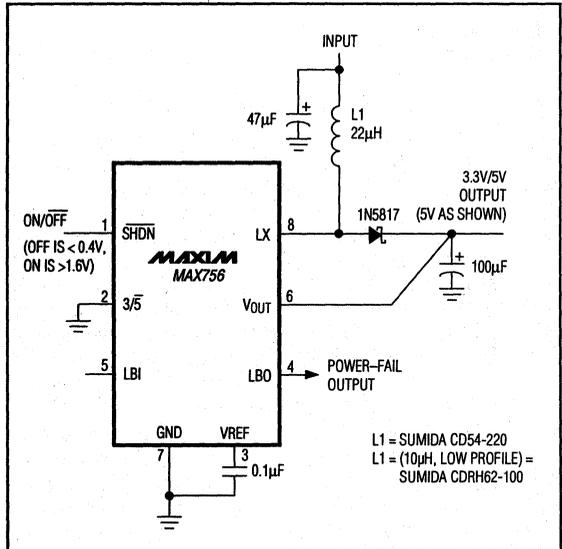
Figure 14. 2-3 Cell Medium Power Boost Regulator

MAX756 draws only 60μA, due to an advanced PFM control scheme.

Low inductor values (5μH to 22μH) allow physically small cores, with little penalty in reduced efficiency or output current capability. High inductor values (>22μH) allow peak current levels to be kept low, reducing the necessary filter and input capacitor sizes in lightly loaded applications.

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2-3 Cells to 3.3V/5V and 5V/12V
at Medium Power

Application Parameters

Input Voltage Range...................................0.9V to V_{OUT}

Input Voltage Range (wall cube) ....7V to 20V

Start-Up Supply Voltage ($I_{LOAD} = 0$) 1.4V

Quiescent Supply Current ($V_{IN} = 3V$)

                Main SMPS = 5V 140µA

                Both SMPS 500µA

Max Load Current Capability ($V_{IN} = 3V$)

                Main SMPS = 5V..............400mA

                Auxiliary SMPS = 12V 120mA

♦ **Dual regulated outputs**

♦ **Pulse-skipping PFM**

♦ **Accepts three input sources**

♦ **0.5MHz switching frequency**

♦ **1.5% reference output (alive in shutdown)**

♦ **Power-fail detection**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX718 Palmtop SMPS**

Application Discussion

Size and cost constraints of PDAs and palmtop computers necessitate higher levels of integration. The following circuit shows a system-engineered IC that integrates four control loops in a dual, low-voltage switching regulator application.

This medium-power palmtop supply can generate 3.3V and 5V, 3.3V and 12V, or 5V and 12V, depending on the state of certain logic control inputs. Two regulated output voltages are generated from one of three input voltage sources: an AC-DC wall-cube adapter (7V to 20V), a main 2- or 3-cell battery, or a lithium backup battery. The dotted-line connection at the top of L2, which powers the auxiliary supply, is normally hard-wired to the main battery, but can also be connected to the main output when power comes from the AC wall adapter. The main switching regulator automatically shuts off to save the batteries when the AC-DC wall cube is plugged in.

The two switch-mode supplies are the same type as found in the MAX756, which has a wide range of maximum switching frequencies. Practical inductor values are from 5µH to over 200µH, allowing one to trade off switching losses and physical size. Lower inductance
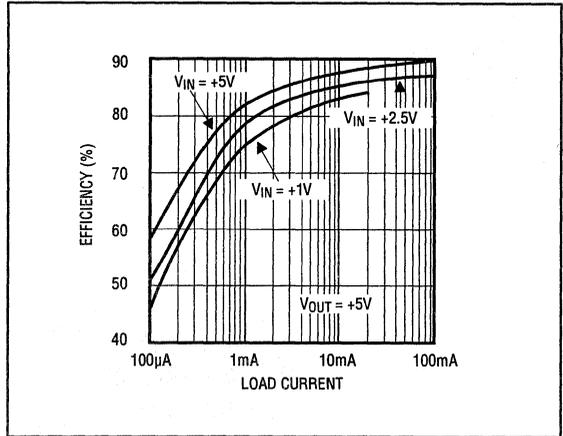
Figure 15. Efficiency vs. Load Current (5V Mode)
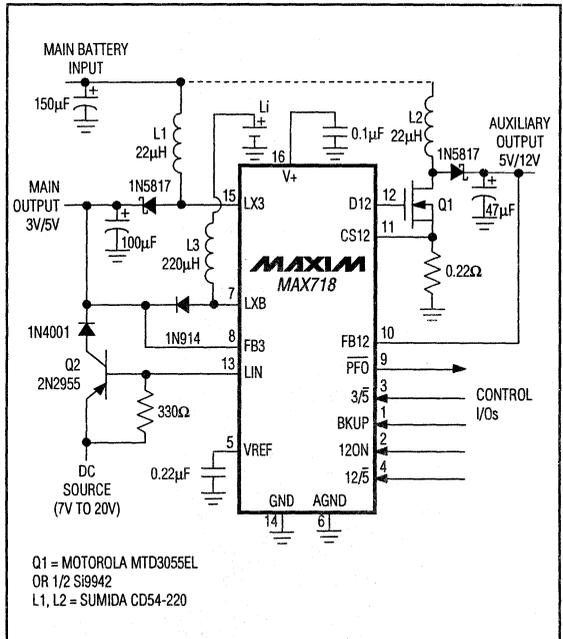
Figure 16. Dual-Output Palmtop Power Supply: 5V/12V Version

values increase frequency without affecting peak currents or load current capability significantly. Inductance values can be increased for lightly-loaded applications, in order to reduce peak currents.

2-3 Cells to 3.3V/5V, 12V, and –18V:
A System Solution

Application Parameters

Input Voltage Range ....1.8V to 5.5V

Quiescent Supply Current (V$_{IN}$ = 3V, 12V OFF) 350µA

Max Load Current Capability	V$_{IN}$ = 2V	V$_{IN}$ = 2.5V
+5V Output	200mA	275mA
+12V Output	40mA	60mA
–18V Output................................		Configurable

♦ Triple output

♦ PFM and PWM

♦ 5msec rise time (12V regulator, full load)

♦ 1.5% reference output (alive in shutdown)

♦ Power-fail detection comparator

♦ Evaluation kit available (MAX722)

Related Data Sheets

♦ MAX722 Palmtop SMPS

♦ MAX734 12V Boost Regulator

Application Discussion

The problem of inadequate gate-drive swing is often encountered when designing low-voltage power supplies. This circuit powers one of its switching regulator ICs from a +5V bus generated by another switching regulator IC to achieve gate-drive levels higher than the battery voltage.

The dual-output MAX722 IC is the heart of this system-engineered power supply intended for ultra-small palmtop-style computers. The main regulator uses a low-
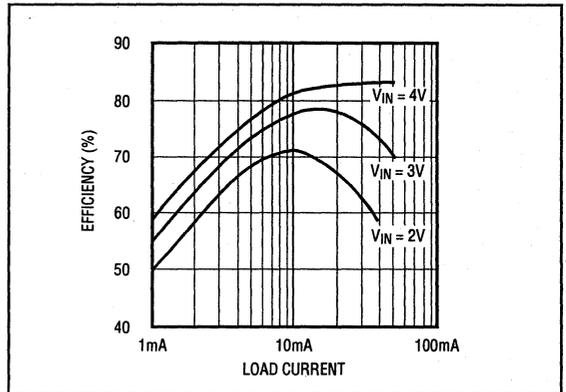
Figure 17. Efficiency vs. Load Current (12V Regulator Only)

threshold MOSFET to generate the 5V logic supply (3.3V is also possible). The MAX722's inverter section provides an adjustable negative bias voltage for LCD contrast control. A MAX734 boost regulator chip generates +12V flash programming voltage for solid-state mass storage or PCMCIA memory cards.

The MAX734's power-supply pin, which draws little current (1mA), is powered from the 5V system supply, while the inductor connects directly to the battery. This scheme provides good gate-drive levels to the MAX734's internal MOSFET while avoiding the compounded efficiency losses and extra loading that would result from powering the inductor from the 5V supply. If the main output is set at 3.3V, the MAX734 V+ pin should be bootstrapped (connect V+ to +12V instead of +5V) for enhanced gate drive.
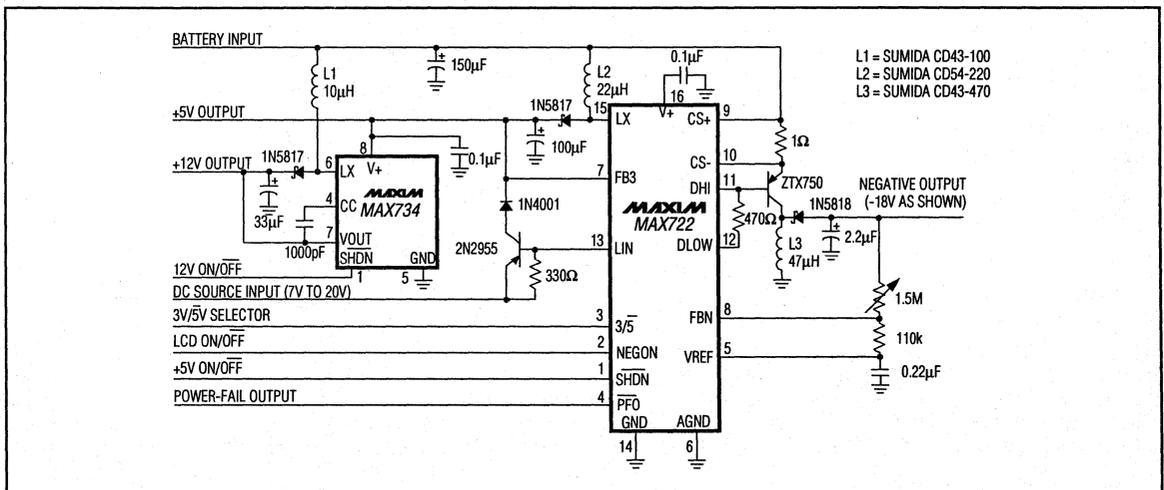
Figure 18. Triple-Output Palmtop Power Supply

2-3 Cells to 5V at Low Power via PWM Boost Regulator

Application Parameters

Input Voltage Range ....2V to 5V

Start-Up Supply Voltage ($I_{LOAD} = 0$) 1.2V

Quiescent Supply Current ($V_{IN} = 3V$).........................2mA

Max Load Current Capability ($V_{IN} = 2.7V$) 100mA

♦ 170kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 30µA shutdown mode

♦ 1.23V reference output

Related Data Sheet

♦ MAX751 Boost Regulator

Application Discussion

In many portable products, such as cellular phones and medical instruments, noise generated by switching regulators is a major consideration. This circuit provides a fixed-frequency PWM alternative to the pulse-skipping control scheme usually found in low-voltage switching regulator ICs. The trade-off for low-noise operation is increased quiescent supply current and subsequent lower efficiency at light loads.

The optional load-disconnect circuit breaks the parasitic path from input to output, allowing the output to go to 0V. In shutdown mode, there is less than 0.6V difference applied to the PNP's base-emitter junction. So, the PNP turns off, breaking the inductor-diode path and incidentally reducing supply current to less than 1µA (by disconnecting the internal feedback resistor divider).

Note: See also the MAX751's big brother, the MAX731, which has a bigger switch transistor and comes in a larger package. Refer to the *3.3V to 5V at Low Power: MAX731 Boost Regulator* circuit for the schematic.
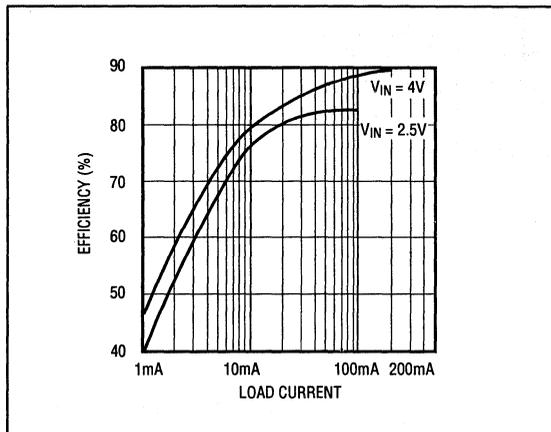
Figure 19. Efficiency vs. Load Current (Bootstrapped)
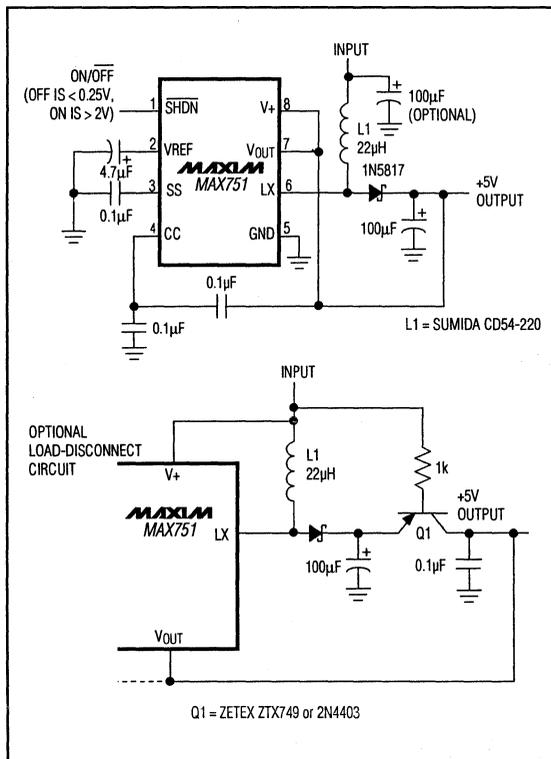
Figure 20. 2-3 Cells to 5V with PWM Boost Regulator

2-3 Cells to 5V at Micro Power

Application Parameters

Input Voltage Range......................................1.6V to 5V

Start-Up Supply Voltage (I_{LOAD} = 0) 2V

Quiescent Supply Current (V_{IN} = 3V) 160µA

Max Load Current Capability (V_{IN} = 3V) 5mA

♦ **Pulse-skipping PFM**

♦ **Cost-effective**

♦ **1µA shutdown mode**

♦ **Low-battery detection comparator**

Related Data Sheet

♦ **MAX630 Boost Regulator**

Application Discussion

Low cost is the main claim to fame of this flea-power step-up regulator. It was included in this collection to fill a need for the minimum possible solution to boost low input voltages, and is most useful in situations where cost, not efficiency, is the driving factor (although efficiency can be improved by substituting a Schottky rectifier and low-resistance inductor).

Note: This circuit is bootstrapped; minimum start-up supply voltage can be improved by applying the input directly to +VS at the expense of low-voltage load current capability.

The MAX630 employed here is the original micropower DC-DC IC, first designed in 1983 for a scientific calculator application. Although mature, the MAX630 is still quite useful for boosting lithium backup batteries to generate the regulated backup power needed by pseudo-static RAM chips and many other lightly loaded applications.

See also the MAX619 data sheet for an inductorless charge-pump solution (a future product).
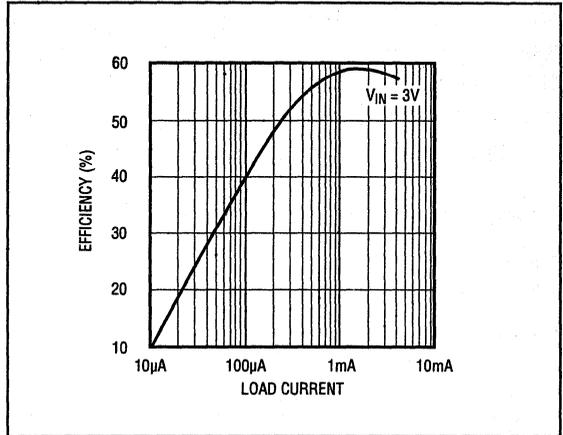
Figure 21. Efficiency vs. Load Current
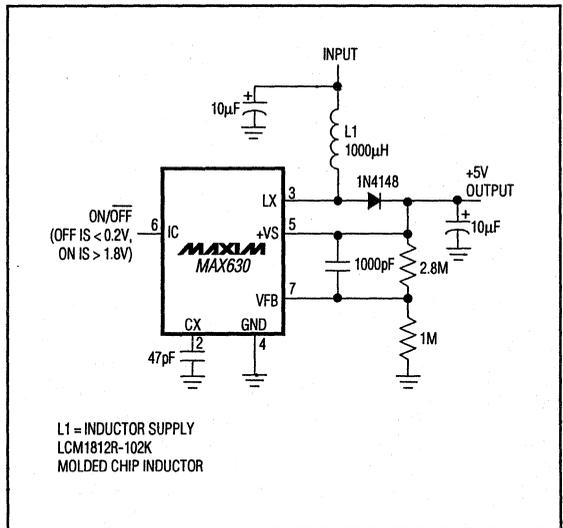
Figure 22. Low-Power, Low-Cost Boost Regulator

MAXIM

3 Cells to 3V/3.3V at Medium Power via Low-Dropout PFET Linear Regulator

Application Parameters

Input Voltage Range......................................3V to 15V

Quiescent Supply Current (V_{IN} = 6.5V, LP mode)..........40μA
                          (V_{IN} = 6.5V, HP mode)........750μA

Max Load Current Capability (V_{IN} = 6V, V_{OUT} = 3.3V) 1A
(max load current is limited by power dissipation)

♦ Low dropout voltage: 100mV at I_{LOAD} = 1A

♦ Supply (ground) current is independent of load

♦ 0.6% accurate reference output

Related Data Sheets

♦ ICL7611 Micropower Op Amp

♦ MAX872 Voltage Reference

Figure 23. Dropout Voltage vs. Load Current

Application Discussion

See the discussion under *5 Cells to 5V via Low-Dropout PFET Linear Regulator.*

When this circuit is powered from a low voltage source such as a 3-cell battery, make sure the PFET selected has an adequately low gate-threshold voltage; for example, the Si9433's rDS(ON) is guaranteed at VGS = 2.7V. See also the MAX682 data sheet (a future product).
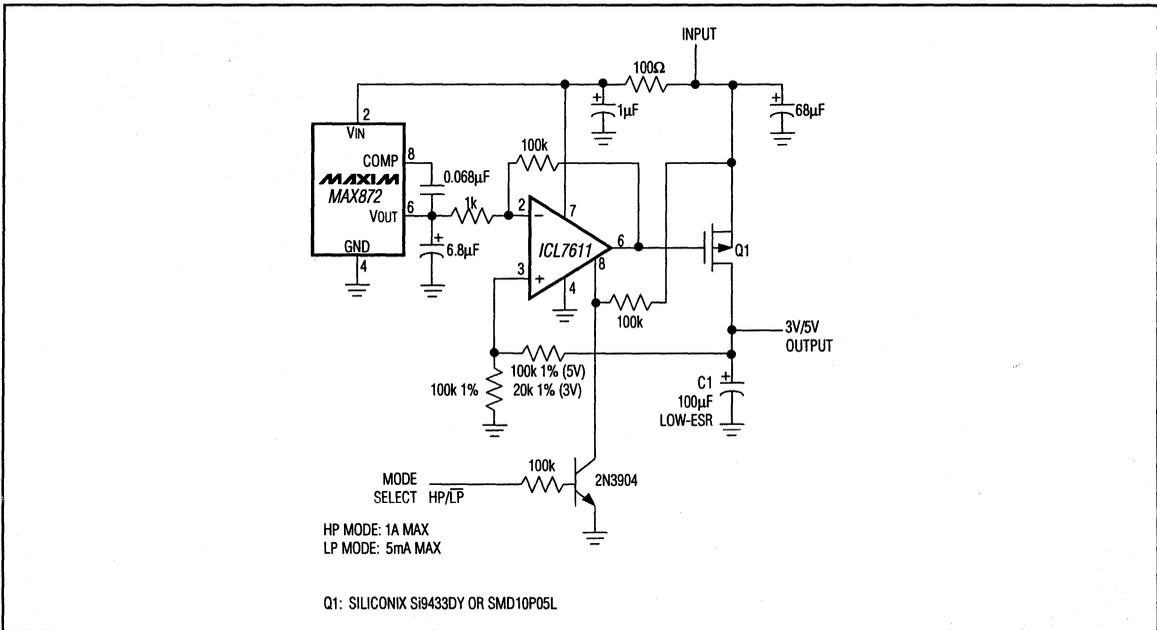
Figure 24. Low-Dropout PFET Linear Regulator

4-6 Cells to 3.3V at Low Power
via Buck Regulator

Application Parameters

	Circuit A	Circuit B
Input Voltage Range	4V to 11V	4V to 11V
Quiescent Supply Current		
(V_{IN} = 4.8V, LP Mode)	60µA	25µA
(V_{IN} = 4.8V, HP Mode)	1.6mA	1.6mA
Max Load Current Capability		
(V_{IN} = 4V, LP Mode)	10mA	50mA
(V_{IN} = 4V, HP Mode)	400mA	400mA
Efficiency at V_{IN} = 4.8V		
(I_{LOAD} = 1mA, LP Mode)	72%	86%
(I_{LOAD} = 100mA, HP Mode)	92%	92%

♦ **170kHz Fixed-Frequency Oscillator**

♦ **Current-Mode PWM or PFM**

♦ **Multiple Comparators for Battery Monitoring**

♦ **High-Power/Low-Power Mode Control**

Related Data Sheets

♦ **MAX639 Buck Regulator**

♦ **MAX750 Buck Regulator**

♦ **MAX8213 Voltage Monitor**

Application Discussion

Small subnotebook-style systems often have very low suspend-mode supply current drains, making high efficiency at light loads a desirable characteristic. At the same time, on-board communication features such as radio modems make low-noise, fixed-frequency operation desirable. These two circuits can both be switched between a low-power PFM mode for suspend-level loads and a high-power PWM mode for normal system operation.

The MAX750A is a PWM buck regulator with internal PFET switch that delivers 400mA load current at input voltages as low as 4V (end-of-life of four NiCds). The MAX750A can be used in conjunction with external circuitry to improve light-load efficiency, as shown in the following two circuits.

The first circuit (Figure 25) operates in a low-noise PWM mode at high current levels, but can be switched into a low-current pulse-skipping mode where the MAX750A is disabled if the output is regulating properly. When commanded by the LP/HP control input, this pulse-skipping mode provides high efficiency at very light loads due to reduced switching losses and lower quiescent current consumption by the MAX750A. Note that the MAX8213 quintuple voltage monitor chip, which contributes an error comparator to regulate the output in low-power mode, can be replaced with a single comparator and inverter if desired.

A second circuit (Figure 26) is slightly more complex, but provides extremely high light-load efficiency due to the exceptionally low quiescent losses of the MAX639 PFM buck regulator chip. The MAX639 is essentially in parallel with the MAX750A, driving the same inductor, and when one chip is on the other is turned off. Efficiency is 70% to 93% from 100µA to 400mA—a 400:1 load current range.

MAXIM

4-6 Cells to 3.3V at Low Power
via Buck Regulator
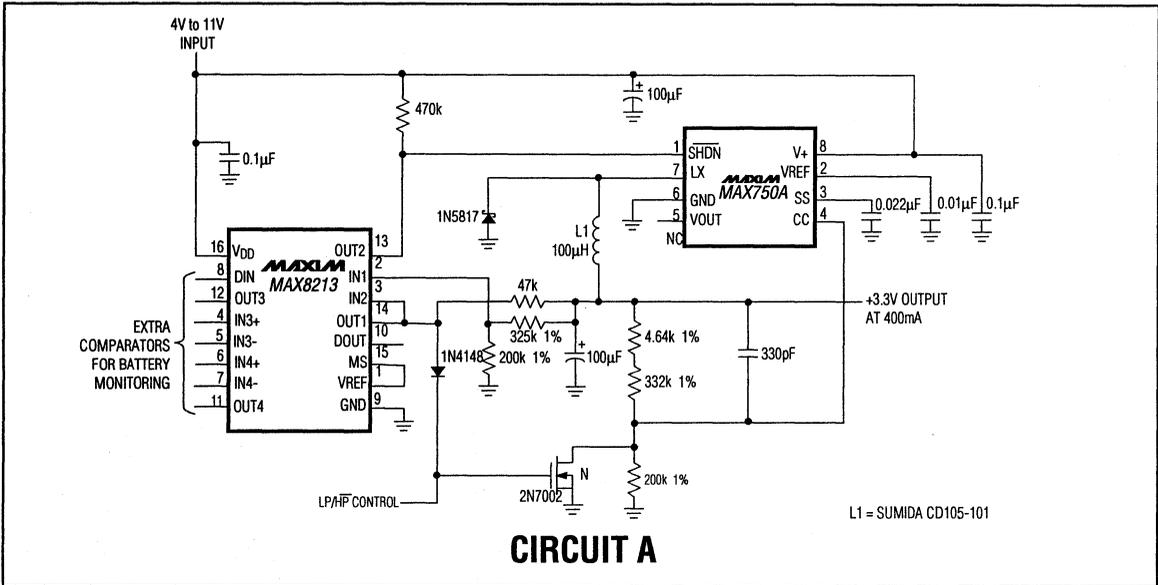
Figure 25. Skip-Mode PFM/PWM 3.3V Buck Regulator
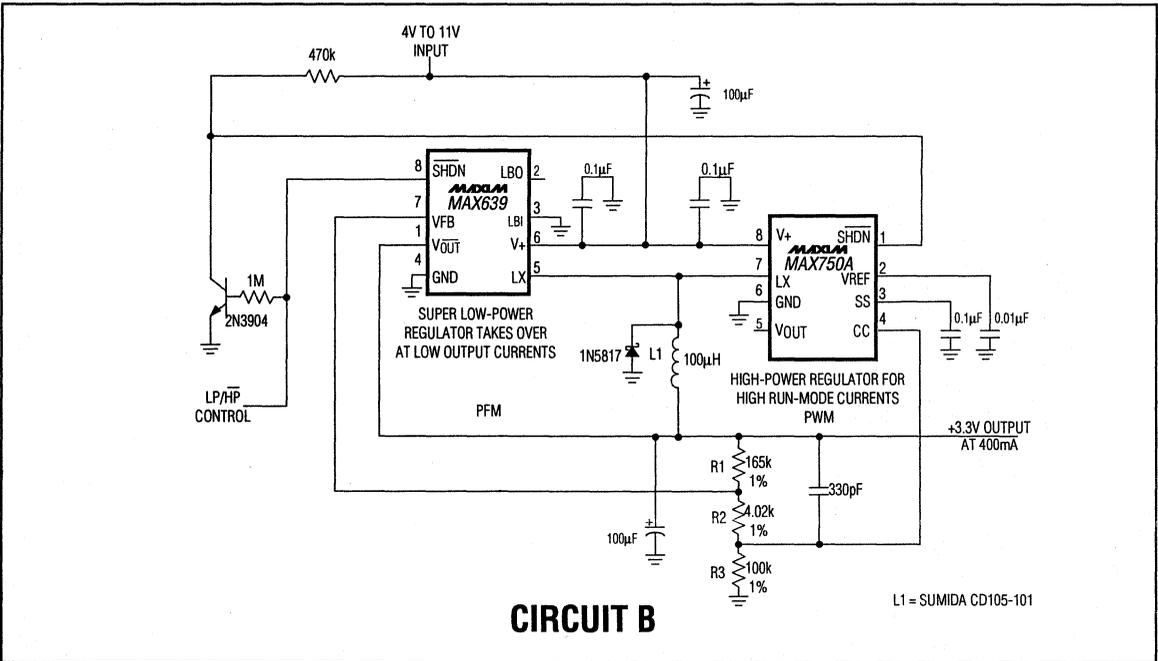
Figure 26. Micropower PFM/PWM Buck Regulator

Section 3
4-Cell to 5V Converters

Generating 5V from 4 series alkaline or zinc battery cells is a special case that places tough requirements on the main DC-DC converter. The difficulty: The battery voltage ranges from 6.2V to 3.6V, which is above and below the main output voltage, eliminating the simple and elegant buck and boost topologies from consideration. The following circuits show four different ways to attack the 4-cell problem.

*See also the discussion under **6-12 Cells to 3.3V, 5V, and 12V at High Power** for an inverter-plus-buck approach.*

4 Cells to 5V via Boost/Step-Down Regulator

Application Parameters

Input Voltage Range......................................1V to 6.2V

Quiescent Supply Current (V_{IN} = 4V) 250µA

$\qquad\qquad\qquad\qquad$ (V_{IN} = 6V).......................320µA

Max Load Current Capability (V_{IN} = 2.5V to 6.2V) 200mA

♦ Internal low VF rectifier

♦ Continues to regulate with V_{IN} > V_{OUT}

♦ Rectifier can be turned off – blocks inductor-diode leakage path and completely disconnects load from battery.

♦ Withstands momentary output short-circuit to ground

♦ Pulse-skipping PFM

♦ Shutdown mode

♦ Adjustable switch current limit

♦ Adjustable-output and fixed 3.0V/3.3V versions also available

Related Data Sheet

♦ MAX877 Boost/Step-Down Regulator

Application Discussion

This unusual switching regulator circuit is deceptively simple in outward appearance. It is a boost regulator, but contains an active rectifier in place of the usual external Schottky diode. This active rectifier allows the MAX877 to overcome many of the normal limitations of the simple boost topology, such as lack of short-circuit protection, lack of true shutdown (V_{OUT} = 0V), and the input voltage range restriction $V_{IN} < V_{OUT}$.

The circuit operates in switch-mode even at high (V_{IN} > V_{OUT}) input voltages, with the active rectifier acting as the switch. This action is more akin to a regulating charge pump than to a buck regulator (buck mode requires a second switch on the high side). Efficiency in this mode approximates that of a linear regulator, which is good over the 4-cell battery voltage range.

Output current limit (of the rectifier) is internally fixed at 1.6A. The low-side switch current limit can be set at 1A by tying ILIM to V+, or reduced by adding a low-value resistor between those pins. See also the MAX777 type, which is very similar but intended for low-voltage applications.

Figure 27. Efficiency vs. Load Current

L1 = SUMIDA CD54-220
L1 (10µH, LOW PROFILE) = SUMIDA CDRH62-100

Figure 28. 4 Cells to 5V: Boost Regulator with Dual-Purpose Synchronous Rectifier

MAXIM

4 Cells to 5V via
Low-Dropout Linear Regulator

Application Parameters

Input Voltage Range ....4V to 16.5V

Quiescent Supply Current (V_{IN} = 6V) 10µA

Max Load Current Capability (V_{IN} = 6V) 250mA

Dropout Voltage (I_{LOAD} = 100mA)..........................100mV

Battery Life
   (4 Alkaline AA at I_{LOAD} = 100mA,
    to V_{OUT} = 4.5V) ....11.2 Hours

Battery Life
   (4 Alkaline AA at I_{LOAD} = 100mA,
    to V_{OUT} = 4.75V) ....7.5 Hours

♦ **No magnetics**

♦ **Low-noise operation**

♦ **1µA shutdown mode**

♦ **Low-battery detect comparator**

Related Data Sheet

♦ MAX667 Linear Regulator

Application Discussion

On the surface, a step-down linear regulator looks like a poor choice for converting 4 cells to 5V; when the output stops regulating and the batteries go into the trash, a fair amount of energy is still left in them. This wastefulness seems just plain untidy from a pure engineering standpoint. However, hard, cold test data indicates that the linear regulator approach achieves good battery life that can equal or even exceed some of the switching regulator methods that follow. The success of the linear regulator can be traced to the fact that its efficiency becomes nearly 100% as the battery voltage nears 5V. Also, there are no pulsed currents as with switching regulators; I^2R losses and heat are therefore lower, so the circuit is gentler to the battery chemistry compared to a switching regulator. And while battery life doesn't match the best switching regulator results, other benefits of linear regulators (cost, size, low noise) still make them attractive.

In general, switching regulator solutions provide a tightly regulated output even at low battery voltages. When the output finally collapses, it does so rather abruptly (in milliseconds). A linear regulator, on the other hand, drops out slowly and gracefully as the battery voltage
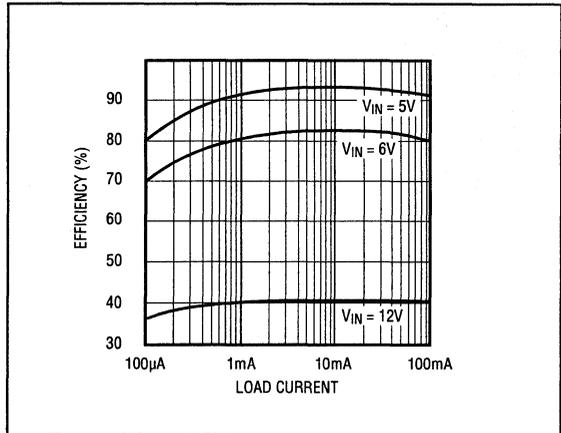
Figure 29. Efficiency vs. Load Current
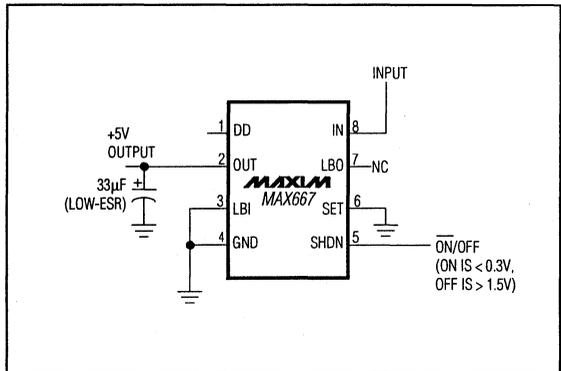
Figure 30. 4 Cells to 5V: Low-Dropout Linear Regulator

decays. This characteristic leads to a problem when comparing linears to switchers: When do you call the battery dead? The linear regulator solution typically provides 50% additional life with a 4-cell battery if one defines "dead" as V_{OUT} = 4.5V instead of 4.75V (see the life test results in the table above).

The MAX667 linear regulator shown here works extremely well in the 4-cell application due to its very low dropout and extremely low quiescent current (10µA). See also the MAX682 data sheet for a PFET-based solution (a future product).

4 Cells to 5V via
Boost Regulator with Diode Step-Down

Application Parameters

Input Voltage Range......................................2V to 6.2V

Start-Up Supply Voltage ($I_{LOAD} = 0$).............................1.5V

Quiescent Supply Current ($V_{IN} = 5V$)..........................70µA

Max Load Current Capability ($V_{IN} = 4V$)....................400mA

Battery Life (4 Alkaline AA at $I_{LOAD} = 100mA$) ......15.5 Hours

♦ **Battery voltage can go above or below output voltage**

♦ **55µA shutdown mode**

♦ **1.25V ±1.5% reference output**

Related Data Sheet

♦ **MAX756 Boost Regulator**

Application Discussion

Pre-regulating the input to a boost switcher is the overall winner for the 4-cell application, since it retains the low peak currents and uncomplicated circuit of the simple boost topology. The basic idea is to boost the battery voltage, once it falls below the desired output voltage, until the battery is sucked dry. When the battery pack is fresh, the switching regulator is disabled, so the worst-case high input voltage of 6.3V is dropped to 5.4V by a silicon rectifier in series with the normal Schottky boost rectifier (a "cheap and dirty" equivalent to a linear regulator). Note that there must be a minimum load of at least 0.5mA or so to prevent diode leakage current from causing output overvoltage. The boost converter operates until the batteries are less than 3V; efficiency is typically 80% when the batteries are fresh, and is nearly 90% at $V_{IN} = 4V$.

This diode-based circuit is conceptually similar to having a linear pre-regulator for a boost regulator, and one can easily substitute a linear regulator for the diode in order to accommodate higher input voltages. Another similar approach is to put the linear regulator at the output of a boost regulator. Finally, if cost is key, one can always omit the PFET switchover circuit, and include only the diode, with some penalty in reduced battery life.
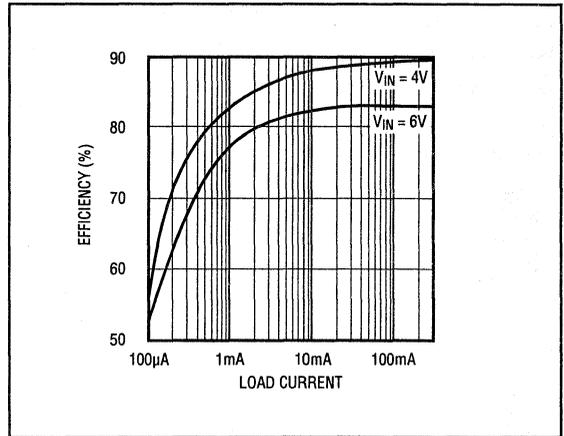
Figure 31. Efficiency vs. Load Current
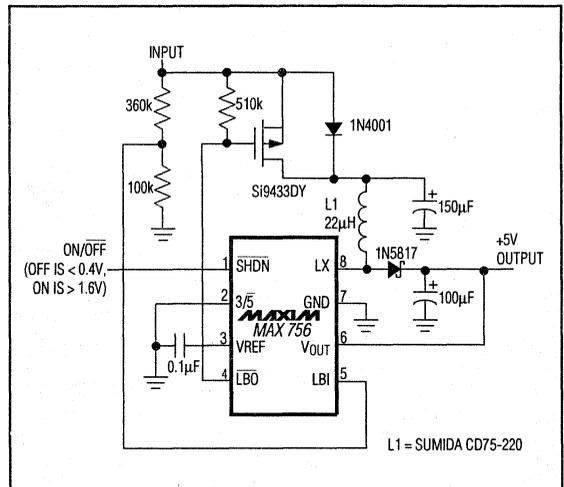
Figure 32. 4 Cells to 5V: Boost Regulator with Diode

MAXIM

4 Cells to 5V via Inverter or Flyback

Application Parameters

Input Voltage Range ....3.8V to 11V

Input Voltage Range (non-bootstrapped mode)..3.8V to 16.5V

Start-Up Supply Voltage (I_{LOAD} = 0) ....4V Max

Quiescent Supply Current (V_{IN} = 5V) 1.8mA

Max Load Current Capability (V_{IN} = 5V)...................200mA

Battery Life (4 Alkaline AA at I_{LOAD} = 100mA) ......13.5 Hours

♦ Battery voltage can go above or below output voltage

♦ Works with any inverter

♦ 165kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 1.23V reference output

♦ 1μA shutdown mode

Related Data Sheet

♦ MAX739 Inverting Regulator

Application Discussion

Another tactic for combatting the 4-cell problem is inverting the battery voltage (using a switch-mode converter to create –5V) and moving the ground reference of the circuit to the negative output. Having the +5V output connected to the battery's negative terminal in this manner may present a problem if other loads in the circuit are referenced to the battery "ground" or if additional voltages must be generated from the stack of batteries. Also, the ratio of peak switch current to load current in this circuit is relatively high (about two times that of a boost regulator with the same output power), necessitating a relatively big inductor core and increasing I²R efficiency losses. Finally, it requires a high-side power switch (PNP or PFET) rather than a more-attractive low-side switch (NPN or NFET). In spite of these drawbacks, this circuit benefits many portable equipment designs due to its simplicity and wide input voltage range.

Flyback transformer and flying inductor solutions give similar results in terms of battery life, due to efficiency losses brought about by high peak currents that are in turn caused by the high peak-current to average load-current ratio of the inverting/flyback topology. In the words of one disappointed flyback experimenter, "Nearly beaten by a linear regulator, for crying out loud." In defense of the flyback and inverter approaches, the input
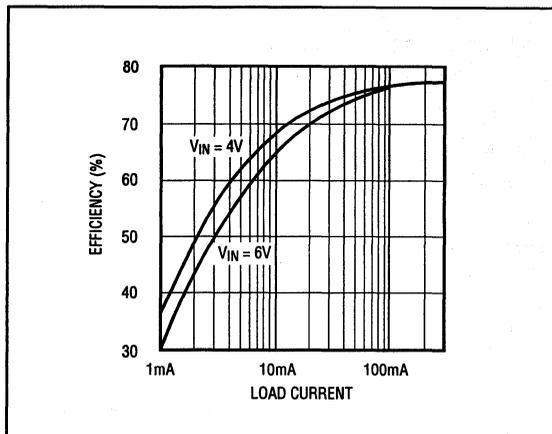
Figure 33. Efficiency vs. Load Current
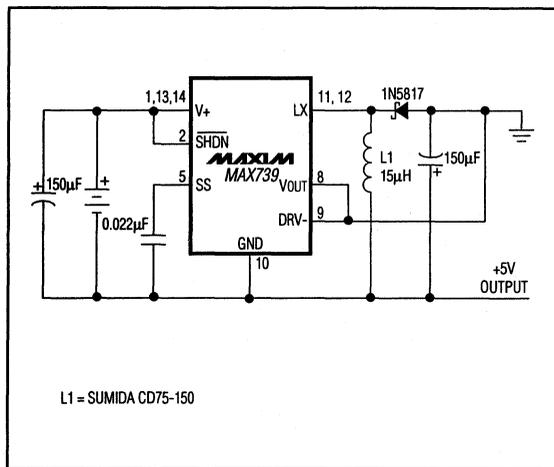
Figure 34. 4 Cells to 5V: Inverter with Battery-Referred Output

voltage range can be made very wide, with much better efficiency at high input voltages than is possible with a linear regulator. Wide voltage range is useful in situations where the circuit must be able to accept alternate battery packs, such as a 12V lead-acid battery (in addition to a 4-cell NiCd or alkaline pack). In shutdown mode the output goes to 0V, which is not automatically the case for boost regulator approaches. And of course, the flyback approach can generate isolated and multiple output voltages by adding windings to the transformer.

4 Cells to 5V via
Step-Up/Step-Down Switchable Topology

Input Voltage Range......................................3V to 6.5V

Quiescent Supply Current (V$_{IN}$ = 5.5V) 50µA

Quiescent Supply Current (V$_{IN}$ = 4.5V) 110µA

Max Load Current Capability (V$_{IN}$ = 3.75V) 200mA

Battery Life (4 Alkaline AA at I$_{LOAD}$ = 100mA) ......17.2 Hours

♦ **Battery voltage can go above or below output voltage**

♦ **Pulse-skipping PFM**

♦ **Shutdown mode**

_____Related Data Sheet

♦ **MAX639 Buck Regulator**

_____Application Discussion

The ultimate weapon to date for taming 4-cell battery packs, this circuit switches from buck to boost mode as the battery falls below 5V, but only requires a single inductor. Switch-mode operation over the entire battery voltage range allows for higher efficiency than the "boost plus linear regulator" scheme, and avoids the high peak currents and I^{2}R losses of the inverting/flyback approach. Efficiency is greater than 90% over nearly the entire battery range, extracting just about all the energy to be had from a 4-cell pack. The trade-off for this high level of
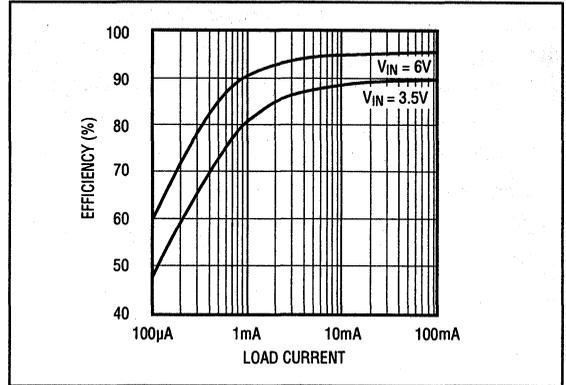
Figure 35. Efficiency vs. Load Current

performance is more complex circuitry. Three power MOSFETs are required (four if you parallel two P-channel MOSFETs for lowest r$_{DS(ON)}$, as shown). Also, there is a ±2% change in output voltage as the battery voltage reaches 5V, required for the topology switchover function.

The low-battery detection comparator built into the MAX639 IC provides the step-up/step-down switchover decision. The comparator monitors either the battery or the output voltage. As the buck regulator goes into dropout, the output begins to fall. As the output voltage passes through 4.85V, the circuit switches from buck into boost mode, and the output regulation point shifts from 4.92V to 4.98V (nominal). If the output voltage rises above 5.15V, the circuit switches back into buck mode.
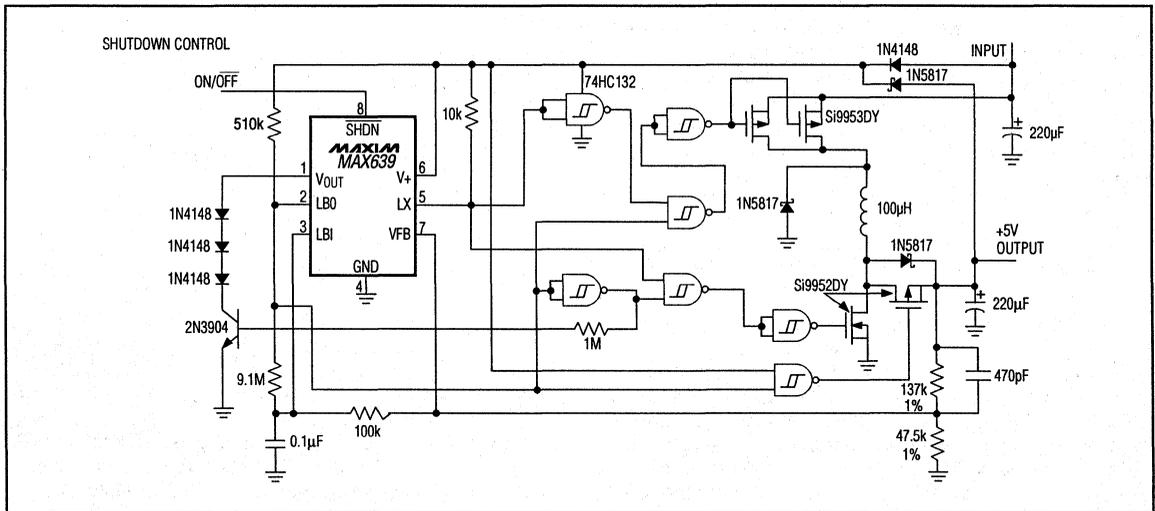
Figure 36. 4 Cells to 5V: Step-Up/Step-Down Switchable Topology

MAXIM

Section 4
Main Power Supplies for High-Voltage Batteries (5 cells and above)

The following circuits are all step-down regulators intended for battery applications. They can be put into three groups:

- *Linear regulators for 5 cells to 5V*
  ICL7611/MAX872 (3.3V also)
  MAX714 Multi-output family

- *Stand-alone buck switching regulators*
  MAX730 PWM with internal PFET
  MAX639 PFM with internal PFET
  MAX786 Idle-Mode™ PWM with external NFET
  MAX738 PWM with internal PFET
  MAX752 PWM with internal NFET
  MAX638 PFM with internal PFET

- *Multiple Buck PWMs per IC (system-engineered)*
  MAX781 Idle-Mode PWM, 3.3V buck plus charger
  MAX782 Idle-Mode PWM, triple-output

Like the low-voltage boost circuits, the step-down switchers are either current-mode PWMs or straight PFMs. The three Idle-Mode circuits operate in PWM mode at moderate to heavy loads and PFM at light loads (MAX786, MAX781, MAX782).

For high-voltage step-down needs in non-battery applications (distributed power supplies, automotive, etc.), see the MAX724/MAX726 data sheet.

5 Cells to 5V via
Low-Dropout PFET Linear Regulator

Application Parameters

Input Voltage Range......................................3V to 15V

Quiescent Supply Current (V_{IN} = 6.5V, LP mode) 40µA

(V_{IN} = 6.5V, HP mode) 750µA

Max Load Current Capability (V_{IN} = 6V, V_{OUT} = 5V) 1A
(max load current is limited by power dissipation)

♦ Low dropout voltage: 100mV at I_{LOAD} = 1A

♦ Supply (ground) current is independent of load

♦ 0.6% accurate reference output

Related Data Sheets

♦ ICL7611 Micropower Op Amp

♦ MAX872 Voltage Reference

Application Discussion

NiCd and NiMH batteries have an end-of-life voltage of almost exactly 1V per cell, making five series cells a magic combination for generating 5V with linear regulators. If you neglect transistor base current and quiescent losses, the efficiency of a linear regulator is equal to V_{OUT}/V_{IN}, which approaches 100% as the input-output difference becomes small. When the batteries are fresh (6V), theoretical efficiency is 83%. As the batteries decay, the efficiency actually improves.

Although more expensive than a PNP transistor, a P-channel MOSFET contributes no wasted power from base current losses and has a lower saturation voltage at light loads than a PNP. The use of readily available logic-level PFETs permits incredibly low dropout voltages even at high load currents. The low dropout characteristic of this circuit (100mV at 1A) permits the system to "ride down" the battery voltage until the output falls out of tolerance (i.e., V_{OUT} < 4.5V).

The ICL7611, with its pin-programmable bias current, allows the circuit to be switched into a low-power (LP) mode where the total supply current is less than 50µA. In this mode, the output is capable of supplying 5mA for RTC and RAM backup. In the high-power (HP) mode, up to 1A output current is available. The input voltage range and output current are limited by the external PFETs' package power dissipation ratings; (V_{IN}-V_{OUT})(I_{OUT}) < 1.25W unless heat-sinking is provided.

The 100µF output capacitor was chosen for 1A maximum load currents and may be scaled down for lighter loads if desired. However, the lag compensation scheme used to provide loop stability in this circuit depends on low effective series resistance (ESR) for this capacitor. Be sure that the loop zero $1/2\pi R_{ESR}C_1$ occurs at a frequency greater than 14kHz. When built with a low-ESR capacitor

Figure 37. Dropout Voltage vs. Load Current

Figure 38. Low-Dropout PFET Linear Regulator

(100µF with less than 0.1Ω ESR), AC load- and line-transient response are excellent, and phase margin is better than 50 degrees under worst-case conditions.

The MAX872 low-power, low-dropout voltage reference used in this circuit is accurate enough (0.6% over temperature) to be valuable as a system reference.

See also the *4 Cells to 5V: MAX667 Low-Dropout Linear Regulator* circuit and the MAX682 data sheet (a future product).

MAXIM

5 Cells to 5V and Multiple Outputs via Low-Dropout PNP Linear Regulators

Application Parameters

Input Voltage Range....................................5.05V to 11V

Quiescent Supply Current (V_{IN} = 6V).......................300µA

Standby Supply Current   (V_{IN} = 6V) 35µA

Max Load Currently Capability
              (AUX OUT, V_{IN} = 6V) .... 1A Continuous

♦ Output voltages: 5V at 1A (2A peak)
                  5V at 100mA
                  −26V at 30mA for LCD

♦ On-board DAC for LCD adjustment

♦ Power-fail and low-battery detect flags

♦ Lithium backup-battery switchover

♦ Linear and PFM switching regulators

♦ Standby and backup modes

Related Data Sheet

♦ MAX714 Subnotebook Supply

Application Discussion

Excess power dissipation at high input voltage is the limiting factor with linear regulators in 5-cell to 5V applications. In battery-powered circuits, excess power dissipation limits their utility if the batteries are fast charged in place. At 1C charge rates, battery voltage can rise as high as 1.8V/cell, and possibly higher if the battery charger is connected when the batteries are removed. If load current is flowing, the high input-output difference may cause excess temperature rise. The resulting hot spots can be a problem in small, hand-held devices, many of which have temperature-sensitive LCDs. However, linear regulators remain nearly unbeatable in the 5-cell to 5V role if the continuous load current is relatively low (perhaps 500mA continuous or less) or if the batteries are charged outside the circuit.

The MAX714-MAX716 system solution ICs generate multiple output voltages from a 5-cell stack. The MAX714 circuit shown here generates two 5V outputs (one at 2A, the other at 100mA) and a negative LCD bias voltage (−10V to −26V) controlled by an internal DAC. Other family members have additional outputs in various flavors. All contain supervisory functions such as low-battery detection. The non-darlington Zetex ZTX788B PNP pass transistors in this circuit have an amazingly high minimum beta of 300 at 1A, holding the efficiency decrease due to base current losses to less than 0.3%.
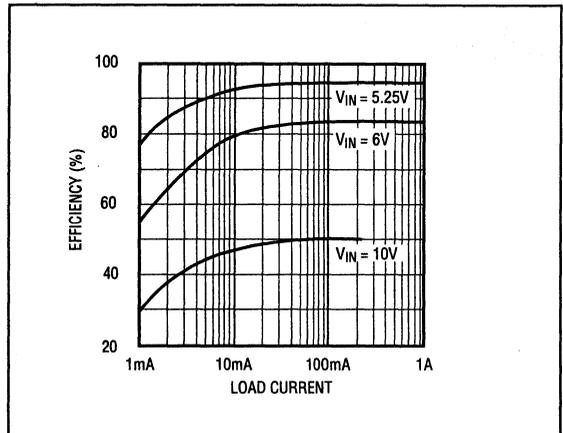
Figure 39. Efficiency vs. Load Current, AUX Output
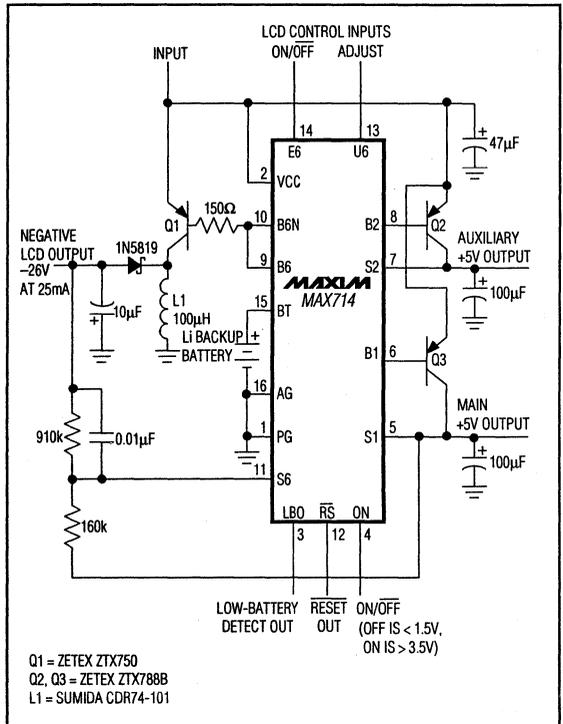
Figure 40. Triple-Output Subnotebook Supply with PNP Linear Regulators

5 Cells to 5V via
Low-Dropout, Low-Power PWM Buck Regulator

Application Parameters

Input Voltage Range .... 5.2V to 11V

Quiescent Supply Current (V_{IN} = 6V) 1.4mA

Max Load Current Capability (V_{IN} = 6V) 500mA

Efficiency (V_{IN} = 6V, I_{LOAD} = 100mA) 95%

♦ Internal P-channel MOSFET

♦ Small 8-pin package

♦ 170kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 6µA shutdown mode

♦ 1.23V reference output

Related Data Sheet

♦ MAX730A Buck Regulator

Application Discussion

If a buck regulator can achieve a very high duty factor, it can mimic a low-dropout linear regulator and "ride down" a falling battery voltage. This can work well in 5-cell to 5V applications and similar low-dropout situations. The MAX730A shown here can achieve duty factors in excess of 95%, so dropout is only 200mV at a 100mA load.
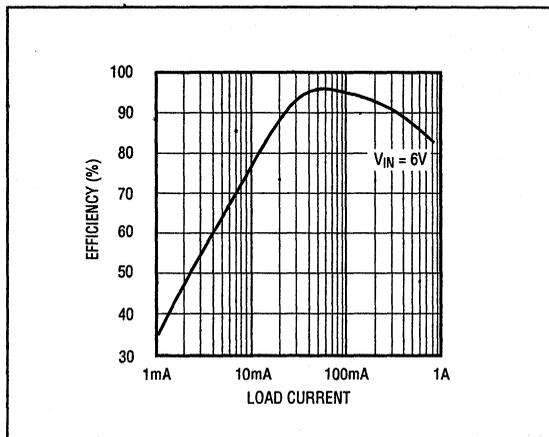
Figure 41. Efficiency vs. Load Current
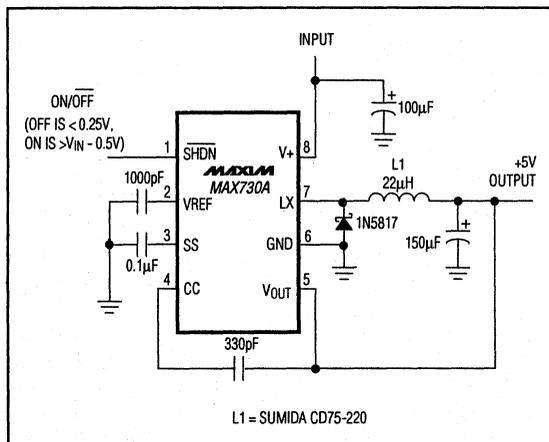
Figure 42. Low-Dropout, Low-Power PWM Buck Regulator

MAXIM

6 Cells or 9V Transistor Radio Battery to 5V/3.3V at Low Power

Application Parameters

Input Voltage Range .... 5.5V to 11.5V

Quiescent Supply Current (V_{IN} = 9V) 10μA

Max Load Current Capability (V_{IN} = 5.5V) 100mA

(V_{IN} = 8V) 175mA

♦ 0.5V dropout voltage

♦ 10μA shutdown mode

♦ Low-battery detect comparator

♦ Evaluation kit available

Related Data Sheet

♦ MAX639 Buck Regulator

Application Discussion

One specialized requirement in battery applications is to squeeze every last drop from a 9V transistor-radio battery, over the widest possible range of load current. To meet this objective, the MAX639 has the lowest quiescent supply current of any step-down regulator IC at the time of writing, with a guaranteed maximum operating supply current of 20μA. Also, for highest efficiency, the MAX639 contains a monster P-channel MOSFET switch. The normally high 94% efficiency can be made as high as 97% by substituting a 470μH inductor.

Although targeted at the common 9V transistor-radio battery (PP3, ANSI 1604A type) the MAX639 is also a good choice for 6-cell designs. The MAX639's ultra-low supply current makes it great for memory-backup applications, where 10μA of supply drain is on the same level as the battery self-discharge current.

A fixed 3.3V-output version, the MAX640, is also available.
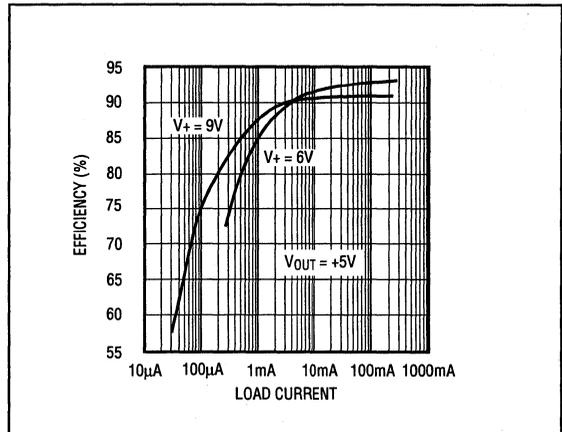
Figure 43. Efficiency vs. Load Current
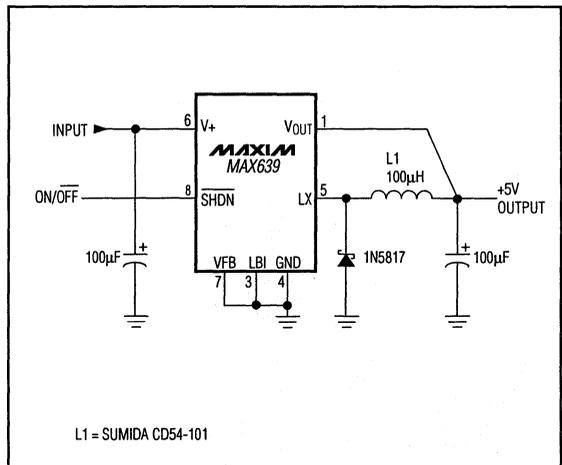
Figure 44. 9V Battery PFM Buck Regulator

5-12 Cells to 3.3V at High Power

Application Parameters

Input Voltage Range ....4.5V to 30V

Quiescent Supply Current (V_{IN} = 15V) 630μA

Max Load Current Capability (V_{IN} = 4.5V).......................3A

♦ **N-Channel MOSFETs**

♦ **Small inductor**

♦ **Two precision low-battery detection comparators**

♦ **25μA shutdown mode**

♦ **3.3V, 1.5% reference output**

♦ **60kHz unity-gain crossover—excellent AC response**

♦ **Synchronization input**

♦ **300kHz/200kHz fixed-frequency oscillator**

Related Data Sheet

♦ **MAX786 Notebook SMPS**

Application Discussion

Cost, size, and efficiency are the driving factors in designing a main power supply for a battery-powered system. This circuit addresses each of these issues with a combination of high operating frequency and all-NFET design.

This buck regulator operates as a fixed-frequency current-mode PWM when load currents are high (1/4 load to full load) and automatically switches over to a pulse-skipping PFM mode at light loads. This idle-mode characteristic results in high efficiency over a wide range of load current, yet still provides low-noise PWM operation when inductor and switch currents reach high levels.
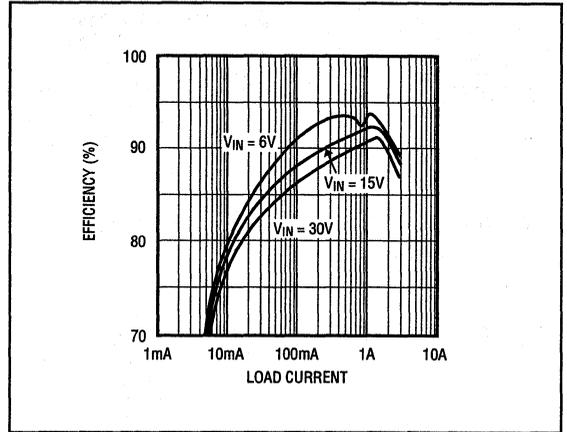
Figure 45. *Efficiency vs. Load Current*

L1 = SUMIDA CDR125-100
Q1,Q2 = SILICONIX Si9410DY
C1,C2 = AVX TPS OR SPRAGUE 595D
D1 = CENTRAL SEMICONDUCTOR CMPSH-3 OR 1N5819
OTHER PINS ARE NO CONNECTS
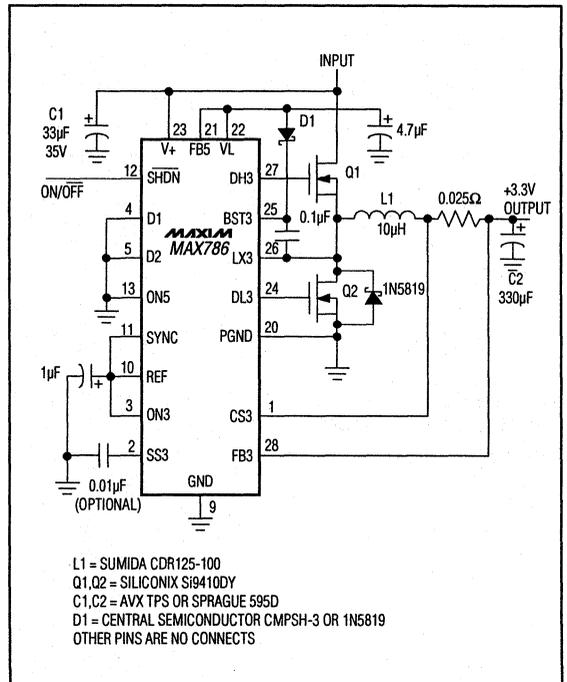
Figure 46. *3.3V PWM Buck Controller with NFET Switch*

MAXIM

6-12 Cells to 5V at High Power

Application Parameters

Input Voltage Range ....5.5V to 30V

Quiescent Supply Current (V_{IN} = 15V) 270µA

Max Load Current Capability (5V output, V_{IN} = 6V) 3A

♦ **N-Channel MOSFETs**

♦ **Small inductor**

♦ **Two precision low-battery detection comparators**

♦ **Comparators double as high-side switch level translators**

♦ **25µA shutdown mode**

♦ **3.3V, 1.5% reference output**

♦ **60kHz unity-gain crossover—excellent AC response**

♦ **Synchronization input**

♦ **300kHz/200kHz fixed-frequency oscillator**

Related Data Sheet

♦ **MAX786 Notebook SMPS**

Application Discussion

There are three often-used methods for designing a power supply for a portable system: from the ground up with discrete components ("555s and baling wire"), from a combination of general-purpose building-block ICs, or from system-level power-supply ICs (as seen later in this collection). This circuit falls into the "building block" category.

This buck regulator operates as a fixed-frequency current-mode PWM when load currents are high (1/4 load to full load) and automatically switches over to a pulse-skipping PFM mode at light loads. This idle-mode characteristic results in high efficiency over a wide range of load current, yet still provides low-noise PWM operation when inductor and switch currents reach high levels.
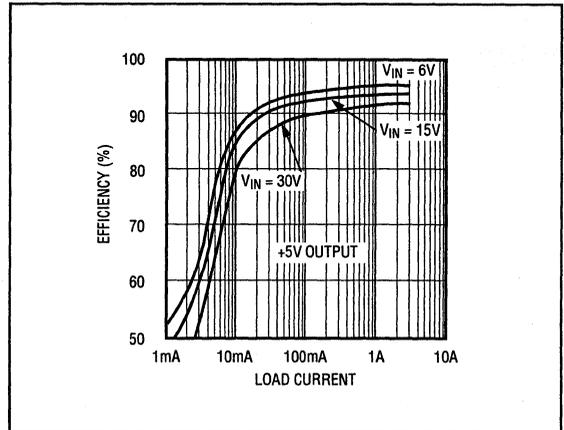

Figure 47. Effiency vs. Load Current
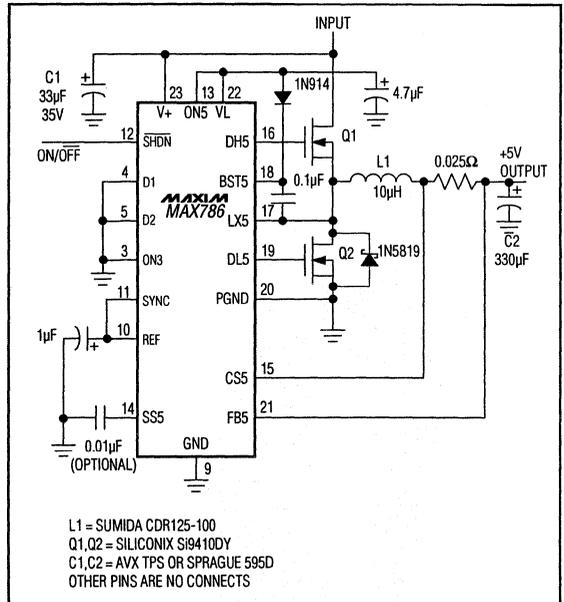
Figure 48. +5V PWM Buck Controller with NFET Switch

4 High-Voltage DC-DC

6-8 Cells to 3.3V/5V at Medium Power

Application Parameters

Input Voltage Range ....6V to 16.5V

Quiescent Supply Current (V_{IN} = 6V) 1.5mA

Max Load Current Capability (V_{IN} = 10V to 16V).........800mA
$\qquad\qquad\qquad\qquad$ (V_{IN} = 6V) 450mA

♦ **Internal PFET switch transistor**

♦ **170kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **6μA shutdown mode**

♦ **1.23V reference output**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX738A Buck Regulator**

Application Discussion

In many applications, size rules, and it makes sense to use a device with an internal power transistor if possible. The building block IC in this application employs an internal PFET switch that fills the IC cavity to provide the highest practical load capability in standard surface-mount packaging.

This workhorse PWM buck regulator provides high efficiency conversion for 6- to 8-cell battery packs, 9V or 12V DC wall adapters, and similar low-voltage bulk supply sources. The MAX738A's internal PFET switch transistor has a much lower saturation voltage than the NPN followers typically employed by bipolar IC switching regulators. This leads to improved efficiency, particularly at low input voltages. See also the MAX744A (low-dropout), MAX748A (fixed 3.3V output), and MAX758 (adjustable) versions.

The MAX1738 is a self-contained DIP version of the MAX738A with all components, including the magnetics, built in.
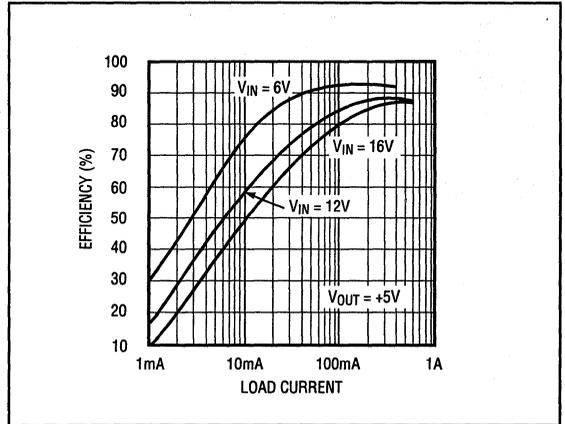
Figure 49. Efficiency vs. Load Current
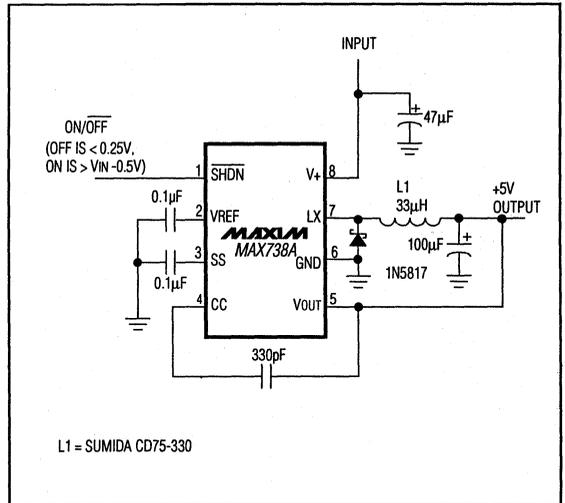
Figure 50. Medium-Power PWM Buck Regulator

MAXIM

6-8 Cells to +5V via
Negative Buck Topology

Application Parameters

Input Voltage Range......................................–6V to –15V

Quiescent Supply Current (V_{IN} = –5V).....................1.5mA

Max Load Current Capability (V_{IN} = –6V) 500mA

♦ Internal NFET switch transistor

♦ Current-mode PWM

♦ 170kHz fixed-frequency oscillator

♦ 1.23V reference output

Related Data Sheet

♦ MAX752 Boost Regulator

Application Discussion

This circuit would normally be used to step down a negative input voltage to a lesser, but still negative, output voltage. In this particular case, a little judicious rearrangement of the system ground reference allows the negative output to become a positive one. However, it only works in situations where the negative battery terminal does not need to be tied to ground. For this reason, the negative buck approach is most useful in systems that don't require multiple output voltages derived from the battery.

The advantage of this approach over a conventional positive buck regulator is that the power switching transistor is on the low side rather than the high side. This arrangement makes it easier to drive the desirable N-channel type of MOSFET. In this example, the MAX752 provides the same performance as its P-channel equivalent (MAX738) circuit with a smaller (and less costly) power transistor.
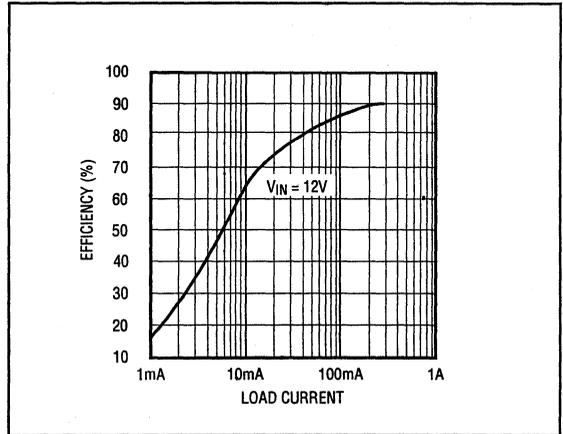
Figure 51. Efficiency vs. Load Current
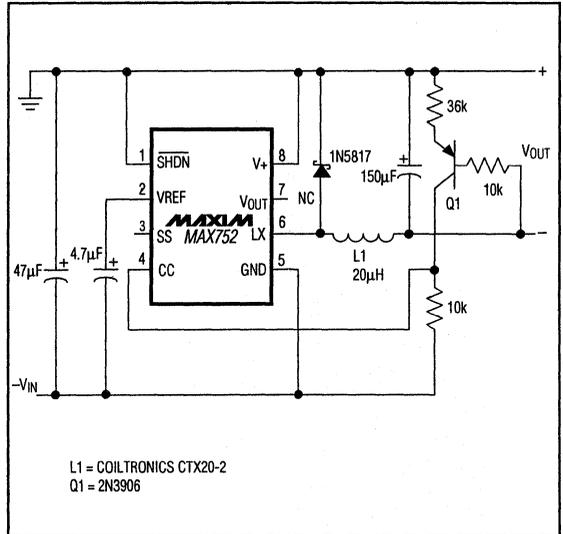
Figure 52. 5V Step-Down via Negative Buck Topology

5-8 Cells to 3.3V and 12V at High Power: Buck Controller with Battery Charger

Application Parameters

Input Voltage Range......................................5V to 18V

Quiescent Supply Current (V_{IN} = 5V)...........................1mA

Max Load Current Capability (V_{IN} = 5V)....1.5A (configurable)

♦ 3.3V current-mode PWM buck controller

♦ 15V (12V) flyback controller

♦ Battery charger current source (buck SMPS)

♦ Dual PCMCIA V$_{PP}$ outputs (0V/V$_{CC}$/12V)

♦ 300kHz fixed-frequency oscillator

♦ 10μA shutdown mode

♦ 2.5V 1.5% reference output

♦ 5V low-dropout linear regulator output

♦ Analog multiplexer

♦ Five level translators for high-side switching

♦ SPI-compatible serial interface

♦ Evaluation kit available

Related Data Sheet

♦ MAX781 Subnotebook SMPS

Application Discussion

One way to reduce a power supply's size and cost is to integrate as many blocks as possible into a system IC solution. Often, this approach results in a significant cost savings compared to the building-block approach; in this example, an integral flyback controller replaces a separate battery-to-12V converter with a few turns of wire, a few cents worth of silicon, and a 2.2μF capacitor. Similarly, PCMCIA 12V switching functions are handled by small, low-cost linear regulator transistors instead of low rDS(ON) switching transistors.

The circuit shown here is a system-engineered solution for small portable systems that have relatively light or nonexistent 5V load requirements. To this end, the MAX781 contains most of the analog-related circuit
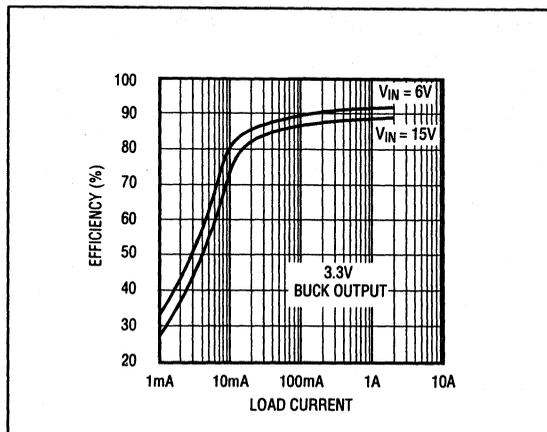
Figure 53. Efficiency vs. Load Current

blocks one might need in a power supply for a small 3.3V-only computer (an on-board 5V low-dropout linear regulator also supplies 25mA for external loads). The heart of this IC is a 3.3V buck controller with synchronous rectifier and integral 15V flyback winding controller. Other major functions include a switch-mode battery charger, dual 0V/3.3V/5V/12V PCMCIA V$_{PP}$ outputs, gate drivers for power switching via external N-channel MOSFETs, and an analog multiplexer that allows an external ADC to monitor various voltages within the MAX781, such as the battery voltage and the output voltages (for power-ready indication).

The battery charger is a switching-regulator current source that assumes the charger intelligence resides off-chip in a microcontroller. This SMPS block is a voltage-mode PWM buck regulator optimized for a current source rather than voltage-source output. The charger is controlled through an SPI 3-wire serial interface, which programs an on-board 7-bit digital-to-analog converter (DAC) to set the charge rate. The core 3.3V/12V supply is a high-performance buck regulator similar to those found in the MAX782 chip that follows.

Note: At the time of printing, this circuit was not yet characterized for 4-cell operation.

MAXIM

5-8 Cells to 3.3V and 12V at High Power: Buck Controller with Battery Charger
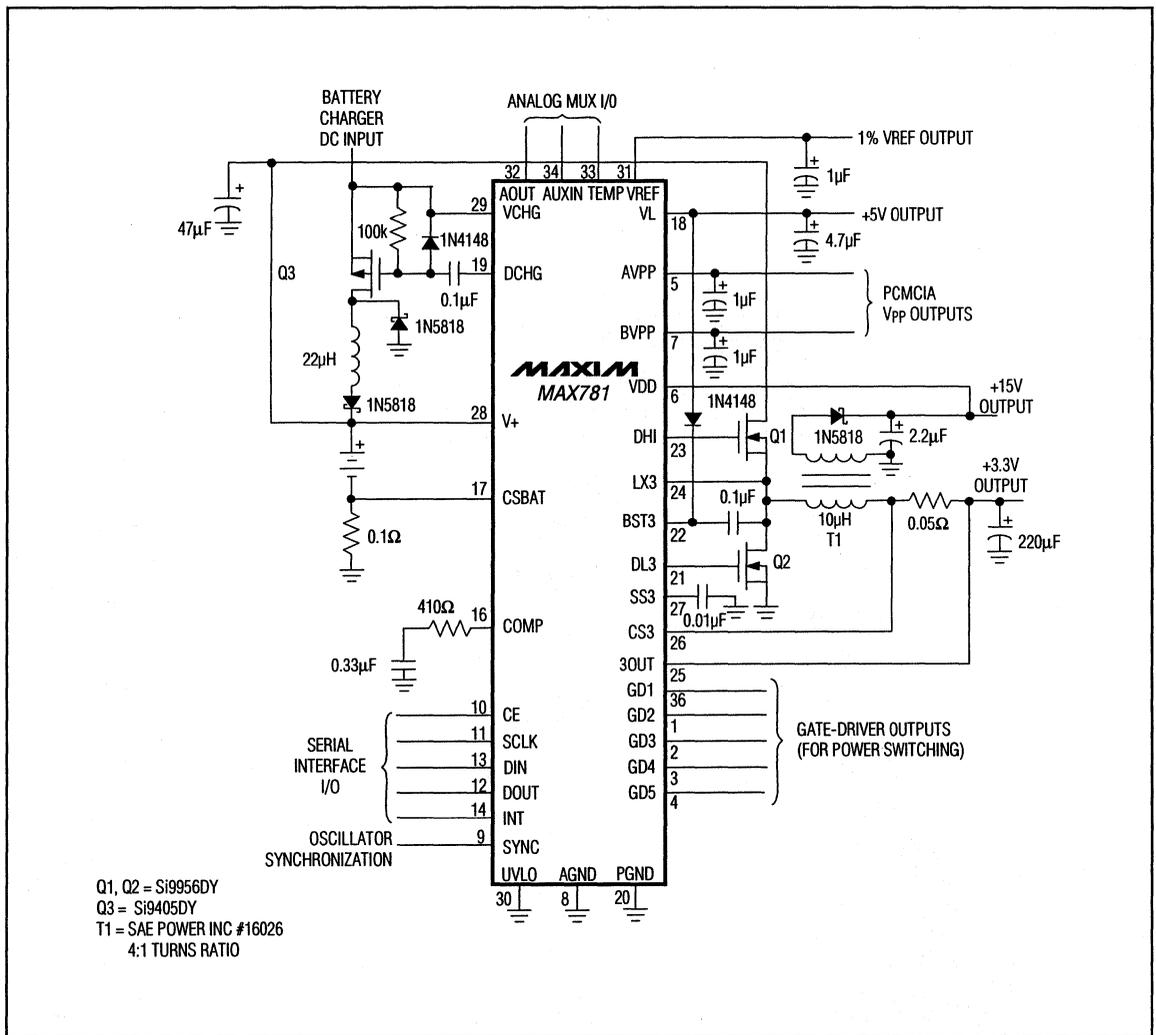
Figure 54. Subnotebook Computer Power Controller

6-12 Cells to 3.3V, 5V, and 12V at High Power

Application Parameters

Input Voltage Range ....5.5V to 30V

Quiescent Supply Current (V_{IN} = 15V) 420μA

Max Load Current Capability

                   (5V output, V_{IN} = 6V) 3A

                   (3.3V output, V_{IN} = 6V) 3A

♦ Integral 15V flyback winding controller

♦ Dual PCMCIA VPP linear regulators (0V, 5V, 12V at 60mA each)

♦ Three precision low-battery detect comparators

♦ Comparators double as high-side switch level translators

♦ 70μA shutdown mode

♦ 3.3V, 1.5% reference output

♦ 60kHz unity-gain crossover — excellent AC response

♦ Synchronization input

♦ 300kHz/200kHz fixed-frequency oscillator

♦ Evaluation kit available

Related Data Sheet

♦ MAX782 Notebook SMPS

Application Discussion

This dual PWM circuit is an integrated solution for the main power supply of a mixed 3V/5V notebook computer. Primary features are high efficiency over a wide range of loading, small external components, and a high level of integration.

There are seven rather than three output voltages, depending on how you count them. The entire list follows:

- 3.3V main (buck SMPS)
- 5V main (buck SMPS)
- 15V high-side (forward/flyback)
- 0V, 5V, 12V PCMCIA (VPPA linear regulator)
- 0V, 5V, 12V PCMCIA (VPPB linear regulator)
- 3.3V reference (linear regulator)
- 5V standby (LDO linear regulator)

The 15V high-side voltage is generated via a flyback winding on the 5V buck inductor. The 15V output is regulated via an extra feedback input to the main 5V buck PWM, which holds the synchronous rectifier on for a longer time period than usual if the 15V output is low. This action forces the flyback winding to operate in the forward mode. Unlike other synchronous rectifier/coupled inductor schemes, this method ensures excellent cross-regulation even with no load on the main +5V output and with no penalty in quiescent supply current.
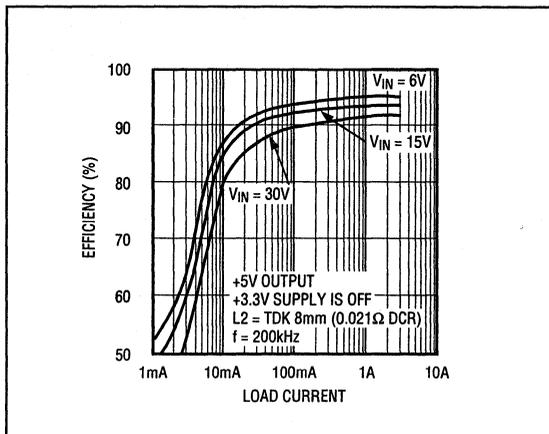
Figure 55. Efficiency vs. Load Current

Monster on-board gate drivers ensure fast switching and low transition losses even at the MAX782's relatively high 300kHz switching frequency. A novel current-mode SMPS architecture, which employs a direct error voltage and current-sense summing technique, results in small filter capacitor values and corrects for load and line transients within three or four switching cycles. Power to the IC is automatically bootstrapped from the main 5V SMPS output for reduced IC power consumption at high input voltages.

See also the MAX786 (dual output) and MAX783 data sheets for other notebook power-supply ICs.

4-Cell and 5-Cell Operation

This circuit can be easily adapted to lower battery voltages by simply disconnecting the battery negative lead from ground and connecting it to the +3.3V output. A new topology is formed, with the +3.3V output generated by an inverting topology and the +5V output generated by bucking the resulting differential between ground and the battery (3.3V + $V_{BATTERY}$). These are the major effects of connecting -$V_{BATTERY}$ to the +3.3V output:

- The battery voltage can fall below 5V without loss of regulation (minimum start-up = 4.2V).
- Battery ground is no longer the same as system ground.
- A portion of the +5V load power, equal to

$$\frac{3.3V}{3.3V + V_{BATTERY}} \times P_{OUT} (5V)$$

must pass through the 3.3V inverter, reducing the 3.3V external load capability.

- +3.3V must be turned on for +5V to work.

MAXIM
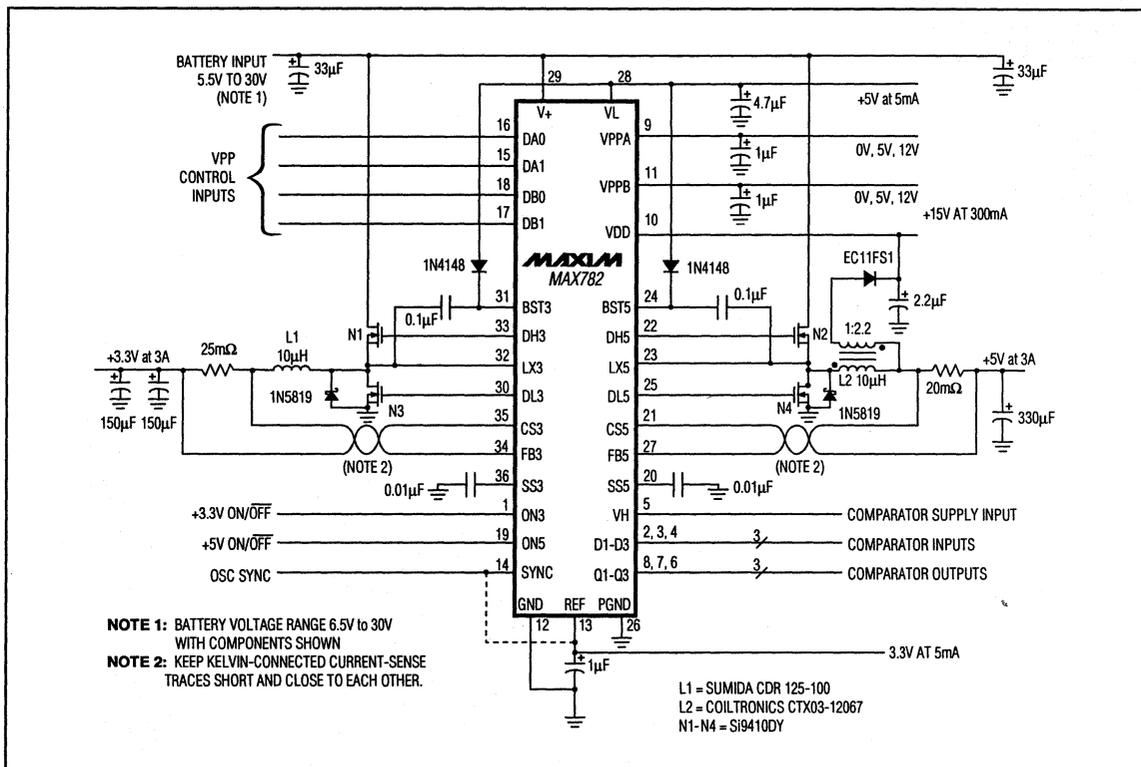
Figure 56. *Triple-Output PWM Buck Controller*

48V Subscriber-Line Telecom Power Supply

Application Parameters

Input Voltage Range ....35V to 72V

Quiescent Supply Current...............................20mA Min

Max Load Current Capability (V_{IN} = 48V) 50mA

♦ "Steals" power from telephone lines

♦ Replaces holding coil

♦ Pulse-skipping PFM

♦ Does not affect voice signal

Related Data Sheet

♦ MAX638 Buck Regulator
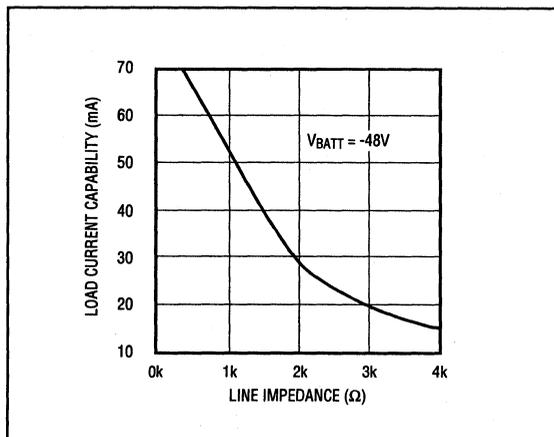
Application Discussion

Although not battery-powered in the usual sense (the batteries are large 48V lead-acid batteries at the central office), this light-fingered circuit is quite useful in portable systems that are connected to subscriber (household) telephone lines, such as modems or telephone test sets. If system power needs can be kept below 250mW, this circuit eliminates the need for a battery pack or external AC adapter altogether by "stealing" power from any ordinary telephone jack without disrupting the voice signal. In peripheral equipment such as a PCMCIA modem card, any power taken from the telephone line spares the battery in the host computer.

The maximum output current available from a subscriber line in the off-hook state is determined by the source impedance of the central office battery and series resistance of the wire, rather than by any regulation or code (such as Part 68 of the FCC Rules). The only restriction on line impedance is that off-hook current be at least 20mA (energizing a central office relay to indicate a desire for network access). It is even acceptable to short out the line, which is exactly what a hold button does.

Maximum power transfer occurs when the source impedance matches the impedance placed on the line. The source impedance of a subscriber line varies greatly, depending on the distance from the central office. The need to draw at least 20mA to indicate an off-hook condition makes perfect impedance matching impractical. Instead, the circuit clamps the line with a 12V zener, which works well for line impedances up to 1700Ω. Because the circuit sinks typically 35mA for all load conditions on the +5V output, a "wet" transformer (one that sinks loop current) is not needed and a "dry" transformer with a smaller, lighter core can be used instead.

Figure 57. Output Current Capability vs. Line Resistance
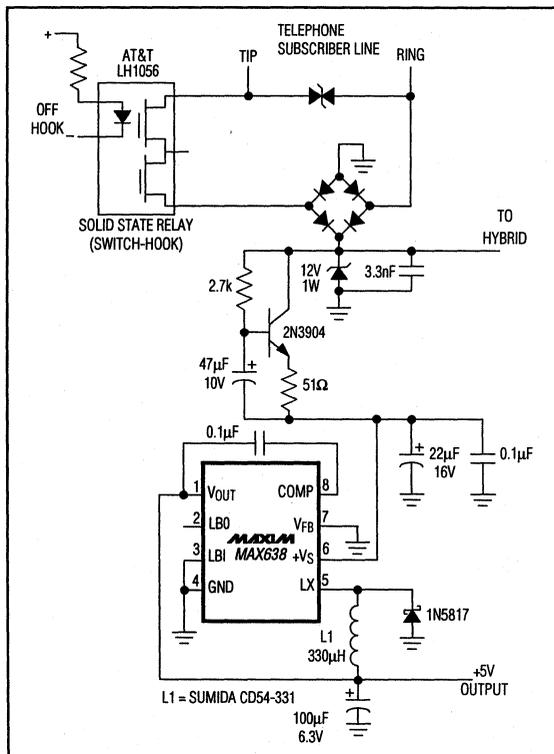
Figure 58. 48V to +5V Subscriber-Line Telecom Power Stealer

MAXIM

Section 5
3V-to-5V and 5V-to-3V Main Power Supplies

Designing 3V-to-5V and 5V-to-3V converters isn't much different from designing their battery-powered counterparts. Circuits that operate from a fixed input instead of a low-impedance battery benefit from a narrower input voltage range, which eases concerns about worst-case duty factor limitations, gate-drive levels, and peak currents. Fixed input circuits also allow for input capacitors with lower operating-voltage and surge current ratings. Soft-start capability, a feature included in the PWM circuits that follow, prevents high in-rush currents upon start-up, so the regulator doesn't glitch the input supply and cause memory failure or activate power-fail alarms when the regulator is powered from a system supply bus.

3V-to-5V and 5V-to-3V Converters

MAX741   3.3V to 5V at High Power

MAX731   3.3V to 5V at Low Power

MAX718   3.3V to 5V and 12V (Dual-Output PFM)

MAX786   5V to 3.3V at High Power

MAX763A   5V to 3V at Low Power

5 3V to 5V
5V to 3V

3.3V to 5V at High Power

Application Parameters

Input Voltage Range .... 2.7V to 5V

Quiescent Supply Current ($V_{IN} = 3.3V$) 3mA

Max Load Current Capability ($V_{IN} = 3V$) 1A

♦ **Small SSOP package**

♦ **150kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **Synchronization input**

♦ **260μA shutdown mode**

♦ **1.23V reference output**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX741 Universal Controller**

Application Discussion

As 3.3V and mixed 3.3V/5V systems become more popular, there is often a need to step up 3.3V to 5V. This situation occurs frequently in peripheral equipment that lacks access to the host system's battery. Desirable characteristics in this situation include fixed-frequency PWM operation (so that input current noise caused by reflected ripple currents doesn't induce noise on the 3.3V input supply), and soft-start.

Although optimized for a fixed 3.3V rather than battery input, this pulse-width modulation (PWM) boost regulator is a good starting point for many low-voltage designs that require low noise and high efficiency. The PWM controller IC employed here is extremely versatile, and has been referred to as the "Swiss army knife" of PWM controllers due to its pin-programmed, reconfigurable nature.

For an alternative pulse-skipping PFM 3.3V-to-5V converter, see the *5V to 12V at 500mA: MAX721 Boost Controller* circuit. When configured with a 5V output for this role, it delivers 750mA at 80% efficiency with no component changes and can get by with smaller capacitors than the MAX741 circuit.
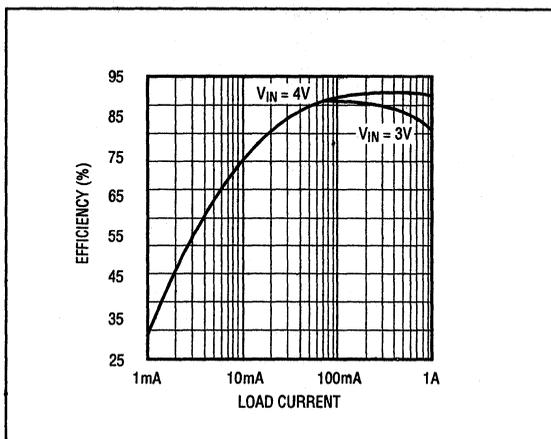

Figure 59. Efficiency vs. Load Current

L1 = COILTRONICS CTX20-4
Q1 = MOTOROLA MTD3055EL
D1 = 1N5817
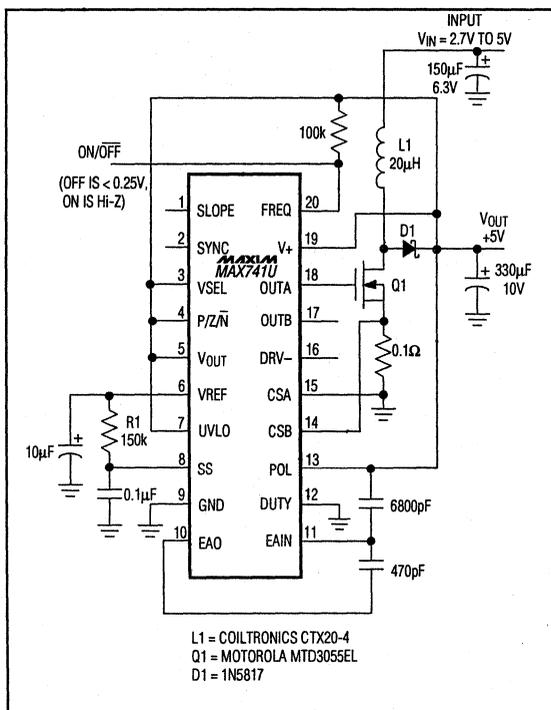
Figure 60. 3.3V to 5V Boost Controller with External MOSFET

MAXIM

3.3V to 5V at Low Power

Application Parameters

Input Voltage Range ....1.4V to 5V

Start-Up Supply Voltage (I_{LOAD} = 0) 1.8V

Quiescent Supply Current (V_{IN} = 3V) 2mA

Max Load Current Capability (V_{IN} = 3V) 350mA

♦ **170kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **35µA shutdown mode**

♦ **1.23V reference output**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX731 Boost Regulator**

Application Discussion

3V-to-5V converters can be useful in battery-powered host systems as well as in peripheral equipment. One example is a subnotebook computer that has omitted any rotating disc drives, thus reducing the maximum load on +5V to 2W or less. It may be simpler and less costly to add a 3V-to-5V converter to a 3.3V buck than to have two separate wide-input-range DC-DCs powered from the battery.

Like the previous circuit, this PWM boost regulator is ideal for low-noise, battery-powered applications such as cellular phones, and is also well cast in the 3.3V-to-5V role.

See also the MAX751, which is similar to the MAX731, but has a smaller 8-pin SO package instead of a 16-pin wide SO and a smaller switch transistor. Refer to the *2-3 Cells to 5V at Low Power via PWM Boost Regulator* for the circuit schematic.

Another alternative with fewer external components is the MAX756 PFM boost regulator (page 10).
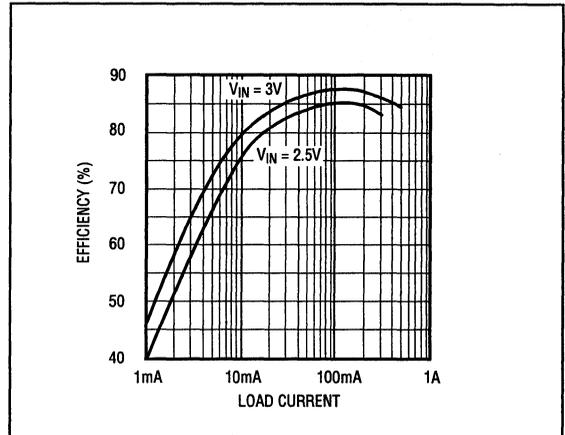
Figure 61. Efficiency vs. Load Current
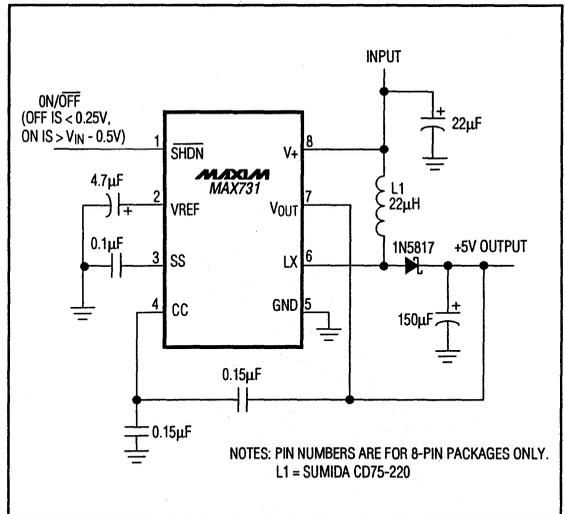
Figure 62. 3.3V to 5V PWM Boost Regulator with Internal MOSFET

3.3V to 5V and 12V:
Dual-Output Boost Controller

Application Parameters

Input Voltage Range .... 0.9V to V$_{OUT}$

Start-Up Supply Voltage (I$_{LOAD}$ = 0) 1.4V

Quiescent Supply Current (V$_{IN}$ = 3V)
Main SMPS = 5V 140µA
Both SMPS 500µA

Max Load Current Capability (V$_{IN}$ = 3V)
Main SMPS = 5V 400mA
Auxiliary SMPS = 12V 120mA

♦ **Dual regulated outputs**

♦ **Pulse-skipping PFM**

♦ **0.5MHz switching frequency**

♦ **Shutdown Mode**

♦ **1.5% reference output (alive in shutdown)**

♦ **Power-fail detection**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX718 Palmtop SMPS**

Application Discussion

Applications requiring a 3V-to-5V converter for supplying V$_{CC}$ to peripheral equipment (through a PCMCIA card socket, for example) often need a +12V supply for flash memory V$_{PP}$ as well. This circuit easily delivers 5V at 400mA and 12V at 120mA when powered from a fixed 3.3V ±10% supply, enough to support two PCMCIA sockets. The 12V output can be programmed to 5V under logic control, achieving the required V$_{PP}$ = V$_{CC}$ state without external switches or pull-ups.

Figure 63. Efficiency vs. Load Current

Figure 64. 3.3V to 5V and 12V Step-Up Converter

MAXIM

5V to 3.3V at High Power

Application Parameters

Input Voltage Range .... 4.5V to 6V

Quiescent Supply Current (V_{IN} = 5V) 780µA

Max Load Current Capability (V_{IN} = 4.5V) 3A

♦ **N-Channel MOSFETs**

♦ **Small inductor**

♦ **Two precision low-battery detection comparators**

♦ **125µA shutdown mode**

♦ **3.3V, 1.5% reference output**

♦ **60kHz unity-gain crossover—excellent AC response**

♦ **Synchronization input**

♦ **300kHz/200kHz oscillator**

Related Data Sheet

♦ **MAX786 Notebook SMPS**

Application Discussion

There are many situations that might require a 5V to 3.3V converter. Putting a 5V-to-3.3V converter on a daughter card to upgrade an existing desktop system with a new 3.3V microprocessor is one such situation. Key parameters in this case are size and cost; efficiency is also important from a standpoint of heat and temperature rise, but isn't critical for battery life (at least in the desktop application). So, cost can optionally be reduced by omitting the usual synchronous rectifier (the synchronous rectifier doesn't help much anyway, since the rectifier duty factor is low). In this circuit, the synchronous rectifier is required for the boost gate-drive generator, but can be a small low-cost 2N7002 instead of the usual power MOSFET.

Buck regulators and linear regulators are both useful for the 5V-to-3.3V task. The linear regulator (one can be adapted from the *5-Cell to 5V with PFET Linear Regulator circuit*) exhibits decent efficiency in this role (66%, discounting quiescent and drive losses). However, in situations where the 5V input is derived from a battery, 66% is probably not acceptable and a switching regulator solution is indicated, such as the one shown here.

This buck regulator operates as a fixed-frequency current-mode PWM when load currents are high (1/4 load to full load) and automatically switches over to a pulse-skipping PFM mode at light loads. This idle-mode
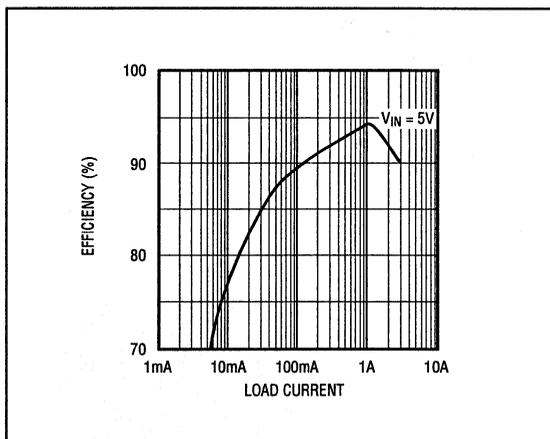
Figure 65. Efficiency vs. Load Current

L1 = SUMIDA CDR125-100
Q1,Q2 = SILICONIX Si9410DY
D1 = CENTRAL SEMICONDUCTOR CMPSH-3 OR 1N5817
C1,C2 = AVX TPS OR SPRAGUE 595D
OTHER PINS ARE NO CONNECTS
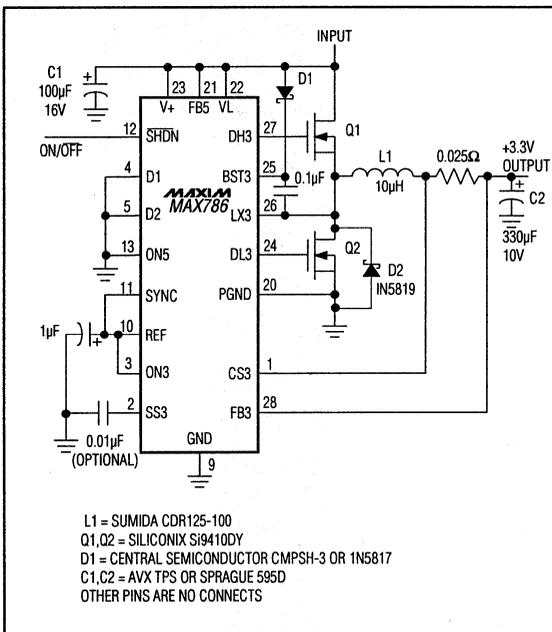
Figure 66. 5V to 3.3V at High Power

characteristic results in high efficiency over a wide range of load current, yet still provides low-noise PWM operation when inductor and switch currents reach high levels.

For a pulse-skipping PFM alternative, see the MAX651 data sheet (a future product).

5V to 3.3V at Low Power

Application Parameters

Input Voltage Range .... 3.5V to 11V

Quiescent Supply Current (V_{IN} = 5V) 1.4mA

Max Load Current Capability (V_{IN} = 4.5V)............... 500mA

Efficiency (V_{IN} = 5V, I_{LOAD} = 100mA)....................... 92%

♦ **Internal P-channel MOSFET**

♦ **Small 8-pin package**

♦ **170kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **6µA shutdown mode**

♦ **1.23V reference output**

Related Data Sheet

♦ **MAX763A Buck Regulator**

Application Discussion

5V to 3V conversion at low power levels is often required for peripherals and daughter cards. Desirable characteristics for such DC-DC converters include fixed-frequency operation (so reflected ripple doesn't induce low-frequency noise on audio or radio circuits in the host) and soft-start.

This efficient little circuit sources a lot of power from a tiny 8-SOIC package and miniature external components. Also, the MAX763A can operate at low input-output differential voltages (200mV) making it useful in 4-cell-powered and other low-dropout applications. The MAX763A has 400mA load current capability at an input voltage of 4V (end-of-life of 4 NiCds).

See also the MAX748A data sheet for a similar device that has a larger switch transistor and 16-pin SOIC package.
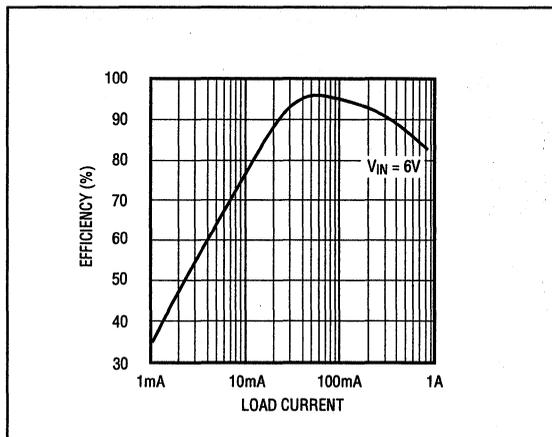
Figure 67. Efficiency vs. Load Current
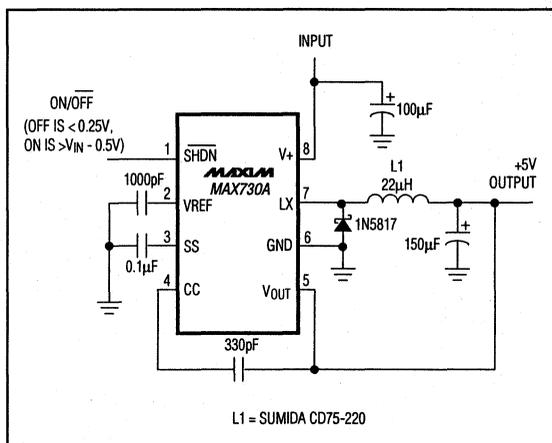
Figure 68. 5V to 3.3V Buck Regulator with Internal MOSFET

MAXIM

Section 6
Display Circuits—
LCD Contrast and CCFT Supplies

Liquid crystal displays (LCDs) generally need two types of power supplies: driver bias supplies and backlight supplies. The LCD segment drivers typically need a negative or positive voltage of approximately 10V to 24V. Display contrast is adjusted by varying the bias voltage. Bias voltage generators come in many varieties, depending on the display size, the level of multiplexing, and whether the display is color or monochrome. While many LCDs are set up for a negative bias voltage, positive voltages are also becoming common, particularly for color panels.

The most efficient form of backlighting today is the cold-cathode fluorescent tube (CCFT) lamp, which needs high-voltage AC power. A power supply to generate this AC voltage is typically not part of the main power supply, as it needs to be located physically close to the display in order to avoid power losses due to cable capacitance. There is both a system solution (MAX753/MAX754) and a stand-alone solution for generating CCFT power in this section. Both are high-efficiency supplies that can be connected directly to the main battery.

LCD Contrast with Digitally Adjusted
Negative Output

Application Parameters

Input Voltage Range .... 2V to 6V

Quiescent Supply Current (V_{IN} = 5V)....................... 310µA

Max Load Current Capability (V_{IN} = 4.5V) 25mA
(configurable)

♦ **On-board 5-bit DAC**

♦ **8-pin SO package**

♦ **Drives PNPs or PFETs**

♦ **Pulse-skipping PFM**

♦ **7µA shutdown mode**

♦ **Evaluation kit available**

Related Data Sheet

♦ MAX749 Negative-Output Controller

Application Discussion

LCD bias voltages can be generated with a flyback winding on the main system V_{CC} converter; however, that approach wastes power because of high losses in the linear regulators needed for post-regulating the rectified winding voltage. A separate, stand-alone DC-DC converter with an inherently adjustable output is usually preferred.

This unique, tiny circuit contains an on-board 5-bit DAC that adjusts the LCD contrast voltage from 1/3 full scale to full scale via a serial interface, eliminating unreliable potentiometers. An external switch transistor allows for trade-offs in power level, cost, breakdown voltage, and efficiency; choices range from a cheap 2N2907A to a fast, low V_{CE} (sat) ZTX750. Highest efficiency (up to 85%) is obtained by shorting out the 470Ω resistor and adding a PFET such as the Siliconix Si9400DY. While the circuit shown is tailored for a fixed 5V supply, it is easily adapted to direct battery connection in 2- and 3-cell systems (see MAX749 data sheet). Also, the 25mA capability of this circuit is given only as an example; being a controller, the load capability can be increased by sizing the external components appropriately.

The output voltage can be adjusted via the serial interface, or by an external potentiometer or PWM signal.
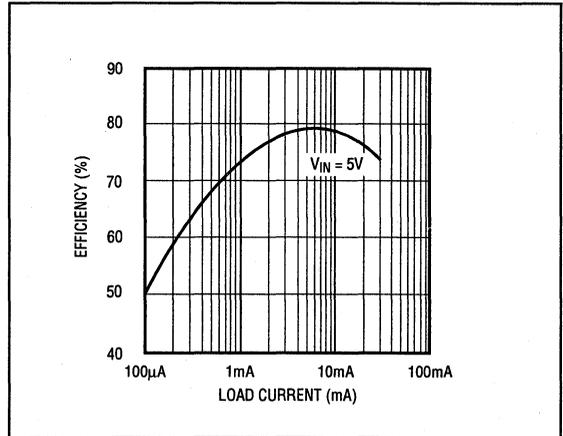

Figure 69. Efficiency vs. Load Current
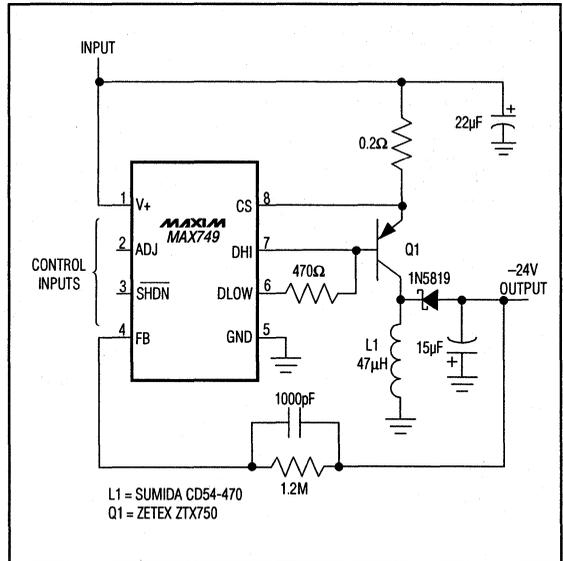
Figure 70. LCD Contrast Supply with DAC and External PNP Switch

MAXIM

LCD Contrast, 5V to Negative Output via Autotransformer

Application Parameters

Input Voltage Range ....4V to 6V

Maximum V_{IN} - V_{OUT} Differential 30V

Quiescent Supply Current (V_{IN} = 5V) 3.7mA

Max Load Current Capability (V_{IN} = 4.75V) 50mA

♦ Internal P-channel MOSFET

♦ 185kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 1µA shutdown mode

♦ 1.23V reference output

♦ Evaluation kit available

Related Data Sheet

♦ MAX759 Inverting Regulator

Application Discussion

Monolithic construction is the advantage of this circuit, as it features a large, low-saturation, internal P-channel MOSFET. The topology shown here trades off higher peak switch currents for a reduced stress voltage on the switch transistor via an autotransformer. The autotransformer shown is an off-the-shelf 0.2" diameter SMT toroid device that reduces the voltage seen at LX according to the turns ratio. Efficiency is over 80%, which is quite good for an inverter having a large input/output voltage ratio and operating from a 4.5V input.

The autotransformer must have less than 2% leakage inductance; otherwise, overvoltage transient spikes generated by the uncoupled magnetic field may damage the switch transistor. Mount the autotransformer close to the device to minimize PC trace inductance in the LX lead.
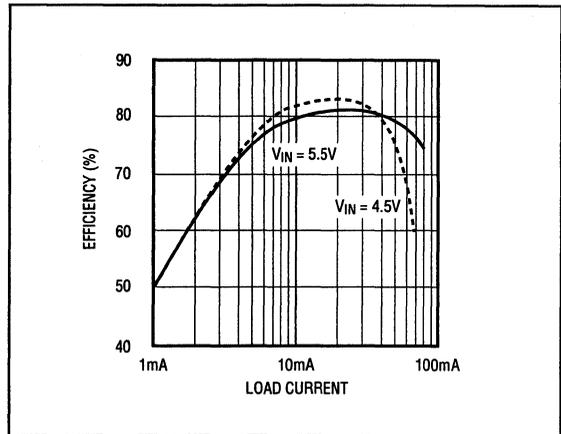
Figure 71. Efficiency vs. Load Current

L1 = COILTRONICS CTX100-1 OR MAGNETICS, INC. "KOOL-MU" 77030-A7
30 TURNS AND 30 TURNS 26 AWG
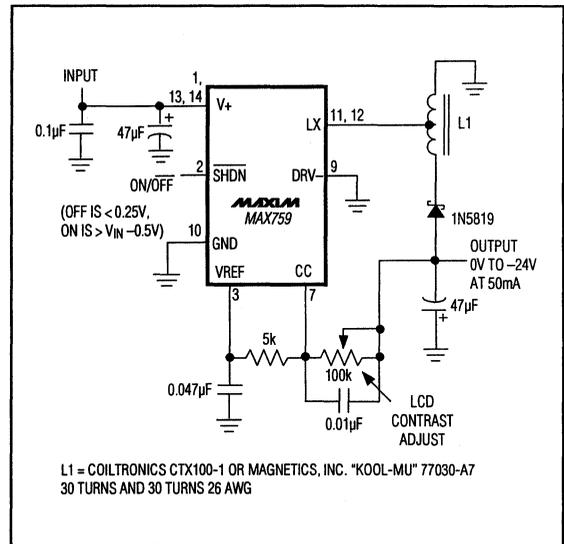
Figure 72. 50mA LCD Contrast Supply with Internal MOSFET

LCD Contrast, 5V to Negative Output at Micro Power

Application Parameters

Input Voltage Range .... 4V to 6V

Maximum V_{IN} - V_{OUT} Differential 24V

Quiescent Supply Current (V_{IN} = 5V) 500µA

Output Adjustment Range (as shown) .... –5V to –15V

Load Regulation (0mA < I_{LOAD} < 10mA) 75mV

Max Load Current Capability
              (V_{IN} = 4.5V, V_{OUT} = –15V) 10mA

♦ Internal P-channel MOSFET

♦ Pulse-skipping PFM

♦ Low-battery detect comparator

♦ 1.31V reference output

♦ 70µA shutdown mode

Figure 73. Efficiency vs. Load Current

Related Data Sheet

♦ MAX634 Inverting Regulator

Application Discussion

Systems such as cellular phones with small multiplexed LCD displays can often get by with a flea-power regulator to provide the LCD bias voltage. The pulse-skipping regulator IC used here (MAX634) is a sister to the original micropower DC-DC IC, the MAX630. Although mature, the MAX634 is often still a cost-effective solution in low-power applications.

Note that the maximum input-to-output voltage differential, normally 24V, can be extended by substituting an autotransformer for the inductor (see Figure 75 below).
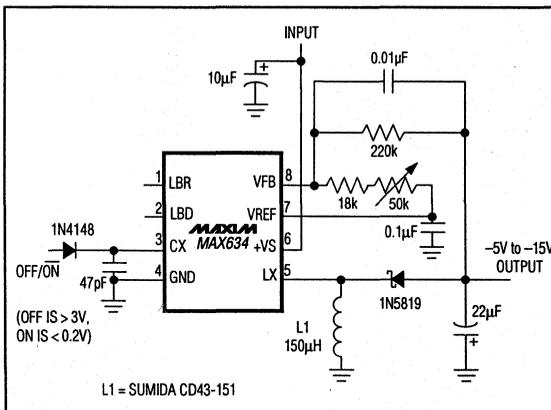
Figure 74. Flea-Power LCD Contrast Supply
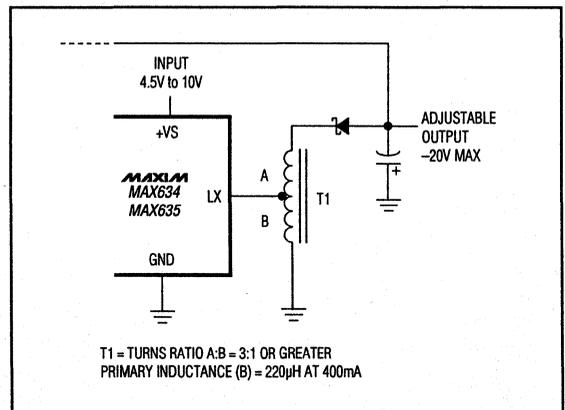
Figure 75. Flea-Power LCD Supply with Autotransformer

MAXIM

LCD Contrast, 4-8 Cells to Negative Output via Charge Pump

Application Parameters

Input Voltage Range .... 4V to 16V

Quiescent Supply Current (V_{IN} = 10V) 330μA

Max Load Current Capability (V_{IN} = 6V, V_{OUT} = −35V) ... 30mA

Load Regulation (V_{OUT} = −17V, I_{LOAD} = 0mA to 30mA) ..1.1%

♦ **Low-side external N-channel MOSFET switch**

♦ **Pulse-skipping PFM**

♦ **1.31V reference output**

♦ **70μA shutdown mode**

♦ **90% efficiency at V_{IN} = 5V**

Related Data Sheet

♦ **MAX634 Inverting Regulator**

Application Discussion

In many cases, the efficiency of the main system 5V supply is so high that powering the LCD supply from 5V instead of from the battery is acceptable. In these cases, the MAX749 circuit given previously is recommended because of size, simplicity and an on-board DAC. If the LCD supply must be powered directly from the battery, use the MAX634 circuit given here.

This circuit is a hybrid—part switching regulator, part charge pump. The switching regulator boosts the input to a high positive output voltage, while the actual negative output voltage is generated with a charge pump tap on
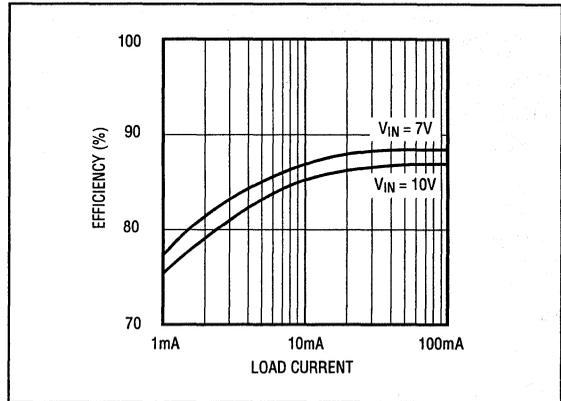
Figure 76. Efficiency vs. Load Current

the switching node. This scheme provides good load regulation and allows for a low-side, N-channel MOSFET switch.

If the optional D1 connection is made, whenever the battery voltage exceeds the absolute value of the output voltage, the output will not lose regulation and begin to track the input as would be the case with a normal boost regulator. Instead, charge-pump action and the regulation loop force the output to the correct value, although the noise is high and efficiency in this mode will drop to a level below that of a linear regulator. Also, capacitor ripple currents increase in this mode. If the battery voltage never exceeds the absolute value of the output voltage, D1 should be connected normally (to ground) for best efficiency.

See also the MAX771 data sheet (a future product).
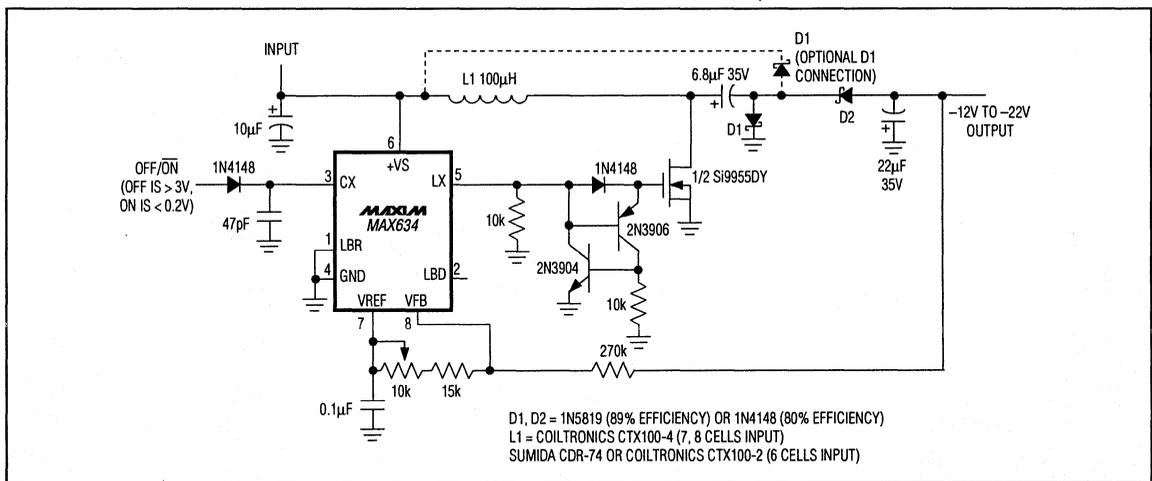
Figure 77. High-Efficiency Negative-Output Boost Regulator with Charge Pump

LCD Contrast, 5-8 Cells to Positive Output

Figure 78. Efficiency vs. Load Current

Application Discussion

Many color LCDs, plus a few of the monochrome type, need a positive instead of negative contrast adjustment voltage. The MAX641 circuit shown here is good in this role because it has high efficiency and a relatively wide input voltage range. The 90% efficiency of this circuit is 5% to 10% better than that of similar circuits made with bipolar transistors.

This circuit's input voltage range makes it suitable for a +5V regulated input or a direct battery connection. For input voltages above 7V, substitute a 100µH inductor for L1 in order to maintain low output noise and ripple (Coiltronics CTX100-4).

See also the MAX761 data sheet (a future product).
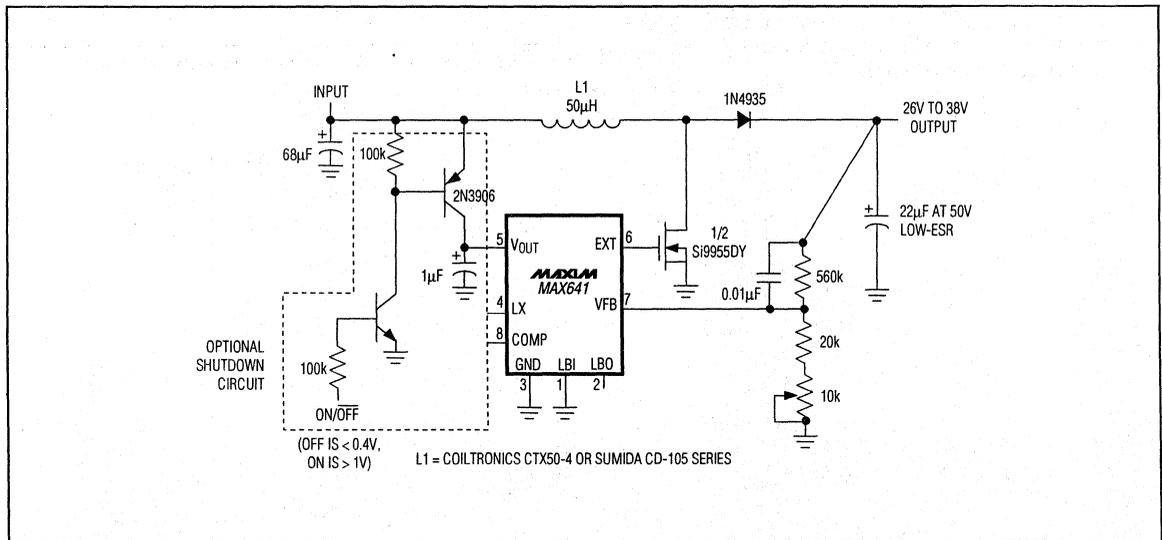
Figure 79. LCD Contrast Supply, 5-8 Cells to Positive Output

MAXIM

CCFT Backlight Inverter with
Current-Fed Royer Oscillator

Application Parameters

Input Voltage Range ....4.5V to 16V

Max Output Power Capability (V_{BATT} = 4.5V) 6W

♦ **Powered directly from battery**

♦ **Resonant (sine wave) operation**

♦ **Shutdown control input**

Related Data Sheet

♦ **MAX752 Boost Regulator**

Application Discussion

This MAX752 circuit is provided as a stand-alone alternative to the MAX753 solution given on the following page. Efficiency is about equal for the two circuits, although the MAX752 lacks the MAX753's on-board DACs and contrast voltage output.

The MAX752 boost regulator IC acts as a switching-regulator current source to feed the tail of a traditional Royer-type self-oscillating DC-DC converter. The MAX752 operates in a current-limited pulse-skipping mode, regulating the tube current by drawing rapid bursts of current. The Royer circuit drives a 33:1 transformer that steps up the battery voltage to AC high voltages (as high as 1200V to strike the lamp). The capacitor C2 and the primary inductance of the transformer form a resonant tank circuit, which provides a low-EMI sine wave drive signal to the tube. A half-wave-rectified signal proportional to tube current is returned to the MAX752's feedback input. Brightness is adjusted by potentiometer R2.
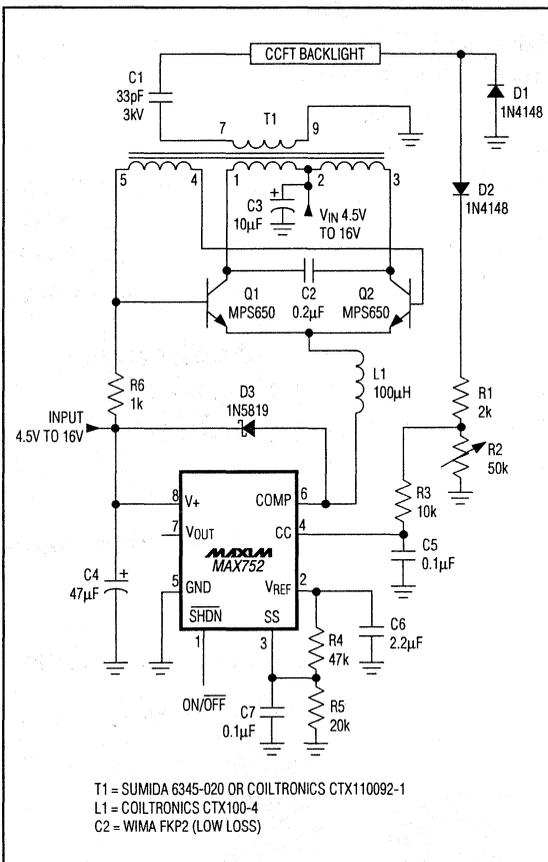
Figure 80. Stand-Alone CCFT Backlight High-Voltage Inverter

LCD Contrast and CCFT Power, 6-8 Cell System Solution

♦ Dual output: 400V AC CCFT and DC contrast voltage

♦ Digitally adjustable—dual on-board DACs

♦ Resonant-mode CCFT operation

♦ 80% efficiency

♦ 75µA shutdown mode (retains digital code)

♦ External low-side N-channel MOSFETs

♦ DC contrast voltages can be positive or negative

♦ Evaluation kit available

Application Discussion

The small cold-cathode fluorescent tube (CCFT) lamps often used to illuminate the LCD of a portable computer need a couple of watts of 400V AC power. This voltage must reach 1200V or so upon start-up in order to arc and turn on the lamp.

In a modern computer design, the backlight usually represents the single greatest continual drain on the battery, so extra circuitry added to improve the CCFT power supply efficiency is well spent. This circuit has been optimized with the specified components to achieve 80% efficiency.

The DC contrast voltage output is generated with either a positive boost topology (MAX754) or a hybrid of boost plus charge pump for negative voltages (MAX753). The contrast generators employ a pulse-skipping PFM scheme with the regulation point set by one of the two on-board 5-bit DACs. The CCFT voltage is generated by a zero-current-switched quasi-resonant flyback topology, requiring only one power switch transistor (unlike a current-fed Royer circuit, which requires three). Tube current is sensed and then applied to an error amplifier that generates an error signal proportional to the DAC setting and actual lamp current. This error signal is fed to a V/F converter, which adjusts current (and brightness) by changing the switching frequency.

Note: CCFT lamp characteristics vary greatly, so it is essential to consult Maxim's Applications Department for specific component recommendations for each new design.

MAXIM

LCD Contrast and CCFT Power, 6-8 Cell System Solution
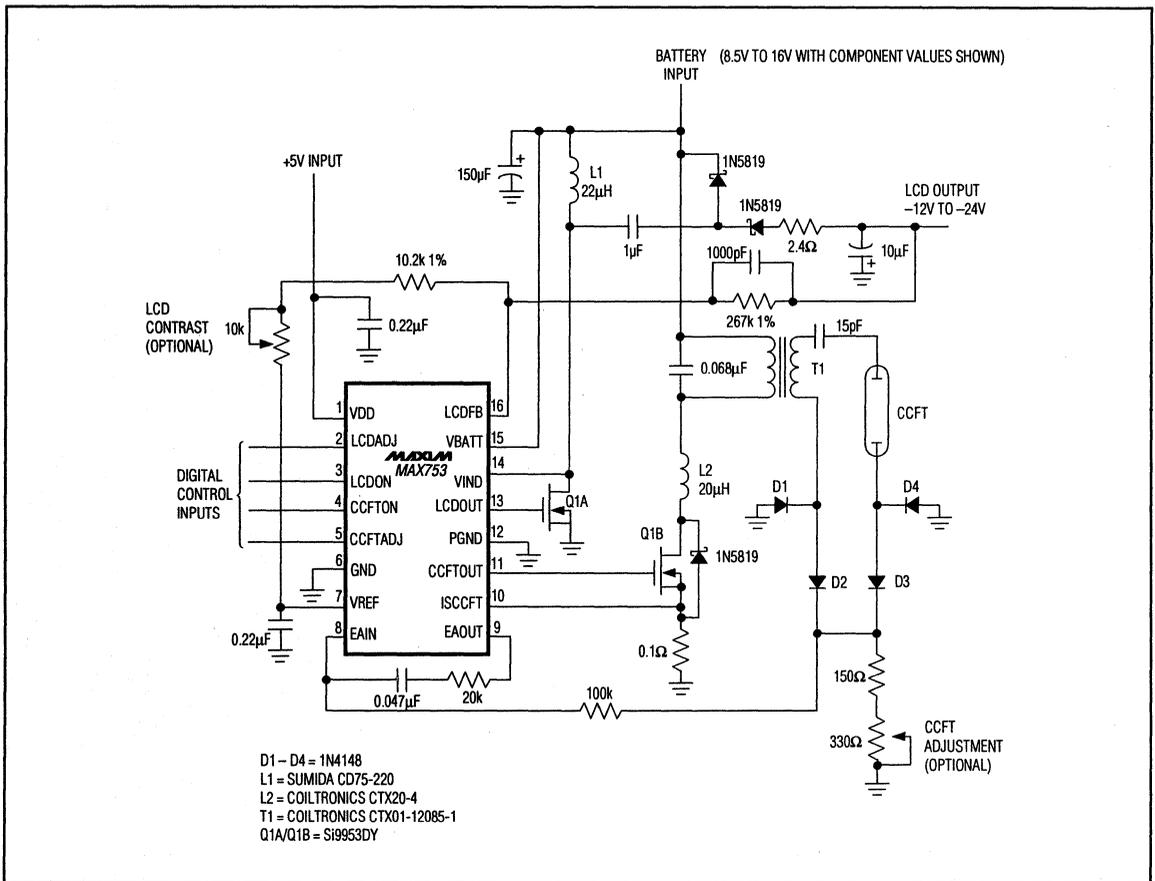
Figure 81. Dual-Output LCD and CCFT Power Supply with Digital Adjustment

Section 7
-5V Generators

Making a negative 5V supply for a battery-powered system is often just a matter of adding a diode-capacitor charge pump to the switching node of a boost converter or adding a transformer winding to the inductor of a buck converter. If tight regulation or efficiency requirements mandate a stand-alone –5V generator, consider the switching regulator and charge-pump solutions given here.

Type	Source Voltage	Description
MAX741	4-8 cell battery or +5V bus	PWM with external PFET
MAX735	+5V bus	PWM with internal PFET
MAX639	2-4 cell battery or +5V bus	PFM with internal PFET
MAX660	+5V bus	Charge pump
MAX1044	+5V bus	Charge pump
MAX739	5-8 cell battery	PWM with internal PFET

7 -5V DC-DC

–5V from +5V or 4-8 Cells at High Power

Application Parameters

Input Voltage Range......................................4V to 15V

Quiescent Supply Current (V$_{IN}$ = 5V)..........................3mA

Max Load Current Capability

  (V$_{IN}$ = 4.75V 1A

  (V$_{IN}$ = 12V)...1.25A

♦ **150kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **Synchronization input**

♦ **30µA shutdown mode**

♦ **1.23V reference output**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX741 Universal Controller**

Application Discussion

-5V at high power is occasionally needed in portable equipment for analog or ECL circuitry. A standard inverting topology is usually indicated, as shown in Figure 83. The relatively wide input voltage range of this circuit makes it useful for 4-8 cell NiCd battery packs as well as with fixed 5V input. The MAX741 "Swiss army knife" PWM controller is pressed into service here as an inverter, driving an external P-channel MOSFET high-side switch. The shrink small-outline package (SSOP) can help keep the surface-mount version of this circuit small.
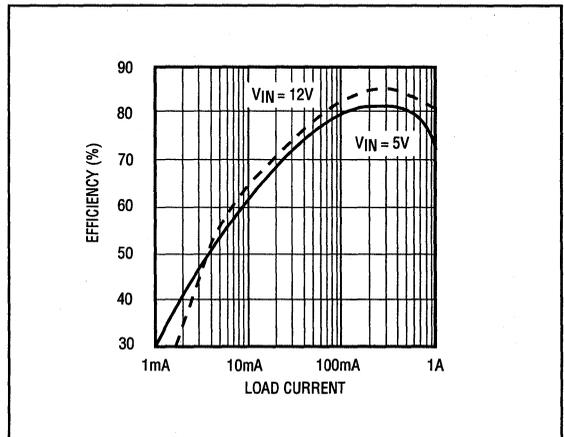
Figure 82. Efficiency vs. Load Current
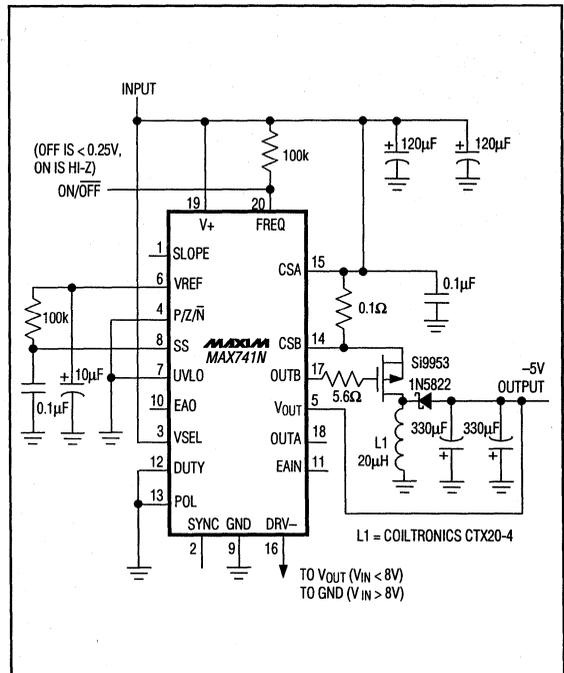
Figure 83. -5V from 5V at 1A: Inverting PWM Controller

MAXIM

–5V from +5V or 5-8 Cells at Medium Power

Application Parameters

Input Voltage Range ....3.8V to 11V

Input Voltage Range (non-bootstrapped mode) ..3.8V to 16.5V

Start-up Supply Voltage ($i_{LOAD} = 0$) ....4V Max

Quiescent Supply Current ($V_{IN} = 5V$) 1.8mA

Max Load Current Capability ($V_{IN} = 5V$) 200mA

♦ **165kHz fixed-frequency oscillator**

♦ **Current-mode PWM**

♦ **1.23V reference output**

♦ **1μA shutdown mode**

Related Data Sheet

♦ **MAX739 Inverting Regulator**

Application Discussion

When cross-regulation or efficiency needs dictate a stand-alone regulator instead of a flyback or coupled-inductor solution for a negative-output DC-DC, a simple inverting (sometimes called buck-boost) topology provides a low-cost solution that uses off-the-shelf magnetics. This -5V generator is optimized for battery voltages above 5V, but not exceeding 16.5V. The MAX739 is a current-mode PWM regulator similar to that found in the *-5V from 5V at Medium Power* circuit that follows, but it exchanges a larger package size and higher cost for a wider supply voltage range.
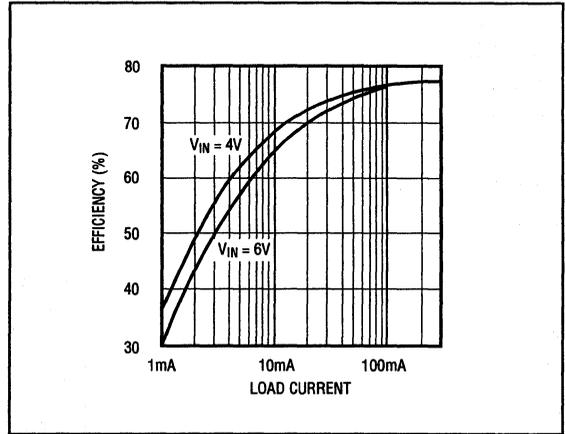
Figure 84. *Efficiency vs. Load Current*
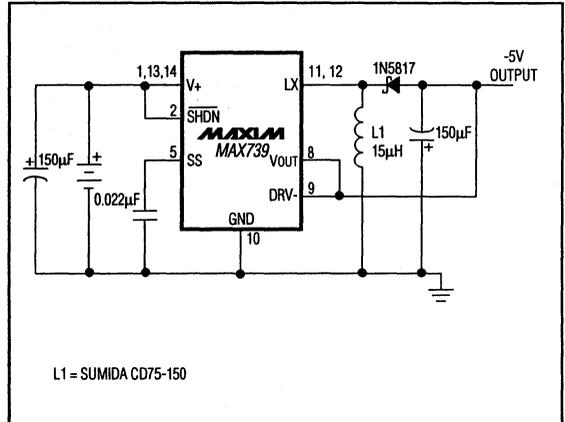
Figure 85. *Inverting PWM Regulator*

–5V from +5V at Medium Power

Application Parameters

Input Voltage Range.......................................4V to 6.2V

Quiescent Supply Current (V_{IN} = 5V) 1.6mA

Max Load Current Capability (V_{IN} = 5V) 200mA

♦ Small 8-pin SO package

♦ 160kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 10µA shutdown mode

♦ 1.23V reference output

♦ Evaluation kit available

Related Data Sheet

♦ MAX735 Inverting Regulator

Application Discussion

-5V at moderate power is often needed for audio circuitry or special interfaces. The PWM solution shown here provides a low-noise solution having tiny external components. This circuit is internally bootstrapped, such that the internal P-channel switch receives as gate drive the full difference between input and output voltages (10V). The resulting low $r_{DS(ON)}$ provides output current capability that is unusually good for an 8-SOIC inverter with internal power transistor.
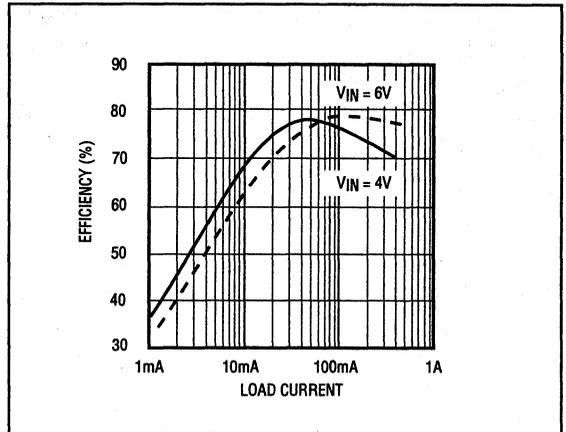
Figure 86. Efficiency vs. Load Current
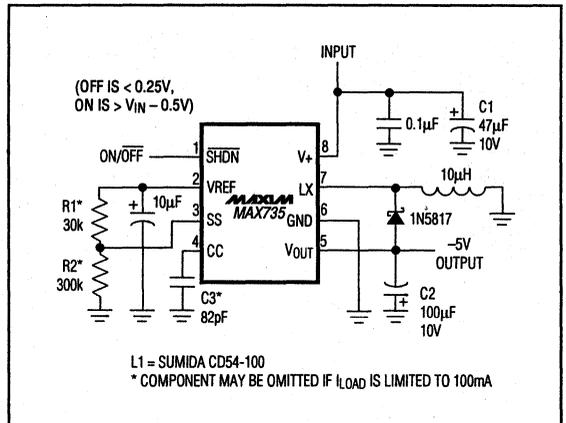
Figure 87. –5V from +5V at 200mA: PWM Inverter

−5V from 5V at Low Power via Inverting Regulator

Application Discussion

"Every step-down IC is an inverter and every inverter IC is a step-down." That statement is nearly always true: Most any buck regulator chip can be fooled to produce negative output voltages, and likewise, inverters can work as buck regulators. This trick, which belongs in every designer's toolbox, is done by rearranging the IC's ground pin reference and substituting the correct switch-mode topology. In this case, a micropower PFM buck regulator IC (MAX639) is employed as an inverter. The IC attempts to regulate the feedback pin (V$_{OUT}$) at a point 5V more positive than the GND pin; since V$_{OUT}$ is at circuit ground, GND is forced to −5V. The trade-off for using the IC in this unintended manner is a shift in the allowable supply range; in this case, the maximum supply voltage capability is reduced because the circuit configuration is inherently bootstrapped.

This particular variation on the buck-becomes-inverter theme has earned a place in this collection by exhibiting good efficiency at light loads (due to its pulse-skipping control loop). Efficiency can be improved by 5% or so over that shown in the graph above by increasing the inductor value to 470µH. The output feedback resistor divider and 1000pF capacitor are optional; if 100mV or so increased noise is acceptable, remove the feedback components, connect VFB to the −5V output, and ground the V$_{OUT}$ pin. Always be sure that a 0.1µF ceramic bypass capacitor is soldered directly to V+, in addition to the usual bulk bypass capacitor.

Figure 88. Efficiency vs. Load Current (three input voltages)
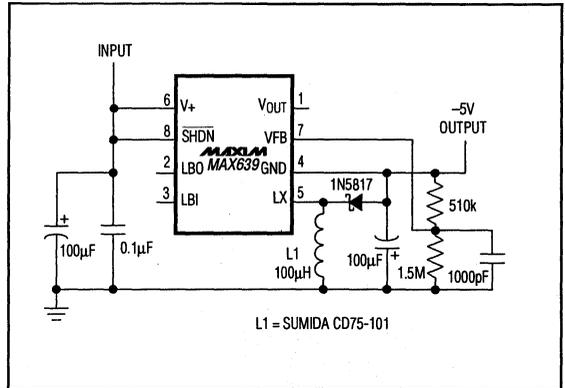
Figure 89. −5V from 5V at 80mA: PFM Inverter

–5V from 5V at Low Power via Charge Pump

Application Parameters

Input Voltage Range ....1.5V to 5.5V

Quiescent Supply Current (V_IN = 5V) 100µA

Output Impedance...6.5Ω

Max Load Current Capability (V_IN = 4.75V) 100mA

♦ **No inductors**

♦ **Small 8-pin SO package**

♦ **0.65V voltage drop at 100mA**

♦ **10kHz/45kHz fixed-frequency oscillator**

♦ **Unregulated output**

♦ **Also works as a doubler (+5V_IN, +10V_OUT)**

♦ **10µA shutdown mode**

Related Data Sheet

♦ **MAX660 Charge Pump**

Application Discussion

The unregulated charge pump approach shown here is less expensive than the equivalent switching regulator, and has very high efficiency at light loads for a low-noise, fixed-frequency converter. Since an unregulated charge pump has no pulse-skipping control loop, there is no low-frequency subharmonic content in the output ripple waveform, making it useful in cellular phones and other low-noise applications. If desired, OSC can be driven directly by a system clock to set a precise switching frequency. An "unregulated" charge pump actually regulates fairly well if operated from a fixed input voltage. In this situation, the MAX660 looks like a 6.5Ω resistor.

An unregulated charge-pump IC such as the MAX660 directly inverts the input voltage, such that the negative output voltage tracks the input (0dB PSRR). Load regulation is determined by the $r_{DS(ON)}$ of the internal MOSFET switches. A charge-pump circuit is a good alternative to the previous inductor-based inverters in applications that can tolerate 0dB PSRR and imperfect load regulation. In the common 5V to –5V application, 0dB PSRR is often not a problem because the input is a regulated 5V supply bus.

The MAX665 is a very similar device with a slightly higher maximum input voltage range. The MAX665 can tolerate an 8V input but has a larger SOIC package.
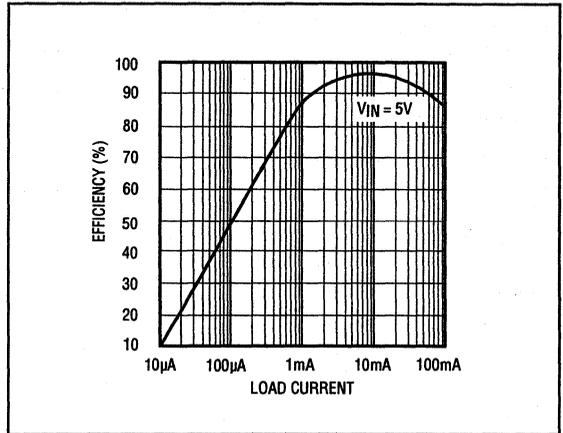
Figure 90. Efficiency vs. Load Current
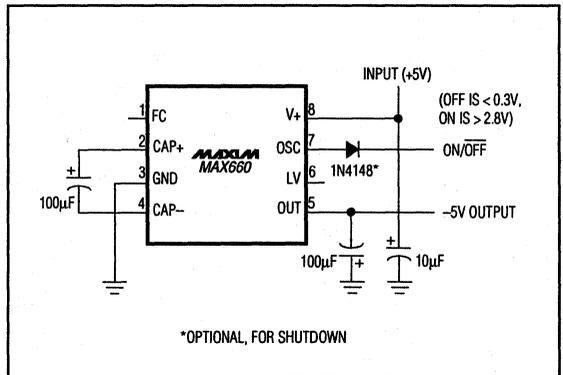
Figure 91. –5V from 5V: Charge Pump Solution

MAXIM

−5V from 5V at Micro Power via Charge Pump

Application Parameters

Input Voltage Range ....1.5V to 10V

Quiescent Supply Current (V_{IN} = 5V) 50µA

Output Impedance...65Ω

Max Load Current Capability (V_{IN} = 4.75V) 10mA

♦ **No inductors**

♦ **8kHz/65kHz fixed-frequency oscillator**

♦ **Unregulated output**

♦ **Can operate as a doubler (V_{OUT} = 2 x V_{IN})**

♦ **1.5µA shutdown mode**

Related Data Sheet

♦ MAX1044 Charge Pump

Application Discussion

This circuit is a scaled-down version of the *−5V from 5V at Low Power: MAX660 Charge Pump* circuit, and the comments given there apply equally here. The MAX1044 is basically identical to the MAX660, except for a somewhat higher input voltage range, ten times reduced output current capability, and lower cost. The final variant of this family of unregulated charge-pump ICs (which all have a standard pinout) is the ICL7662, which again trades off output resistance/current capability for increased supply voltage range. The ICL7662 can tolerate a 20V input, but has a 140Ω typical output resistance (V_{IN} = 5V).
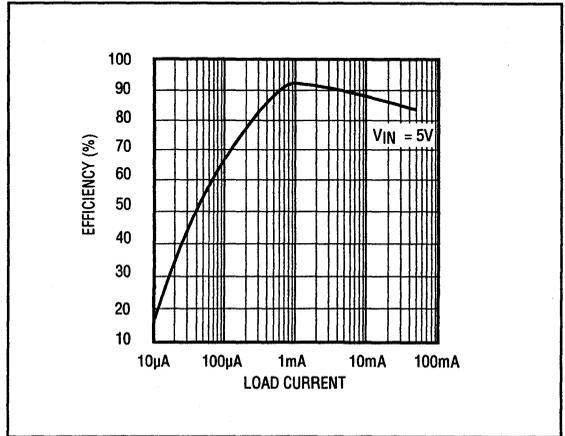
Figure 92. Efficiency vs. Load Current
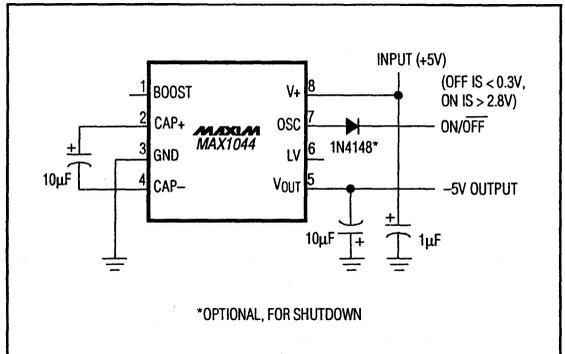
Figure 93. Micropower Charge-Pump Inverter

Section 8
Flash Memory, PCMCIA,
and Other +12V Power Supplies

VPP is a label for the 12V DC input terminal on flash memory ICs. Proper operation of the flash IC restricts this voltage to a narrow window, sandwiched between the conditions of overvoltage (with possible damage to the memory), and undervoltage (which can cause faulty programming due to insufficient charge transfer). Consequently, the 5% data sheet tolerance limit is an essential specification. The circuits that follow are designed to generate accurate, clean VPP waveforms that have fast rise times without overshoot and ringing.

Flash-memory power supplies are commonly specified in multiples of 30mA — the worst-case IPP current drawn by a typical byte-wide flash EEPROM chip during its erase cycle. This current is nearly independent of the memory size, even for experimental VLSI devices. Therefore, most of the following solutions are optimized for 30mA, 60mA, or 120mA output capability.

8 Flash Memory

5V to 12V at 30mA via Charge Pump

Input Voltage Range ....**4.5V to 5.5V**

Quiescent Supply Current (V$_{IN}$ = 5V) **300μA**

Max Load Current Capability (V$_{IN}$ = 4.75V) **30mA**

Start-Up Rise Time..**400μsec**

♦ **No inductors**

♦ **Pulse-skipping PFM**

♦ **1μA shutdown mode**

♦ **Evaluation kit available**

_____Related Data Sheet

♦ **MAX662 12V Charge Pump**

_____Application Discussion

12V at 30mA is a common requirement in portable equipment, for both mass-storage and software-update applications. +12V for mass storage or memory cards usually needs 60mA or more, but many palmtop applications can get by with 30mA by programming 8 bits instead of 16 bits at a time. Software and bios update applications, typically implemented with boot-block flash chips, only require 30mA since 8-bit-wide programming is nearly universal.

The MAX662 regulated charge-pump IC first doubles the input voltage and then adds 5V onto that, using the traditional flying-capacitor voltage-doubling technique. A pulse-skipping pulse-frequency modulation (PFM) control loop forces the output down to 12V ±5% over all line and load conditions by gating off the charge pump when the output is in regulation.

The MAX662 circuit is extremely small, taking up only 0.25in^2 of PC board territory. The internal oscillator frequency is 0.4MHz, keeping capacitors small. Guaranteed 30mA output current capability makes it a good fit for the embedded control and software update types of flash memory applications.
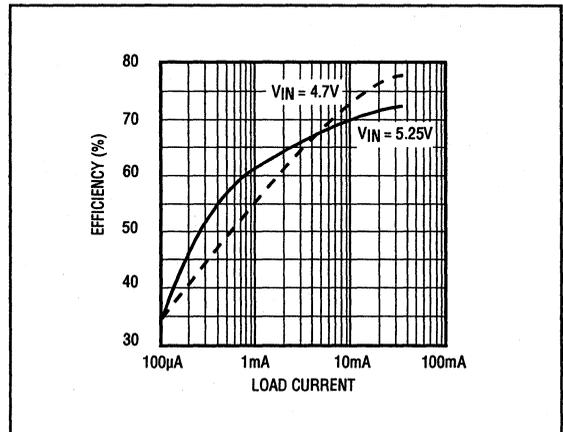


Figure 94. Efficiency vs. Load Current
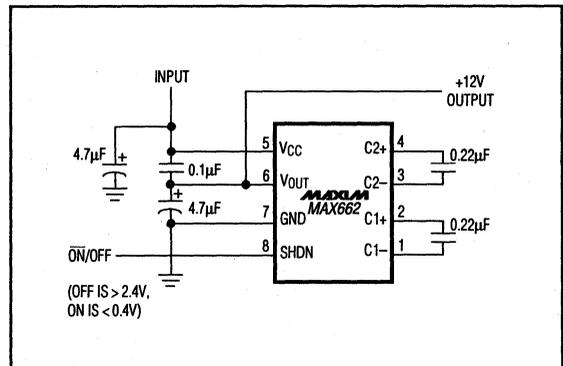
Figure 95. 5V to 12V Regulated Charge Pump

MAXIM

5V to 12V at 120mA

Input Voltage Range ....4V to 12V

Quiescent Supply Current (V_{IN} = 5V) 1.3mA

Max Load Current Capability (V_{IN} = 5V, MAX732) 150mA

Efficiency (I_{LOAD} = 60mA)

  MAX732 ....90%

  MAX734 ....85%

Start-Up Rise Time 1.5msec

♦ 170kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 70µA shutdown mode

♦ 8-pin SO package (MAX734)

♦ 1.23V reference output

♦ Soft-start circuit

♦ Evaluation kits available

Related Data Sheet

♦ MAX734 12V Boost Regulator

Application Discussion

12V at 120mA is a common design requirement for portable computers, as this is the power required to support VPP (peripheral and programming voltage) for two PCMCIA card sockets. This circuit provides a tiny solution, with a core size requirement only half that of competitive devices (18µH vs. 33µH) due to a relatively high switching frequency. Clean, PWM fixed-frequency switching ensures low-noise input ripple current characteristics so as not to pollute the system +5V bus with random noise.

The MAX734 DC-DC regulator IC used in this circuit contains a current-mode PWM controller and 2A power MOSFET. The regulator is digitally controlled through its shutdown ($\overline{SHDN}$) pin. When low, $\overline{SHDN}$ disables the device and reduces the supply current to 70µA. In this inactive state, the series-DC connection of inductor and rectifier places VPP at the level of V_{IN} minus the forward drop of the rectifier diode.

Because this low level of VPP (approximately 4.7V) cannot program a flash memory device, there is no need for an extra switch transistor that disconnects the output completely. When $\overline{SHDN}$ goes high, the PWM begins switching and drives VPP to 12V with in 1.5msec. Efficiency is greater than 85% over most of the load range.
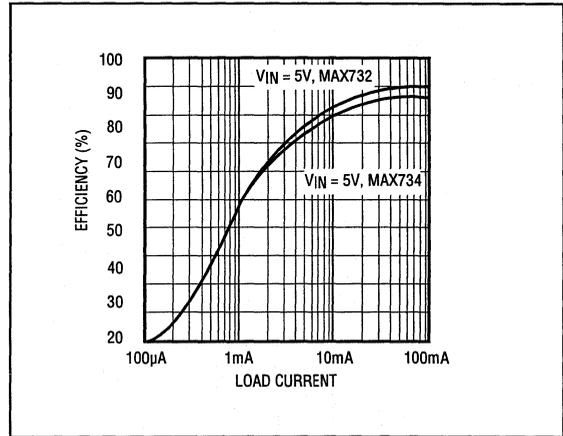
Figure 96. Efficiency vs. Load Current
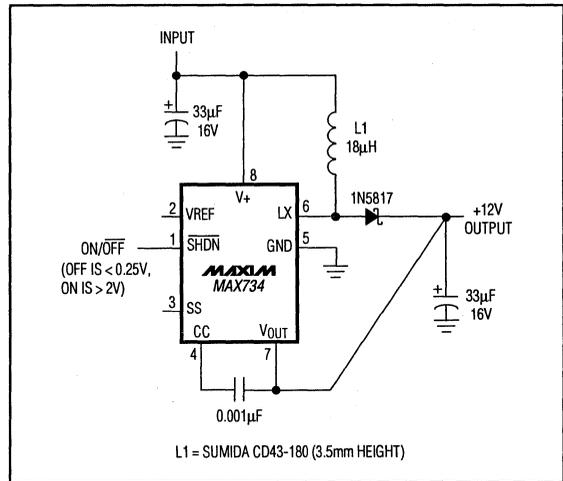
Figure 97. 5V to 12V PWM Boost Regulator

Soft-start is a nice feature in situations where the 12V DC-DC is put inside a PCMCIA memory card and in other applications where the characteristics of the 5V source may be unknown. With soft-start, the designer can control the amplitude of the start-up current surge that the circuit places on the 5V source (and avoid tripping the system V_{CC} power monitor/reset circuit) simply by adding a low-value timing capacitor from SS to GND.

The MAX732 is a high-current version of the MAX734 with slightly better efficiency. The MAX1732 is a self-contained DIP hybrid version of this device with all components, including magnetics, built in.

5V to 12V at 500mA

Input Voltage Range......................................2.8V to 6V

Quiescent Supply Current (V_{IN} = 5V) 300μA

Max Load Current Capability (V_{IN} = 4.75V)...............500mA

♦ **Small external components**

♦ **Pulse-skipping PFM**

♦ **1.5% reference output**

♦ **30μA shutdown mode**

_____Related Data Sheet

♦ **MAX721 Palmtop SMPS**

_____Application Discussion

Normally, the MAX721 controller IC in this 12V boost circuit is meant to operate from 2 AA cells. However, it leads a secret life as a general-purpose boost controller, here pressed into service with a 5V input. If a larger MOSFET is used to increase the output power capability, buffer D12 with a MOSFET driver (the driver within the MAX721 is not intended to drive MOSFETS with more than 15nC total gate charge).

The MAX721 is amazingly tolerant of bad construction technique and poor-quality components, since it is a pulse-skipper and therefore doesn't require a large pole at the output for loop stability. Ultimately, this means that the circuit can be made physically smaller than PWM counterparts, with no risk of bad transient response or output overshoot. Low-frequency noise in the output ripple waveform is the trade-off. If a fixed-frequency PWM solution is needed, use the MAX741.
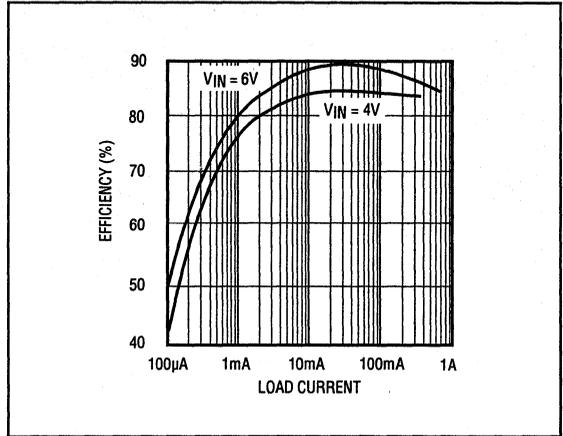
Figure 98. Efficiency vs. Load Current

L1 = SUMIDA CD75-220
Q1 = 1/2 SILICONIX Si9942
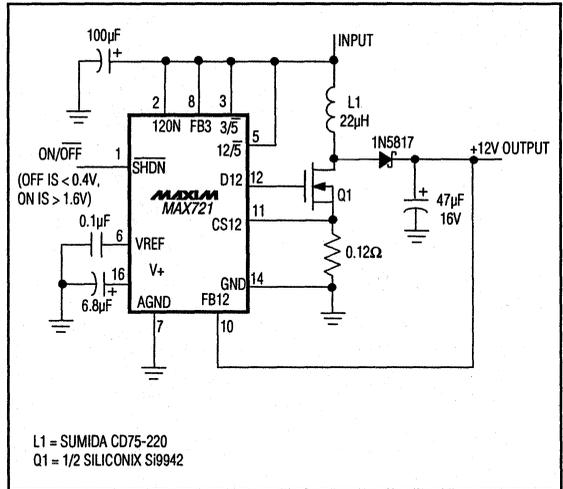
Figure 99. 5V to 12V Medium-Power PFM Boost Controller

MAXIM

5V to 12V with Micropower Shutdown Mode

Application Parameters

Input Voltage Range ....4V to 7V

Quiescent Supply Current (V_{IN} = 5V) 1.3mA

Max Load Current Capability (V_{IN} = 4.5V) 120mA

Start-Up Rise Time 1.5msec

♦ 6μA shutdown mode

♦ 170kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ 1.23V reference output

♦ Low surge current on start-up

Related Data Sheet

♦ MAX734 12V Boost Regulator

Application Discussion

To be truly micropower, the supply current of a switching regulator should be down at the level of the battery self-leakage current (typically 20μA or so) or less. Boost regulators in general are difficult to shut down completely because of the series connection of inductor and rectifier, which forces the output to V_{IN}-V_{DIODE}. Even if the load is not drawing current, the regulator's own feedback resistors act as a load.

Figure 101 shows a boost regulator using an external P-channel power MOSFET as a high-side load switch, which enables the standby current to be cut to 6μA typically. The MAX734's connection to the feedback resistor divider (V_{OUT}) is on the output side of the load switch, and is therefore disconnected when the circuit is shut down.

The MOSFET switch provides an unexpected bonus: It can be used as part of an RC filter to eliminate high-frequency switching noise. This filter consists of the switch's $r_{DS(ON)}$ and an optional 0.1μF ceramic capacitor from the output to ground.
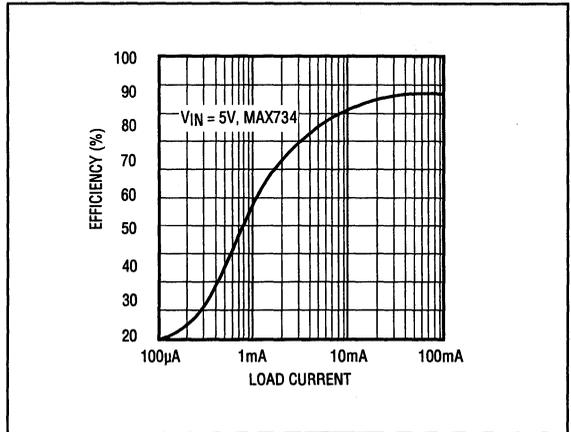
Figure 100. Efficiency vs. Load Current
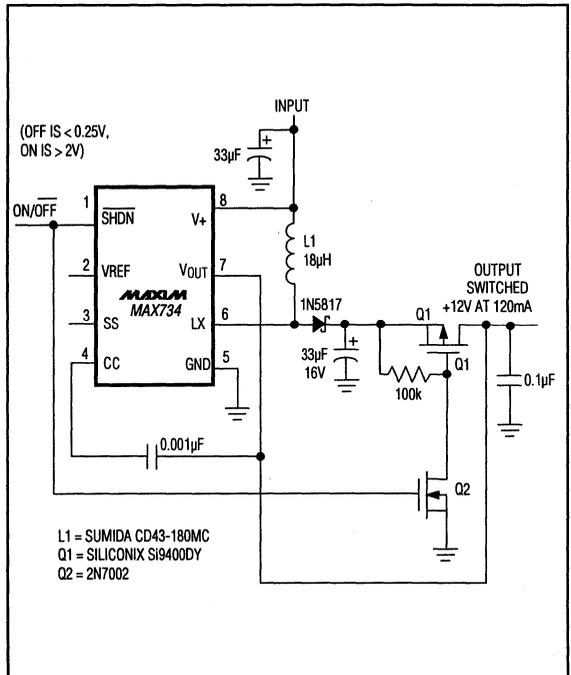
Figure 101. 5V to 12V Boost Regulator with Micropower Shutdown

3.3V to 12V at 80mA

Application Parameters

Input Voltage Range......................................2V to 12V

Start-Up Supply Voltage (I_{LOAD} = 0)..........................2.2V

Quiescent Supply Current (V_{IN} = 3.3V)...................10.3mA

(V_{IN} = 5V).........................6mA

Shutdown Supply Current.....................................35µA

Max Load Current Capability (V_{IN} = 3.0V).................80mA

(V_{IN} = 2.0V)..................40mA

Start-Up Rise Time..4msec

♦ Small 8-pin SO package

♦ Tiny 3mm diameter inductor

♦ 170kHz fixed-frequency oscillator

♦ Current-mode PWM

♦ Soft-start pin

♦ 1.23V reference output

Related Data Sheet

♦ MAX734 12V Boost Regulator

Application Discussion

This circuit is bootstrapped, meaning that the supply voltage for the switching regulator is derived from the output rather than the input. A path from input to output, vital to initial start-up, is provided by the series connection of inductor and diode common to all boost regulators. If a 5V supply voltage is available in the system, it is best to power the MAX734 from it rather than the 12V output to minimize losses due to the device supply current. See the *2-3 Cell to 3.3V/5V, 12V, and –18V: A System Solution* circuit for an example. This circuit will not start up under loads greater than 10mA, which is not usually considered a problem in flash memory applications, because virtually no I_{PP} current is drawn until the erase or write command is given.

Operating supply current can be reduced by adding a 2.7kΩ resistor in series with V+. This resistor drops the supply voltage to the IC thereby reducing current flow due to the MOSFET gate charge.
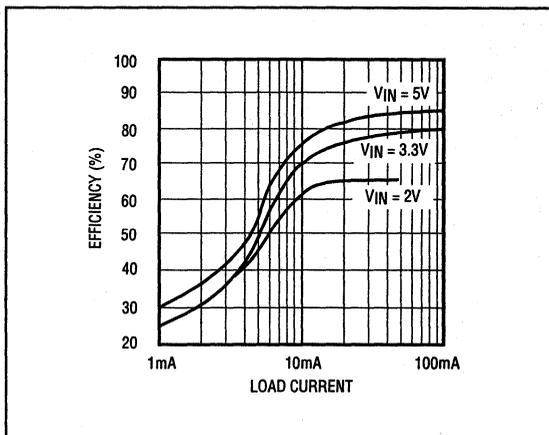
Figure 102. Efficiency vs. Load Current
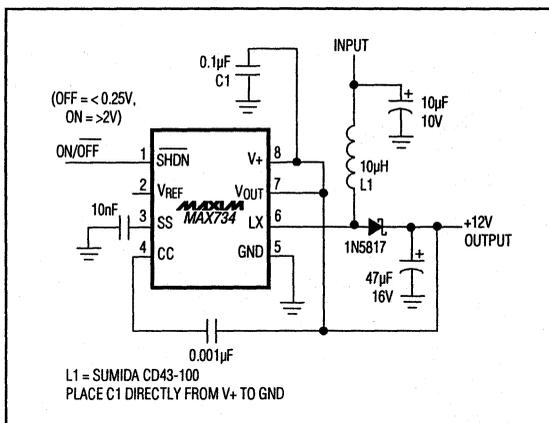
Figure 103. Bootstrapped, Low-Voltage, +12V-Output Boost Regulator

MAXIM

2-3 Cells to 12V at 60mA

Application Parameters

Input Voltage Range ....0.9V to 5.5V

Start-Up Supply Voltage (I_{LOAD} = 0) 1.4V

Quiescent Supply Current (V_{IN} = 3V)

         Main SMPS = 5V 140µA

         Both SMPS 500µA

Max Load Current Capability (V_{IN} = 3V)

         Main SMPS = 5V 400mA

         Auxiliary SMPS = 12V.....120mA

♦ **Dual regulated outputs**

♦ **Pulse-skipping PFM**

♦ **Accepts three input sources**

♦ **0.5MHz switching frequency**

♦ **1.5% reference output (alive in shutdown)**

♦ **Power-fail detection**

♦ **Evaluation kit available**

Related Data Sheet

♦ **MAX718 Palmtop SMPS**

## Application Discussion

Getting 12V at 1W from a battery that can be less than 2V (as in 2-cell applications) is trickier than it sounds. Peak currents can exceed 1A due to the high voltage step-up ratio, and can really hammer small high-impedance batteries unless filtered properly. Commercially available power MOSFETs won't even switch with gate-drive levels less than 2V. The choice: Use creaky old bipolar transistors with attendant frequency limitations due to stored base charge (read: big inductors and capacitors) or find a way to get adequate gate drive for start-up. This circuit solves these problems by operating at a high frequency to improve filtering and by deriving the gate drive for the 12V SMPS from the main 3V/5V SMPS.

This medium-power palmtop supply can generate 3.3V and 5V, 3.3V and 12V, or 5V and 12V, depending on the state of certain logic control inputs. Two regulated output voltages are generated from one of three input voltage sources: an AC-DC wall-cube adapter (7V to 20V), a main 2- or 3-cell battery, or a lithium backup battery. The dotted-line connection at the top of L2, which powers the auxiliary supply, is normally hard-wired to the main battery, but can also be connected to the main output when power comes from the AC wall adapter. The main switching regulator automatically shuts off to save the batteries when the AC-DC wall cube is plugged in.
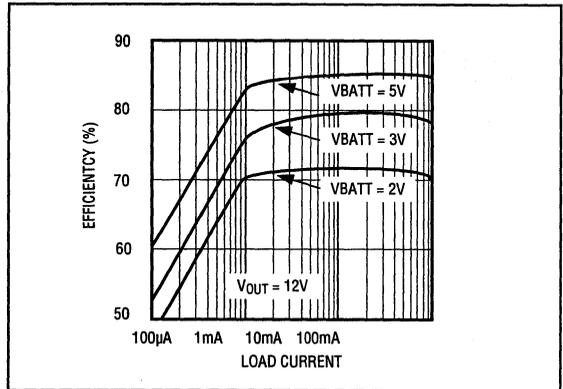
Figure 104. Efficiency vs. Load Current (5V mode)
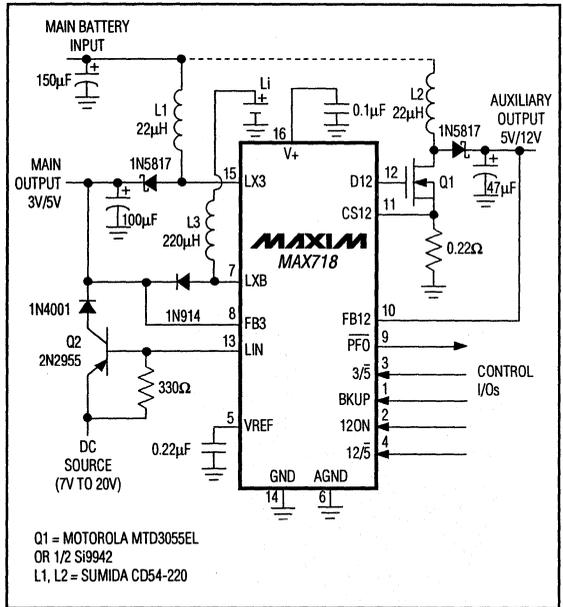
Figure 105. 2-3 Cells to 3V/5V and 5V/12V: A System Solution

The two switch-mode supplies are the same type as found in the MAX756, which has a wide range of maximum switching frequencies. Practical inductor values are from 5µH to over 200µH, allowing one to trade off switching losses and physical size. Lower inductance values increase frequency without affecting peak currents or load current capability significantly. Inductance values can be increased for lightly-loaded applications, in order to reduce peak currents.

PCMCIA Power Switching Network

Application Parameters

Quiescent Supply Current....................................350µA

Shutdown Supply Current 10µA

Max 12V Load Current Capability (each output) 100mA

VPP Switch On-Resistance...................................1.6Ω

♦ **Shrink small-outline package (SSOP)**

♦ **Two 0V/VCC/12V switched VPP outputs**

♦ **Two 0V/3.3V/5V high-side VCC switch controllers**

♦ **Latched or transparent logic interface**

♦ **VPP valid detection comparators**

♦ **1.25V reference output**

♦ **Meets PCMCIA Rev. 2.0 specs**

♦ **Compatible with standard PCMCIA controllers:**
    Intel 82365SL-DF
    Cirrus CL-PD6720
    Fujitsu MB86301

Related Data Sheet

♦ **MAX780 PCMCIA Switch**

Application Discussion

In September 1991, a standard for removable memory cards was adopted in preliminary form by an association of portable computer and memory card manufacturers. PCMCIA (Personal Computer Memory Card International Association) PC Card release 2.0 sets the V_{PP} (programming and peripheral voltage) and V_{CC} power requirements for flash memory cards and other types as well, such as SRAM, DRAM, EPROM, EEPROM, and OTP. Figure 90's circuit integrates the power switching functions needed for two PCMCIA card sockets in a host computer.

The 12V outputs are capable of sourcing 100mA per socket in the 12V state, allowing for 16-bit-wide flash programming (30mA/chip). In the 5V state, the maximum load requirement drops to 2mA, which is the worst-case power drain of the non-flash-type EEPROMs that need 5V V_{PP} programming voltages. Therefore, the PCMCIA circuit needs a strong 12V switch, but can get by with a weak device for the 5V state. The 0V state is needed in order to prevent "hot insertion," where someone would plug a card into a socket connector with live power, possibly causing loss of data retention.

Discrete N-channel MOSFETs perform the V_{CC} output switching. 0V/3.3V/5V switching action may require an extra series MOSFET in the path from +3.3V to V_{CC} (see

C1 = GND AV_{PP1}	AV_{PP0}	RESULT
0	0	$AV_{PP} = 0V$
0	1	$AV_{PP} = V_{CCIN}$
1	0	$AV_{PP} = V_{PPIN}$
1	1	$AV_{PP} = High-Z$
BV_{PP1}	BV_{PP0}	RESULT
0	0	$BV_{PP} = 0V$
0	1	$BV_{PP} = V_{CCIN}$
1	0	$BV_{PP} = V_{PPIN}$
1	1	$BV_{PP} = High-Z$

C1 = GND AV_{CC1}	AV_{CC0}	RESULT	CARD MODE
0	0	ADRV3 = GND ADRV5 = GND	Card A $V_{CC} = 0V$
0	1	ADRV3 = High-Z ADRV5 = GND	Card A $V_{CC} = 3.3V$
1	0	ADRV3 = GND ADRV5 = High-Z	Card A $V_{CC} = 5V$
1	1	ADRV3 = GND ADRV5 = GND	Card A $V_{CC} = 0V$
BV_{CC1}	BV_{CC0}	RESULT	CARD MODE
0	0	BDRV3 = GND BDRV5 = GND	Card B $V_{CC} = 0V$
0	1	BDRV3 = High-Z BDRV5 = GND	Card B $V_{CC} = 3.3V$
1	0	BDRV3 = GND BDRV5 = High-Z	Card B $V_{CC} = 5V$
1	1	BDRV3 = GND BDRV5 = GND	Card B $V_{CC} = 0V$

Figure 106. MAX780 Truth Tables

the MAX780 data sheet) in order to prevent hot insertion caused by the path through the MOSFET body diode.

Note: This PCMCIA switching function can be achieved at much lower cost with an integral power supply solution such as the MAX782 or MAX783. See *6-12 Cells to 3/3V, 5V, and 12V at High Power: MAX782 Dual Buck Controller.*

Also see the stripped-down versions of the MAX780A (B,C, and D suffix) as well as the single-channel and dual-channel versions (MAX614 and MAX613).

MAXIM

PCMCIA Power Switching Network
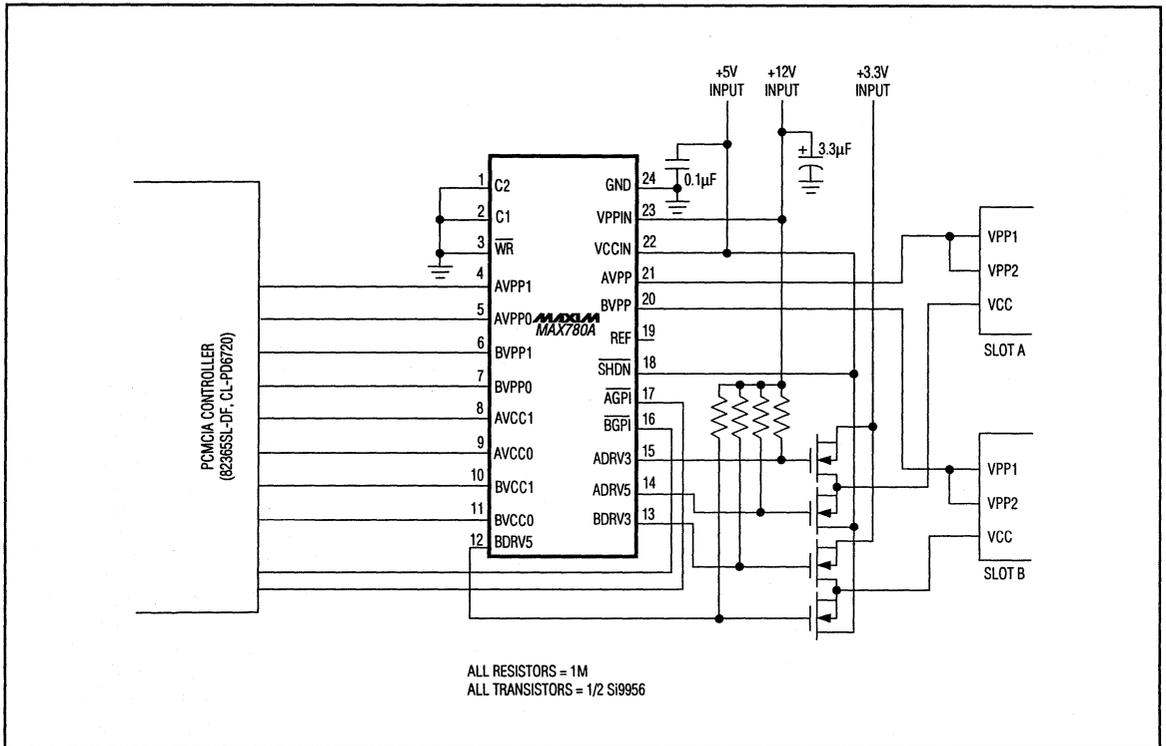
Figure 107. PCMCIA Switching Network

Section 9
Miscellaneous Circuits

Low-Dropout Linear Regulator with External PNP and Diode-OR'ed Output

High-Side Current-Sense Amplifier: ICL7612

N-Channel High-Side Power Switches: MAX620 Charge Pump

System Voltage Monitor: MAX8214 Quintuple Detector

Low-Dropout Linear Regulator with External PNP and Diode-OR'ed Output

Application Parameters

Input Voltage Range.................................5.4V to 16.5V

Quiescent Supply Current (V_{IN} = 10V) 20µA

Max Load Current Capability (V_{IN} = 6V)...................500mA

Dropout Voltage (I_{LOAD} = 100mA)..........................400mV

♦ 5µA shutdown mode

♦ Low-battery detect comparator

Related Data Sheet

♦ MAX666 Linear Regulator

Application Discussion

This linear regulator circuit is useful for uninterruptible battery-backup applications as well as for low-power circuits that use batteries for main power and optionally take power from wall-cube type AC adapters. The main advantage of this circuit over monolithic IC linear regulator solutions is that the pass transistor is external and can be sized appropriately to handle the required power dissipation. If the power dissipated is low enough, the MAX666's internal 50mA power transistor can replace the 2N2905. The MAX667 should also be considered in these cases, because it has a bigger (250mA) pass transistor and lower dropout voltage.

The MAX666 IC works well as a controller of external PNP transistors and has very low quiescent supply current. This circuit, although shown with a boost converter to provide the auxiliary power input, could just as easily be powered from a buck regulator or a second linear regulator.
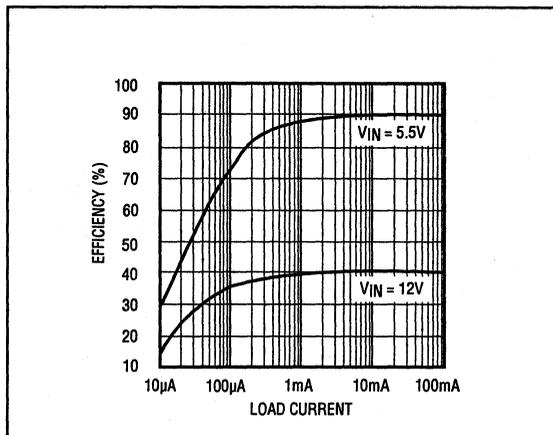
Figure 108. Efficiency vs. Load Current
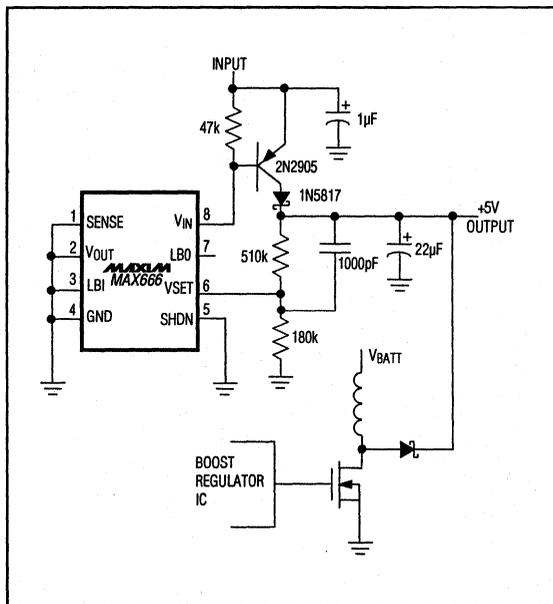
Figure 109. Low-Dropout PNP Linear Regulator with Diode OR'ed Output for Battery Backup

MAXIM

High-Side Current-Sense Amplifier

Application Parameters

Input Voltage Range ....4.5V to 48V

Quiescent Supply Current (V$_{IN}$ = 5V) 20µA

Gain Factor...1V/Amp

♦ **Senses current in the battery positive lead**

♦ **Requires no precision resistor network**

Related Data Sheet

♦ **ICL7612A Micropower Op Amp**

Application Discussion

This op-amp circuit senses current in the positive battery lead, allowing the battery negative terminal to be directly connected to circuit ground. The output is a ground — referenced output voltage directly proportional to the current flowing in the low-value sense resistor. The output voltage is typically applied to the input of an A/D converter or integrating V/F converter. Since the I$_O$ terminal is a true current source, it can be referenced to any level within the supply rails.

The main advantage of this circuit is that it does the job of an instrumentation amplifier without needing the precision resistor network that differential amplifiers usually require. The ICL7612A's common-mode input voltage range includes its own positive supply rail. Feedback via the small-signal JFET forces the voltage across R1 to equal the voltage across the sense resistor. The current through R1 must flow to the output. So, the value of R1 determines the transconductance I$_O$/VSENSE. R1 should be kept in the range of 100 x RSENSE to 1000 x RSENSE.

V$_{SUPPLY}$ (V)	R$_Z$ (Ω)
+5	120k
+9	320k
+12	470k
+24	1.1M
+48	2.2M

Figure 110. Limiting Resistor Selection Table

$$R_Z = \frac{V_{SUPPLY} - 2.5V}{20\mu A}$$

$$V_{OUT} = I_{LOAD} \times R_{OUT} \times \frac{R_{SENSE}}{R1}$$
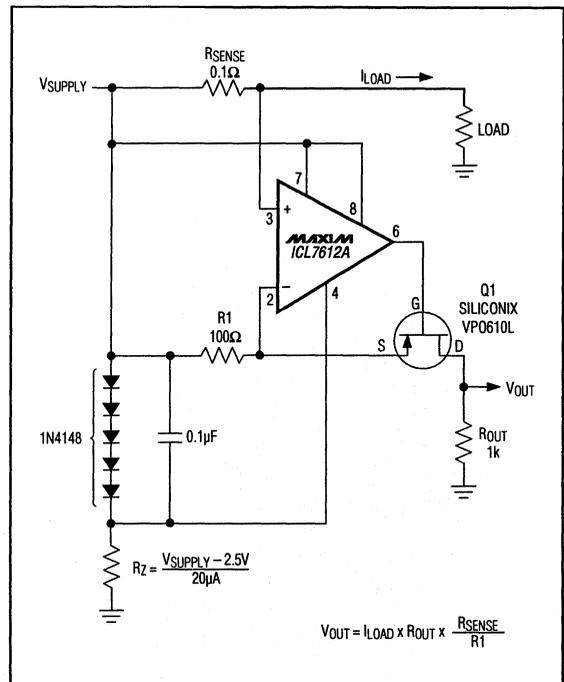
Figure 111. Micropower Positive Supply Current Monitor

MAXIM

Miscellaneous Circuits **9**

N-Channel High-Side Power Switches

Application Parameters

Input Voltage Range .... **3.5V to 16.5V**

Quiescent Supply Current (V_{IN} = 5V) **70µA**

Maximum Load Current (each switch) **5A**

♦ **Regulated charge-pump supply:**
$$V_{GATE} = (V_{BATT} + 11V)$$

♦ **Undervoltage lockout**

♦ **Power-ready detection**

♦ **Latched or transparent logic interface**

Related Data Sheet

♦ **MAX620 High-Side Charge Pump**

Application Discussion

This circuit provides four high-current MOSFET load switches for power management. The MOSFETs are N-channel source-followers for minimum $r_{DS(ON)}$. To turn on each switch, the MOSFET gate is forced 11V above the battery by the MAX620 micropower charge-pump regulator.

This family of charge-pump, high-side power supplies offers numerous devices, including devices with internal pump capacitors and internal N-channel MOSFETs, as well as a single stand-alone 8-SOIC power-supply chip (MAX622).
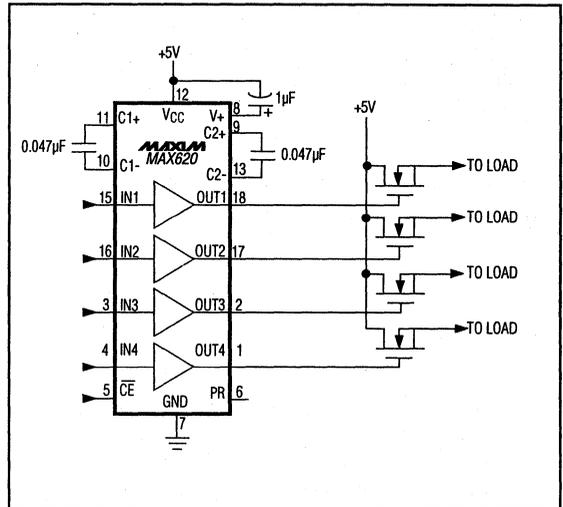

Figure 112. Quad High-Side Power Switch

MAXIM

System Voltage Monitor

Application Parameters

Input Voltage Range (monitored voltage).......1.25V to >100V

Input Voltage Range (IC only) ....2.7V to 11V

Quiescent Supply Current (V_{IN} = 5V) 16µA

Threshold Accuracy Error (T_{MIN} to T_{MAX}) ....±1% Max

♦ Five precision comparators plus reference

♦ 1.25V, 0.75% reference output

♦ Built-in hysteresis

Related Data Sheet

♦ MAX8214 Voltage Monitor

Application Discussion

Large, portable systems often require several voltage monitoring comparators to detect the status of main and backup batteries as well as for power-fail monitoring and AC adapter detection. This circuit fits that socket nicely, while burning only 3µA per comparator and providing good threshold accuracy plus built-in hysteresis.

Other similar circuits include the ICL7665A dual voltage monitor, MAX8211 and MAX8212 single voltage monitors, and the ultra-low current MAX912 (basically, a single version of the MAX8214, but with high output drive capability). There are also two versions having internal divider resistors for preset trip voltages (MAX8215 and MAX8216), and a version with open-drain outputs (MAX8213).

Another useful IC is the 2.5V low-dropout MAX872 reference, a three-terminal type that consumes 10µA and operates from supplies as low as 2.7V. The MAX872 can be connected to any external comparator to create a precision voltage monitor.
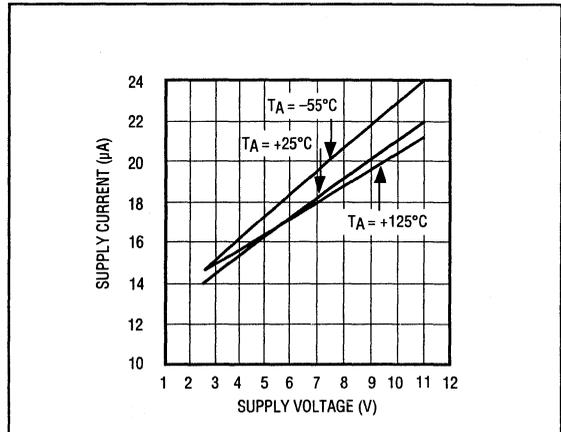

Figure 113. Supply Current vs. Supply Voltage
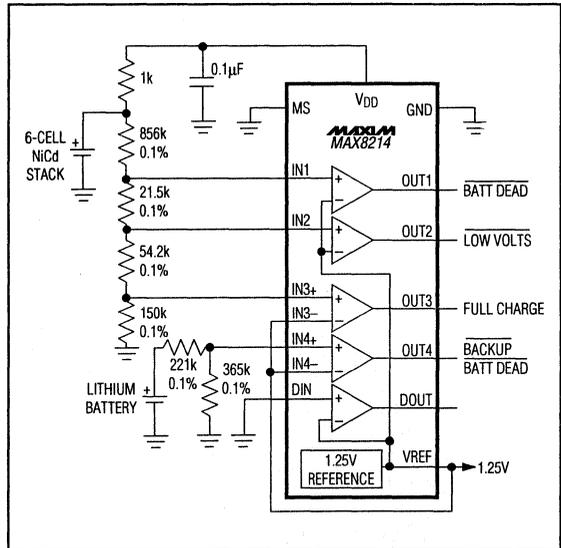
Figure 114. Precision Multiple Comparator with On-Chip Reference

Appendix A
Switch-Mode Design Equations

There are literally thousands of design equations for switch-mode power supplies. These equations, most of which are of only academic interest to the system designer, could easily fill several books. Instead of throwing reams of such equations at the reader, only a few key equations are included here, hopefully revealing more forest than trees.

Key parameters to be calculated include duty factor and the critical point, so the designer knows if the converter is operating in the discontinuous-conduction mode (inductor current returns to zero each cycle) or continuous-conduction mode (with a DC offset current built up in the inductor).

The equations also describe the relationship between inductor value and peak current; once these are known, the most important specifications for external components become known. For example, knowing the inductor value and peak current allows one to specify the inductor's saturation current rating, as well as the peak current rating needed for any external switch transistors and rectifiers.

Note: The equations for fixed-time PFMs produce impossible results if the circuit is assumed to be operating in discontinuous mode when in fact the input-output voltage ratio and on-time/off-time ratio force the circuit into continuous mode. Check the critical point first.

Boost Topology

| OPERATING CONDITIONS	PWM	PFM (CURRENT-LIMITED)	PFM (FIXED-TIME)
Discontinuous Mode	$I_{PEAK} = \sqrt{\dfrac{2I_{OUT}(V_{OUT} + V_D - V_{IN})}{fL}}$ $\text{Duty Cycle} = \dfrac{fL(I_{PEAK})}{V_{IN} - V_{SW}} \times 100\%$	$I_{PEAK} = \dfrac{(V_{IN} - V_{SW})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{(V_{IN} - V_{SW})^2 (T_{ON})^2}{2L(V_{OUT} + V_D - V_{IN})(T_{ON} + T_{OFF})}$	$I_{PEAK} = \dfrac{(V_{IN} - V_{SW})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{(V_{IN} - V_{SW})^2 (T_{ON})^2 f}{2L(V_{OUT} + V_D - V_{IN})}$
Critical Point (Crossover)	$I_{OUT(CRITICAL)} = \dfrac{(V_{OUT} + V_D - V_{IN})(V_{IN})^2}{2fL(V_{OUT} + V_D)^2}$	$L_{(CRITICAL)} = \dfrac{(V_{OUT} + V_D - V_{IN} + V_{SW})(T_{OFF})}{I_{LIMIT}}$	$\text{Duty Cycle (Critical)} = \dfrac{V_{OUT} + V_D - V_{IN}}{V_{OUT} + V_D} \times 100\%$
Continuous Mode	$I_{PEAK} = \dfrac{I_{OUT}(V_{OUT} + V_D)}{V_{IN} - V_{SW}} +$ $\dfrac{(V_{IN} - V_{SW})(V_{OUT} + V_D - V_{IN})}{2fL(V_{OUT} + V_D)}$ $\text{Duty Cycle} = \dfrac{V_{OUT} + V_D - V_{IN}}{V_{OUT} + V_D} \times 100\%$	$I_{PEAK} = I_{LIMIT}$ $I_{OUT(MAX)} =$ $\left(I_{LIMIT} - \dfrac{(V_{OUT} + V_D - V_{IN})T_{OFF}}{2L} \right)\left(\dfrac{V_{IN} - V_{SW}}{V_{OUT} + V_D} \right)$ $\text{Duty Cycle} = \dfrac{V_{OUT} + V_D - V_{IN}}{V_{OUT} + V_D} \times 100\%$	Operation of fixed-time PFMs in the continuous mode is unpredictable due to the lack of current limiting and usually not recommended. Continuous conduction in fixed-time PFMs does not depend on load current, only on input/output voltage ratio. If the circuit has a maximum duty cycle capability that exceeds critical duty cycle, continuous mode results. Most fixed-time PFM ICs have fixed 50% duty cycles.

Boost Topology (continued)
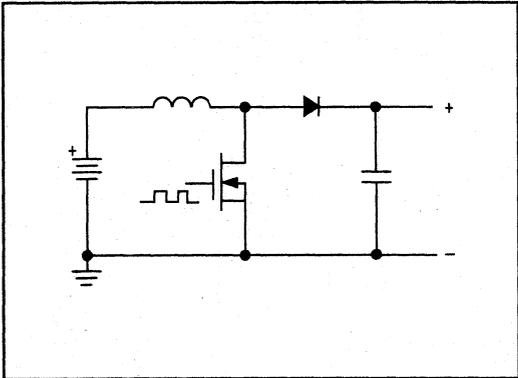
BOOST TOPOLOGY SCHEMATIC
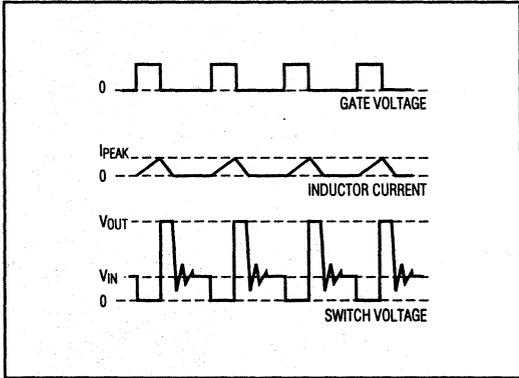
DISCONTINUOUS WAVEFORMS
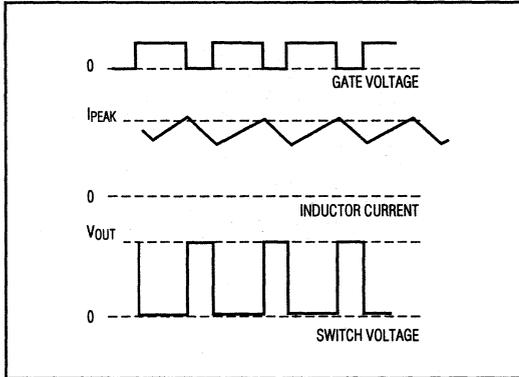
CONTINUOUS WAVEFORMS

Buck Topology

| OPERATING CONDITIONS	PWM	PFM (CURRENT-LIMITED)	PFM (FIXED-TIME)
Discontinuous Mode	$I_{PEAK} = \sqrt{\dfrac{2I_{OUT}(V_{IN} - V_{SW} - V_{OUT})(V_{OUT} + V_D)}{fL(V_{IN} + V_D)}}$ $\text{Duty Cycle} = \dfrac{fL(I_{PEAK})}{V_{IN} - V_{SW} - V_{OUT}} \times 100\%$	$I_{PEAK} = \dfrac{(V_{IN} - V_{SW} - V_{OUT})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{\left(\dfrac{V_{IN} - V_{OUT}}{V_{OUT}} + 1\right)(V_{IN} - V_{OUT})(T_{ON})^2}{2L(T_{OFF} + T_{ON})}$	$I_{PEAK} = \dfrac{(V_{IN} - V_{SW} - V_{OUT})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{\left(\dfrac{V_{IN} - V_{OUT}}{V_{OUT}} + 1\right)(V_{IN} - V_{OUT})(T_{ON})^2 f}{2L}$
Critical Point (Crossover)	$I_{OUT(CRITICAL)} = \dfrac{(V_{OUT} + V_D)(V_{IN} - V_{SW} - V_{OUT})}{2fL(V_{IN})}$	$L_{(CRITICAL)} = \dfrac{(V_{OUT} + V_D)T_{OFF}}{I_{LIMIT}}$	$\text{Duty Cycle (Critical)} = \dfrac{V_{OUT} + V_D}{V_{IN} - V_{SW}} \times 100\%$
Continuous Mode	$I_{PEAK} = I_{OUT} + \dfrac{V_{OUT}(V_{IN} - V_{SW} - V_{OUT})}{2fL(V_{IN})}$ $\text{Duty Cycle} = \dfrac{V_{OUT} + V_D}{V_{IN} - V_{SW}} \times 100\%$	$I_{PEAK} = I_{LIMIT}$ $I_{OUT(MAX)} = I_{LIMIT} - \dfrac{(V_{OUT} + V_D)T_{OFF}}{2L}$ $\text{Duty Cycle} = \dfrac{V_{OUT} + V_D}{V_{IN} - V_{SW}} \times 100\%$	Operation of fixed-time PFMs in the continuous mode is unpredictable due to the lack of current limiting and usually not recommended. Continuous conduction in fixed-time PFMs does not depend on load current, only on input/output voltage ratio. If the circuit has a maximum duty cycle capability that exceeds critical duty cycle, continuous mode results. Most fixed-time PFM ICs have fixed 50% duty cycles.

Buck Topology (continued)

BUCK TOPOLOGY SCHEMATIC

GATE VOLTAGE

I_{PEAK}

INDUCTOR CURRENT

V_{IN}

V_{OUT}

SWITCH VOLTAGE

DISCONTINUOUS WAVEFORMS

GATE VOLTAGE

I_{PEAK}

INDUCTOR CURRENT

V_{OUT}

SWITCH VOLTAGE
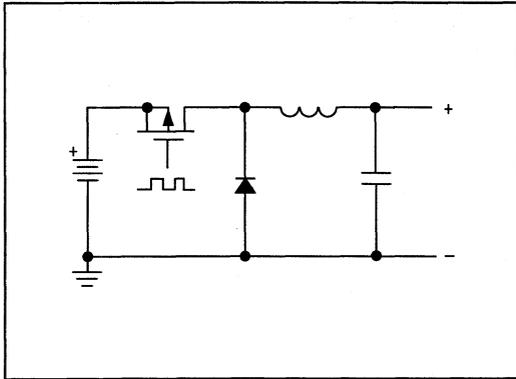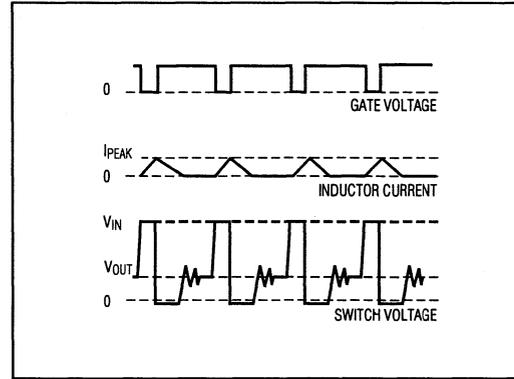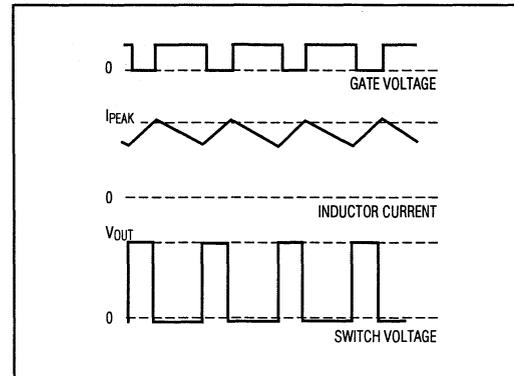
CONTINUOUS WAVEFORMS

Inverting Topology

| OPERATING CONDITIONS	PWM	PFM (CURRENT-LIMITED)	PFM (FIXED-TIME)
Discontinuous Mode	$I_{PEAK} = \sqrt{\dfrac{2I_{OUT}(V_{OUT}+V_D)}{fL}}$ $\text{Duty Cycle} = \dfrac{fL(I_{PEAK})}{V_{IN}-V_{SW}} \times 100\%$	$I_{PEAK} = \dfrac{(V_{IN}-V_{SW})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{(V_{IN}-V_{SW})^2(T_{ON})^2}{2L(V_{OUT}+V_D)(T_{ON}+T_{OFF})}$	$I_{PEAK} = \dfrac{(V_{IN}-V_{SW})T_{ON}}{L}$ $I_{OUT(MAX)} = \dfrac{(V_{IN}-V_{SW})^2(T_{ON})^2 f}{2L(V_{OUT}+V_D)}$
Critical Point (Crossover)	$I_{OUT(CRITICAL)} = \dfrac{(V_{IN})^2}{2fL(V_{IN}+V_{OUT})^2}$	$L(\text{Critical}) = \dfrac{(V_{OUT}+V_D)(T_{OFF})}{I_{LIMIT}}$	$\text{Duty Cycle (Critical)} = \dfrac{V_{OUT}+V_D}{V_{IN}-V_{SW}+V_{OUT}} \times 100\%$
Continuous Mode	$I_{PEAK} = \dfrac{(V_{IN}-V_{SW})(V_{OUT}+V_D+V_{IN})}{2fL(V_{OUT}+V_D)} + \dfrac{I_{OUT}(V_{OUT}+V_D+V_{IN})}{V_{IN}-V_{SW}}$ $\text{Duty Cycle} = \dfrac{V_{OUT}+V_D}{V_{IN}-V_{SW}+V_{OUT}} \times 100\%$	$I_{PEAK} = I_{LIMIT},\quad I_{OUT(MAX)} =$ $\left(I_{LIMIT} - \dfrac{(V_{OUT}+V_D)T_{OFF}}{2L}\right)\left(\dfrac{V_{IN}-V_{SW}}{V_{OUT}+V_D+V_{IN}}\right)$ $\text{Duty Cycle} = \dfrac{V_{OUT}+V_D}{V_{IN}-V_{SW}+V_{OUT}} \times 100\%$	Operation of fixed-time PFMs in the continuous mode is unpredictable due to the lack of current limiting and usually not recommended. Continuous conduction in fixed-time PFMs does not depend on load current, only on input/output voltage ratio. If the circuit has a maximum duty cycle capability that exceeds critical duty cycle, continuous mode results. Most fixed-time PFM ICs have fixed 50% duty cycles.

Inverting Topology (continued)
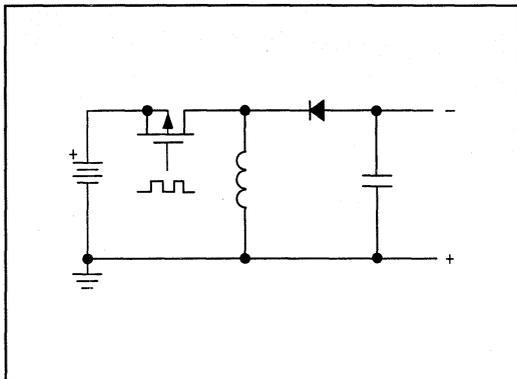
INVERTING TOPOLOGY SCHEMATIC
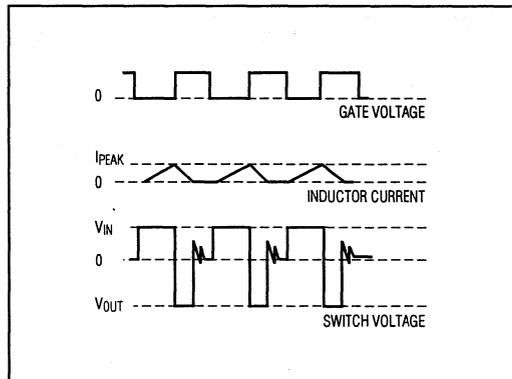
DISCONTINUOUS WAVEFORMS
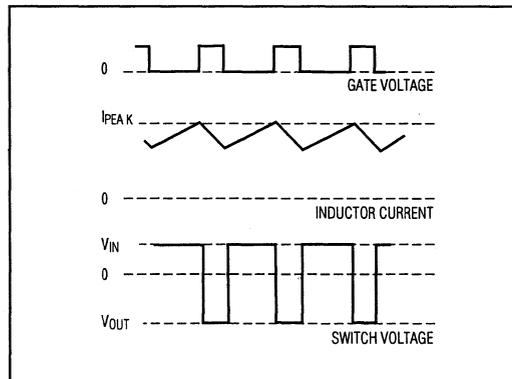
CONTINUOUS WAVEFORMS

Appendix B
Abbreviation Glossary

AA — AA-size cell (ANSI type 15A, usually alkaline)

ABPTS — "Atomic batteries to power...
    Turbines to speed..."

ADC — analog-to-digital converter

CCFT — cold-cathode fluorescent tube

DAC — digital-to-analog converter

DCR — DC resistance

DPAK — TO-252 surface-mount power package

ESR — effective series resistance

f — switching frequency

HP — high-power

I_{LIMIT} — peak current-limit threshold

I_{OUT} — output (load) current

I_{PEAK} — peak current (inductor, switch)

JFET — junction field-effect transistor

L — inductance value

LCD — liquid-crystal display

LDO — low dropout

Li — Lithium

LP — low-power

Mux — multiplexer

NiCd — nickel-cadmium

NFET — N-channel power MOSFET

NiMH — nickel-metal-hydride

PCMCIA — Personal Computer Memory Card
    International Association

P_D — power dissipation

PFET — P-channel power MOSFET

PFM — pulse-frequency modulation

PSRR — power-supply rejection ratio

PWM — pulse-width modulation

$r_{DS(ON)}$ — on-resistance, drain to source

RTC — real-time clock

SMPS — switch-mode power supply

SMT — surface-mount type

SSOP — shrink small-outline package (fine lead pitch)

T_A — ambient temperature

T_{OFF} — off-time

T_{ON} — on-time

V_D — diode forward voltage (typ 0.4V)

VF — forward voltage

V_{IL} — logic input low voltage

V_{IH} — logic input high voltage

VLSI — very large-scale integration

V_{PP} — peripheral and programming voltage

VSW — switch transistor forward voltage (typ 0.2V)

Appendix C
Surface-Mount Component Suppliers

Component Type	Company	Factory FAX [country code]	USA Phone
Inductors	Coiltronics	[1] 407 241-9339	(407) 241-7876
Low-value resistors	IRC	[1] 213 722-9028	(213) 772-2000
Tantalum capacitors	Matsuo	[81] 6-331-1386	(714) 969-2491
Ceramic capacitors	Murata-Erie	[1] 404 736-3030	(404) 736-1300
Rectifiers and MOSFETS	N.I.E.C.	[81] 3-3494-7414	(805) 867-2555*
MOSFETS	Siliconix	[1] 408 727-5414	(408) 988-8000
Tantalum capacitors	Sprague	[1] 508 339-5063	(508) 339-8900
Inductors	Sumida	[81] 3-3607-5428	(708) 956-0666
Inductors	TDK	[81] 3-3278-5358	(708) 803-6100
Transistors	Zetex	[44] 61 627 5467	(516) 543-7100
Transistors and MOSFETS	Motorola		(602) 244-6900
Inductors	SAE POWER	[1] 408 986-8529	(408) 987-2700
Inductors	Gowanda	[1] 716 532-2702	(716) 532-2234
Inductors	Inductor Supply	[1] 714 978-2411	(800) 854-1881
Inductor Cores	Magnetics, Inc.	[1] 412 282-6955	(412) 282-8282
Tantalum Capacitors (TPS)	AVX	[1] 803 626 3123	(803) 448-9411
Electrolytic Capacitors (OS-CON)	Sanyo	[81] 0720 70 1174	(619) 661-6835

Construction Notes

Many of the switch-mode supplies given in this book operate with high frequencies and have large peak current levels. Careful component selection and board construction is mandatory for high-frequency SMPSs.

Use etched PC boards with a continuous ground plane where practical; failing that, use a copper-clad board with traces cut by exacto-knife or razor blade; failing that, use a breadboard with soldered-in point-to-point wiring. Breadboard materials with pre-etched DIP solder pads are excellent for prototyping, even for surface-mount components (you can use the DIP pads as lands for the surface-mount components). Plug-in plastic protoboards and wire-wrap techniques are absolutely unacceptable. .

In high-power circuits, trace out the high current paths on the schematic and keep these paths short when doing the wiring. This is especially true for the ground; keeping the high-current ground paths short wins 90% of the layout battle.

Except for micropower circuits, inductors and capacitors must be high-quality types intended for switching-regulator applications. See the table above. Usually, the stuff found at the local electronics junk store is garbage (iron-core chokes, standard aluminum electrolytic capacitors, etc). Plan for at least 2-3 week lead times to acquire the samples you need to do a good design.

For high-power applications, good capacitors are critical. Four reliable vendors are:

- Sprague – 595D series SMT Tantalum
- Sanyo – OS-CON type electrolytic
- AVX – TPS series SMT Tantalum
- Nichicon – PL series aluminum electrolytic

Appendix D
Power-Supply Product Selection Guide

Part Number	Input Voltage Range (V)	Linear Output Voltage (V)	DC-DC Output Voltages (V)	Auxiliary Outputs (V)	Quiescent Supply Current Max Over Temp. (µA)	EV Kit	Temp. Ranges	Package Options*	Features	Price[†] 1000-up ($)
MAX714	5.05 to 11	2 at +5V	-5 to -26 adj. LCD driver	N/A	200 per enabled output line		C,E,M	DIP,SO	Independent shutdowns, backup-battery switchover, $\overline{RESET}$ and power-fail warning outputs	3.40
MAX715	5.05 to 11	3 at +5V	-5 to -26 adj.	-5 adj., +12 or +15 adj.	200 per enabled output line		C,E,M	DIP,SO	PC layout and parts list available	5.75
MAX716	5.05 to 11	4 at +5V	-5 to -26 adj.	-5 adj., +12 or +15 adj.	200 per enabled output line	Yes	C,E,M	DIP,SO, SSOP	Independent shutdowns, backup-battery switchover, $\overline{RESET}$ and power-fail warning outputs	5.95
MAX717-721	0.9 to 5.5 (battery), 7 to 18 (plug-in adapter)	N/A	+3.3 (MAX717), +3.3 or +5 (MAX718/720), +3.0 or +5 (MAX719/721)	+5 or +12 (all)	60, 40 shutdown	Yes (MAX717-MAX719)	C,E	SO	Built-in switchover from main battery to plug-in adapter power, low-voltage warning, AC detect, clock & RAM keep-alive mini-switcher from backup battery	4.95
MAX722/723	0.85 to 5.5 (battery), 7 to 18 (plug-in adapter)	N/A	+3.3 or +5 (MAX722) +3 or +5 (MAX723)	Neg. LCD (0 to -40) (all)	60, 40 shutdown	Yes	C,E	SO	Built-in switchover from main batttery to plug-in adapter power, low-voltage warning	4.63
MAX781	5 to 18	3.3 at 10mA 5.0 at 25mA	3.3, 14, battery charger	Battery charger, current source, dual V_{PP} outputs	100 shutdown, 750 standby, 2mA operating	Yes	C,E	SSOP	High-power controller to 50W or more, dual PCMCIA V_{PP} outputs, analog mux, SPI interface	††
MAX782	5.5 to 30	3.3 at 5mA 5.0 at 25mA	3.3, 5.0, 14	Dual V_{PP} outputs	70 standby, 750 per output enabled	Yes	C,E	SSOP	High-power dual controller to 50W or more, dual PCMCIA V_{PP} outputs, three precision voltage monitors,	5.95
MAX783	5.5 to 30	3.3 at 5mA 5.0 at 25mA	3.3, 5.0, 14	Dual V_{PP} outputs	70 standby 750 per output enabled		C,E	SSOP	High-power dual controller to 50W or more, dual PCMCIA V_{PP} outputs, three precision voltage monitors, optimized for 6-cell operation	5.95
MAX786	5.5 to 30	3.3 at 5mA 5.0 at 25mA	3.3, 5.0	N/A	40 shutdown 70 standby 750 per output enabled	Yes	C,E	SSOP	High-power dual controller to 50W or more, two precision voltage monitors	4.15

* Package Options: DIP = Dual-In-Line Package, SO = Small Outline, SSOP = Shrink Small-Outline Package
† Prices provided are for design guidance only and are FOB USA. International prices will differ due to local duties, taxes, and exchange rates.
†† Future product - contact factory for pricing and availability.

MOSFET Drivers

Part Number	Output Resistance (Ω), max(typ)	Rise/Fall T_A=+25°C (ns max)	Rise/Fall Over Temp. (ns max)	Peak Output Current (A)	Supply Voltage (V)	Package Options*	Temp. Ranges**	Features	Price† 1000-up ($)
MAX4420/4429	2.5(1.5)	30/30(2500pF)	60/60(2500pF)	6	4.5 to 18	DIP,SO	C,E,M	Single noninverting/inverting	1.71
MAX4426/4427/4428	10(4)	30/30(1000pF)	40/40(1000pF)	1.5	4.5 to 18	DIP,SO	C,E,M	Dual inverting/dual noninverting/dual mixed	1.61
MAX626/627/628	15(4)	30/30(1000pF)	40/40(1000pF)	2	4.5 to 18	DIP,SO	C,E,M	Dual inverting/dual noninverting/dual mixed	1.49
TSC426/427/428	15(6)	30/30(1000pF)	60/40(1000pF)	1.5	4.5 to 18	DIP,SO	C,E,M	Dual inverting/dual noninverting/dual mixed	1.06
MXT429	2.5(1.5)	35/35(2500pF)	70/70(2500pF)	6	7.0 to 18	DIP,SO	C,E,M	Single inverting	1.67
ICL7667	12(4)	30/30(1000pF)	40/40(1000pF)	1.5	4.5 to 15	DIP,SO	C,E,M	Dual inverting	1.12

High-Side MOSFET Drivers

Part Number	Supply Voltage Range (V)	Quiescent Supply Current (mA), max(typ)	Switching Frequency (kHz)	Package Options*	Temp. Ranges**	Features	Price† 1000-up ($)
MAX620	4.5 to 16.5	0.5(0.070)	70	DIP,SO	C,E	Quad high-side driver, V_{CC}+11V output	3.85
MAX621	4.5 to 16.5	0.5(0.070)	70	DIP	C,E	Quad high-side driver, V_{CC}+11V output, internal capacitors	5.82
MAX625	4.5 to 16.5	0.5(0.070)	70	DIP	C,E	Quad high-side switch, 4 internal 0.2Ω N-channel MOSFETs, internal capacitors	9.98

*   Package Options: DIP = Dual-In-Line Package, SO = Small Outline, TO-__ = Can
**   Temperature Ranges: C = 0°C to +70°C, E = -40°C to +85°C, M = -55°C to +125°C
†   Prices provided are for design guidance and are FOB USA. International prices will differ due to local duties, taxes, and exchange rates.

Part Number	Input Voltage Range (V)	Output Voltage (V)	Quiescent Supply Current (mA), max(typ)	Output (mA typ)	Control Scheme	Package Options*	EV Kit	Temp. Ranges**	Features	Price† 1000-up ($)
STEP-UP/STEP-DOWN SWITCHING REGULATORS										
MAX877/878/879	1 to 5.5	5/(3.3 or 3)/adj.	0.310(0.220)	240	PFM	DIP,SO	Yes	C,E,M	Gives regulated output when input above and below the output; no transformer	††
STEP-UP SWITCHING REGULATORS										
MAX4193	2.4 to 16.5	Adj.	0.200(0.090)	300mW	PFM	DIP,SO		C,E,M	Improved RC4193 2nd source	1.74
MAX630	2 to 16.5	Adj.	0.125(0.070)	300mW	PFM	DIP,SO		C,E,M	Improved RC4193 2nd source	2.88
MAX631	1.5 to 5.6	5, adj.	0.4(0.135)	40	PFM	DIP,SO		C,E,M	Only 2 external components	2.56
MAX632	1.5 to 12.6	12, adj.	2.0(0.5)	25	PFM	DIP,SO		C,E,M	Only 2 external components	2.56
MAX633	1.5 to 15.6	15, adj.	2.5(0.75)	20	PFM	DIP,SO		C,E,M	Only 2 external components	2.56
MAX641	1.5 to 5.6	5, adj.	0.4(0.135)	300	PFM	DIP,SO		C,E,M	PFM controller	2.87
MAX642	1.5 to 12.6	12, adj.	2.0(0.5)	550	PFM	DIP,SO		C,E,M	PFM controller	2.87
MAX643	1.5 to 15.6	15, adj.	2.5(0.75)	325	PFM	DIP,SO		C,E,M	PFM controller	2.87
MAX654	1.15 to 5.6	5	(0.08)	40	PFM	DIP,SO	Yes	C,E,M	Optimized for 1 cell input	3.35
MAX655	1.5 to 5.6	5	(0.04)	60	PFM	DIP,SO	Yes	C,E,M	Optimized for 2 cell input	3.35
MAX656	1.15 to 5.6	5	(0.08)	250	PFM	DIP,SO		C,E,M	Drives external MOSFET	3.35
MAX657	1.15 to 3.6	3	(0.08)	60	PFM	DIP,SO	Yes	C,E,M	Optimized for 1 cell input	3.35
MAX658	1.5 to 5.6	5	(0.04)	110	PFM	DIP,SO		C,E,M	Drives external MOSFET	3.35
MAX731	1.8 to 5.25	5	4(2)	200	PWM	DIP,SO	Yes	C,E,M		3.20
MAX732	4 to 9.3	12	3(1.7),	200	PWM	DIP,SO	Yes	C,E,M	Flash memory programmer, ±4%, output voltage tolerance	2.66
MAX733	4 to 11	15	3(1.7)	125	PWM	DIP,SO	Yes	C,E,M		3.23
MAX734	1.9 to 12	12	2.5(1.1)	120	PWM	DIP,SO	Yes	C,E,M	Flash memory programmer	2.23
MAX741U	1.8 to 15.5	5,12,15, adj.	3.5(1.6)	5W	PWM	DIP,SSOP	Yes	C,E,M	PWM step-up controller, $3V_{IN}$ to $5V_{OUT}$ at 1A, 85% efficient	3.64
MAX751	1.2 to 5.25	5	3.5(2)	175	PWM	DIP,SO	Yes	C,E,M		2.35
MAX752	1.8 to 16	Adj.	4(2)	2.4W	PWM	DIP,SO	Yes	C,E,M		3.20
MAX756/757	1.1 to 5.5	(3.3 or 5)/adj.	0.060	300	PFM	DIP,SO	Yes	C,E	Best combination of low I_Q & high 86% efficiency	1.95
MAX761/762	2 to 16.5	12/15 or adj. to 16.5	0.1	120	PFM	DIP,SO	Yes	C,E,M	12V flash programmer, high efficiency over wide I_{OUT} range	††
MAX770/771/772	2 to 16.5	5/12/15 or adj. to 28	0.1	1A	PFM	DIP,SO	Yes	C,E,M	Controllers, high efficiency over wide I_{OUT} range	††
MAX773	3 to 16.5	Adj. to 48	0.1	1A	PFM	DIP,SO		C,E,M	Controller, high-voltage output, high efficiency over wide I_{OUT} range	††
MAX777/778/779	1 to 6	5/(3 or 3.3)/adj.	0.310(0.220)	300	PFM	DIP,SO	Yes	C,E,M	On-chip active diode, true turn off in shutdown	††
MAX856/857	1.1 to 5.5	(3.3 or 5)/adj.	0.060	150	PFM	DIP,SO	Yes	C,E	Best combination of low I_Q & high 85% efficiency	††
STEP-DOWN SWITCHING REGULATORS										
MAX638	2.6 to 16.5	5, adj.	0.6(0.135)	75	PFM	DIP,SO		C,E,M	Only 3 external components	2.56
MAX639/640/653	4 to 11.5	5/3.3/3 or adj.	0.02(0.01)	225	PFM	DIP,SO	Yes	C,E,M	>90% efficiencies over wide range (1mA to 225mA)	2.96
MAX649/651/652	4 to 16.5	5/3.3/3 or adj.	0.100	1A	PFM	DIP,SO	Yes	C,E,M	>90% efficiency over wide range, drives external P-channel FET	††

*   Package Options: DIP = Dual-In-Line Package, SO = Small Outline, SSOP = Shrink Small-Outline Package
**   Temperature Ranges: C = 0°C to +70°C, E = -40°C to +85°C, M = -55°C to +125°C
†   Prices provided are for design guidance and are FOB USA. International prices will differ due to local duties, taxes, and exchanges rates.
††   Future product - contact factory for pricing and availability.

Part Number	Input Voltage Range (V)	Output Voltage (V)	Quiescent Supply Current (mA), max(typ)	Output (mA typ)	Control Scheme	Package Options*	EV Kit	Temp. Ranges**	Features	Price† 1000-up ($)
DUAL-OUTPUT SWITCHING REGULATORS										
MAX742	4.2 to 10	±12,±15	15(8)	±15W	PWM	DIP,SO		C,E,M	Drives external MOSFETs	3.91
MAX743	4.2 to 6	±12,±15	30(20)	±1.5W	PWM	DIP,SO	Yes	C,E,M	Internal power MOSFETs, production kit available	4.49
MAX753	4.5 to 6	CCFT adj., -LCD adj.	3	to 20W	PFM	DIP,SO		C,E	CCFT backlight and -LCD outputs, digital adjust	4.45
MAX754	4.5 to 6	CCFT adj., +LCD adj.	3	to 20W	PFM	DIP,SO		C,E	CCFT backlight and +LCD outputs, digital adjust	4.45

Part Number	Input Voltage Range (V)	Output Voltage (V)	Quiescent Supply Current (mA), max(typ)	Output (mA typ)	Package Options*	EV Kit	Temp. Ranges**	Features	Price† 1000-up ($)
CHARGE-PUMP CONVERTERS-UNREGULATED									
MAX1044	1.5 to 10	$-V_{IN}, +2 \times V_{IN}$	0.200(0.03)	20	DIP,SO		C,E,M	60kHz osc. boost mode	1.19
MAX660	1.5 to 5.5	$-V_{IN}, +2 \times V_{IN}$	1.0(0.6)	100	DIP,SO		C,E,M	8-pin SOIC	2.95
MAX665	1.5 to 8	$-V_{IN}, +2 \times V_{IN}$	1.0(0.6)	100	DIP,SO		C,E,M		3.96
MAX680	2 to 6	$\pm2 \times V_{IN}$	2(1)	±10	DIP,SO		C,E,M	Dual output	1.87
MAX681	2 to 6	$\pm2 \times V_{IN}$	2(1)	±10	DIP		C,E	No external components (internal caps)	4.64
ICL7660	1.5 to 10	$-V_{IN}, +2 \times V_{IN}$	0.175(0.110)	10	DIP,SO,TO-99		C,E,M		1.09
ICL7662	4.5 to 20	$-V_{IN}, +2 \times V_{IN}$	0.6(0.25)	10	DIP,SO,TO-99		C,I		1.86
Si7661	4.5 to 20	$-V_{IN}, + 2 \times V_{IN}$	2(0.3)	10	DIP,SO,TO-99		C,I		1.86
CHARGE-PUMP CONVERTERS-REGULATED									
MAX619	2 to 3.6	5	0.15	15mA	DIP,SO	Yes	C,E,M	No inductors	††
MAX622	3.5 to 16.5	$V_{IN} + 11V$	0.5(0.07)	500µA	DIP,SO		C,E	3 external capacitors, high-side switching MAX662	1.86
MAX623	3.5 to 16.5	$V_{IN} + 11V$	0.5(0.07)	500µA	DIP		C,E	No external capacitors, high-side switching	2.85
MAX662	4.5 to 5.5	12	1(0.32)	30mA, guaranteed over temp.	DIP,SO	Yes	C	Flash memory programmer, no inductors, lowest-cost	2.09

Part Number	Input Voltage Range (V)	Output Voltage (V)	Quiescent Supply Current (mA), max(typ)	Output (mA typ or min)	Package Options*	Temp. Ranges**	Package Size	Price† 1000-up ($)
MODULES								
MAX1732	4.5 to 6	12	1.7(0.07)	120	14 DIP	C	0.27" x 0.77" x 0.29" (6.86 mm x 19.57mm x 7.37mm)	18.29
MAX1738	6.6 to 16	5	1.7(0.06)	500	14 DIP	C	0.27" x 0.77" x 0.29" (6.86 mm x 19.57mm x 7.37mm)	17.07
MAX1743	4.5 to 5.5	±12 or ±15	20(2.2)	125 or 100	24 DIP	C	0.57" x 1.27" x 0.345" (14.42mm x 32.32mm x 8.75mm)	23.78

* Package Options: DIP = Dual-In-Line Package, SO = Small Outline, SSOP = Shrink Small-Outline Package, TO-__ = Can

** Temperature Ranges: C = 0°C to +70°C, I = -25°C to +85°C, E = -40°C to +85°C, M = -55°C to +125°C

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†† Future product - contact factory for pricing and availability.

Part Number	Input Voltage Range (V)	Output Voltage (V)	Quiescent Supply Current (mA), max(typ)	Output (mA typ)	Control Scheme	Package Options*	EV Kit	Temp. Ranges**	Features	Price† 1000-up ($)
MAX724/724H	3.5 to 40/60	Adj.(2.5 to 40)	20(8.5)	5A	PWM	TO-220,TO-3		C,E,M	High power, few external components	4.69
MAX726/726H	3.5 to 40/60	Adj.(2.5 to 40)	20(8.5)	2A	PWM	TO-220,TO-3		C,E,M	High power, few external components	3.00
MAX727/727H	3.5 to 40/60	5	20(8.5)	2A	PWM	TO-220,TO-3		C,E,M	High power, few external components	3.00
MAX728/728H	3.5 to 40/60	3.3	20(8.5)	2A	PWM	TO-220,TO-3		C,E,M	High power, few external components	3.00
MAX729/729H	3.5 to 40/60	3	12(8.5)	2A	PWM	TO-220,TO-3		C,E,M	High power, few external components	3.00
MAX730/730A	5.2 to 11	5	3(1.7)	300	PWM	DIP,SO	Yes	C,E,M	90% efficiencies, MAX730A improves I_{OUT} & dropout	3.09
MAX738/738A	6 to 16	5	3(1.7)	750	PWM	DIP,SO	Yes	C,E,M	>85% efficiencies, MAX738A improves I_{OUT} & dropout	3.23
MAX741D	2.7 to 15.5	5, adj.	4.0(2.8)	3A	PWM	DIP,SSOP	Yes	C,E,M	PWM step-down controller, 6.5V_{IN} to 5V_{OUT} at 3A, 90% efficient	3.64
MAX744A	4.75 to 16	5	2.5 (1.2)	750	PWM	DIP,SO	Yes	C,E,M	Optimized for cellular communications	††
MAX746	4 to 15	5/adj.	1	2.5A	PWM	DIP,SO	Yes	C,E,M	90% efficiencies, drives external N-channel FET	††
MAX747	4 to 15	5/adj.	1	2.5A	PWM	DIP,SO	Yes	C,E,M	90% efficiencies, drives external P-channel FET	††
MAX748A	4.75 to 16	3.3	3(1.7)	500	PWM	DIP,SO	Yes	C,E,M	>85% efficiencies	††
MAX750/750A	4 to 11	Adj.	3(1.7)	1.5W	PWM	DIP,SO	Yes	C,E,M	90% efficiencies, MAX750A improves I_{OUT} & dropout	2.92
MAX758/785A	4 to 16	Adj.	3(1.7)	3.75W	PWM	DIP,SO	Yes	C,E,M	>85% efficiencies, MAX758A improves I_{OUT} & dropout	3.23
MAX763A	4 to 11	3.3	3(1.7)	250	PWM	DIP,SO	Yes	C,E,M	80% efficiencies	††
MAX787/787H	3.5 to 40/60	5	12(8.5)	5A	PWM	TO-220,TO-3		C,E,M	High power, few external components	4.69
MAX788/788H	3.5 to 40/60	3.3	12(8.5)	5A	PWM	TO-220,TO-3		C,E,M	High power, few external components	4.69
MAX789/789H	3.5 to 40/60	3	12(8.5)	5A	PWM	TO-220,TO-3		C,E,M	High power, few external components	4.69
LT1074/1074HV	3.5 to 40/60	Adj.(2.5 to 40)	20(8.5)	5A	PWM	TO-220,TO-3		C,E,M	High power, few external components	4.83
LT1076/1076HV	3.5 to 40/60	Adj.(2.5 to 40)	12(8.5)	2A	PWM	TO-220,TO-3		C,E,M	High power, few external components	3.03
INVERTING SWITCHING REGULATORS										
MAX4391	4 to 16.5	up to -20	0.25(0.09)	400mW	PFM	DIP,SO		C,E,M	Improved RC4391 2nd source	2.09
MAX634	2.3 to 16.5	up to -20	0.15(0.07)	400mW	PFM	DIP,SO		C,E,M	Improved RC4391 2nd source	2.61
MAX635	2.3 to 16.5	-5, adj.	0.15(0.08)	50	PFM	DIP,SO		C,E,M	Only 3 external components	2.56
MAX636	2.3 to 16.5	-12, adj.	0.15(0.08)	40	PFM	DIP,SO		C,E,M	Only 3 external components	2.56
MAX637	2.3 to 16.5	-15, adj.	0.15(0.07)	25	PFM	DIP,SO		C,E,M	Only 3 external components	2.56
MAX650	-54 to -42	5	10(0.5)	250	PFM	DIP,SO		C,E,M	Telecom applications	3.50
MAX735	4 to 6.2	-5	3(1.6)	275	PWM	DIP,SO		C,E,M	>80% efficiencies	2.55
MAX736	4 to 8.6	-12	3(1.6)	125	PWM	DIP,SO	Yes	C,E,M	>80% efficiencies	2.95
MAX737	4 to 5.5	-15	4.5(2.5)	100	PWM	DIP,SO	Yes	C,E,M	>80% efficiencies	2.95
MAX739	4 to 15	-5	3(1.6)	500	PWM	DIP,SO	Yes	C,E,M	>80% efficiencies	2.95
MAX741N	2.7 to 15.5	-5,-12,-15, adj.	4.0(2.2)	5W	PWM	DIP,SSOP		C,E,M	PWM inverting controller, high efficiency	3.64
MAX749	2 to 6	Adj.	0.06	5W	PFM	DIP,SO	Yes	C,E,M	Digital adjust for - LCD	2.49
MAX755	2.7 to 9	Adj.	3.5(1.8)	1.4W	PWM	DIP,SO		C,E,M	>80% efficiencies	2.55
MAX759	4 to 15	Adj.	4(2.1)	1.5W	PWM	DIP,SO	Yes	C,E,M	LCD driver, >80% efficiencies	2.95
MAX764/765/766	3 to 16.5	-5/-12/-15 or adj. to 21V∆	0.1	200	PFM	DIP,SO	Yes	C,E,M	High efficiency over wide I_{OUT} range	††
MAX774/775/776	3 to 16.5	-5/-12/-15 or adj. to 21V∆	0.1	1A	PFM	DIP,SO	Yes	C,E,M	Controllers, high efficiency over wide I_{OUT} range	††

*   Package Options: DIP = Dual-In-Line Package, SO = Small Outline, SSOP = Shrink Small-Outline Package, TO-__ = Can
** Temperature Ranges: C = 0°C to +70°C, E = -40°C to +85°C, M = -55°C to +125°C
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Part Number	Input Voltage Range (V)	Output Voltage (V)	Dropout Voltage (V)	Quiescent Current (μA), max(typ)	Output Voltage Accuracy (%)	Shutdown	Package Options*	Temp. Ranges**	Price† 1000-up ($)
AC-DC REGULATORS									
MAX610	120/240VAC	Fixed 5 or adj.(1.3 to 9)	N/A	150(70)	±4	No	DIP	C	1.30
MAX611	120/240VAC	Fixed 5	N/A	150(70)	±4	No	DIP	C	1.30
MAX612	120/240VAC	Fixed 5 or adj.(1.3 to 15)	N/A	150(70)	±4	No	DIP	C	1.30
DC LINEAR REGULATORS–POSITIVE OUTPUT									
MAX663	2 to 16.5	Fixed 5 or adj.(1.3 to 15)	0.9 at 40mA	12(6)	±5	Yes	DIP,SO	C,E,M	1.91
MAX666	2 to 16.5	Fixed 5 or adj.(1.3 to 15)	0.9 at 40mA	12(6)	±5	Yes	DIP,SO	C,E,M	2.22
MAX667	3.5 to 16.5	Fixed 5 or adj.(1.3 to 15)	0.15 at 200mA	25(20)	±4	Yes	DIP,SO	C,E,M	2.35
MAX682-685	2.7 to 12	Adj./5/3.3/3	0.1 at 200mA	15(5)	±4	Yes	DIP,SO	C,E,M	††
ICL7663	1.5 to 16	Adj.(1.3 to 15)	0.9 at 40mA	10(3.5)	±8	Yes	DIP,SO,TO-99	C,E,I,M	1.81
ICL7663A	2.0 to 16	Adj.(1.3 to 15)	0.9 at 40mA	10(3.5)	±1	Yes	DIP,SO,TO-99	C,E,I,M	1.99
ICL7663B	1.5 to 16	Adj.(1.3 to 15)	0.9 at 40mA	10(3.5)	±8	Yes	DIP,SO,TO-99	C,E,I,M	1.81
DC LINEAR REGULATORS–NEGATIVE OUTPUT									
MAX664	-2 to -16.5	Fixed -5 or -1.3 to -15	0.35 at 40mA	12(6)	±5	Yes	DIP,SO	C,E,M	2.33
ICL7664	-2 to -16	-1.3 to -15	0.4 at 30mA	10(3.5)	±8	Yes	DIP,SO,TO-99	C,I,M	1.27
ICL7664A	-2 to -16	-1.3 to -15	0.4 at 30mA	10(3.5)	±1	Yes	DIP,SO,TO-99	C,I,M	1.56

*   Package Options: DIP = Dual-In-Line Package, SO = Small Outline, TO-__= Can
** Temperature Ranges: C = 0°C to +70°C, I = -25°C to +85°C, E = -40°C to +85°C, M = -55°C to +125°C
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Display Power Supplies

Part Number	Input Voltage Range (V)	DC-DC Output Voltages (V)	Quiscent Supply Current (μA typ)	EV Kit	Package Options*	Features	Price† 1000-up ($)
MAX749	2 to 6	Negative LCD	60	Yes	DIP/SO	Digital LCD adjustment	2.49
MAX753	6 to 24	CCFT drive, configurable; Negative LCD, configurable	100		DIP/SO	Digital CCFT and LCD adjustment	4.45
MAX754	6 to 24	CCFT drive, configurable; Positive LCD, configurable	100		DIP/SO	Digital CCFT and LCD adjustment	4.45
MAX759	4 to 15	Negative LCD, adjustable	1.2mA	Yes	DIP/SO	Internal MOSFET	2.95

PCMCIA / Flash Memory Supplies

Part Number	Input Voltage Range (V)	12V Output Current (mA)	EV Kit	Package Options*	Features	Price† 1000-up ($)
MAX662	4.5 to 5.5	30	Yes	DIP/SO	No inductors, low cost	2.09
MAX717-721	0.9 to 5.5 (battery), 7 to 18 (plug-in adapter)	120	Yes	SO	Built-in switchover from main battery to plug-in adapter power, low-voltage warning, AC detect, clock & RAM keep-alive mini-switcher from backup battery	4.95
MAX732	4.0 to 9.3	200	Yes	DIP/SO	4% output tolerance	2.66
MAX734	1.9 to 11	120	Yes	DIP/SO	Small 8-pin package, adjustable soft-start	2.23
MAX761	2 to 16.5	120	Yes	DIP/SO	12V flash programmer, high efficiency over wide I_{OUT} range	††
MAX780	3.3/5/12	Two V_{PP} outputs, 60mA each		DIP/SO	Industry-standard interface, V_{PP} outputs, V_{CC} control	2.25
MAX1732	4 to 6	120		DIP	Module, no external-components	18.29

Battery Chargers

Part Number	No. of Cells Charged	Fast-Charge	Trickle-Charge Rates	Charge Termination Method	EV Kit	Package Options*	Temp. Ranges**	Features	Price† 1000-up ($)
MAX712	1 to 16 NiMH	C/3 to 4C	C/16, adj.	$\Delta V/\Delta t=0$, Temp., Timer	Yes	DIP,SO	C,E,M	Inexpensive, few external components, uses switch-mode regulator or linear regulator to control current, supply load while charging	3.09
MAX713	1 to 16 NiMH or NiCd	C/3 to 4C	C/16, adj.	$\Delta V/\Delta t<0$, Temp., Timer	Yes	DIP,SO	C,E,M	Inexpensive, few external components, uses switch-mode regulator or linear regulator to control current, supply load while charging	3.09

* Package Options: DIP = Dual-In-Line Package, SO = Small Outline
** Temperature Ranges: C = 0°C to +70°C, E = -40°C to +85°C, M = -55°C to +125°C
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Appendix E
Evaluation Kit Ordering Table

Part Number	EV Kit	Package Type	Order Free Sample*	EV Kit Price† ($)
A/D CONVERTERS				
MAX120	MAX120EVKIT-DIP	DIP		82.00
MAX121	MAX121EVKIT-DIP	DIP		85.00
MAX122	MAX120EVKIT-DIP	DIP	MAX122BCNG	82.00
MAX132	MAX132EVKIT-DIP	DIP		95.00
MAX134	MAX134EVBRD-DIP	DIP		125.00
MAX152	MAX152EVKIT-DIP	DIP		65.00
MAX153	MAX152EVKIT-DIP	DIP	MAX153CPP	65.00
MAX155	MAX155EVKIT-DIP	DIP		95.00
MAX176	MAX176EVKIT-DIP	DIP		82.00
MAX180	MAX180EVKIT-DIP	DIP		95.00
MAX186	MAX186EVKIT-DIP	DIP		55.00
	MAX186EVSYS-DIP	DIP		150.00
MAX187	MAX187EVKIT-DIP	DIP		††
MAX188	MAX186EVKIT-DIP	DIP	MAX188DCPP	55.00
	MAX186EVSYS-DIP	DIP	MAX188DCPP	150.00
MAX189	MAX187EVKIT-DIP	DIP	MAX187BCPA	††
MAX190	MAX190EVKIT-DIP	DIP		95.00
MAX191	MAX191EVKIT-DIP	DIP		95.00
MAX195	MAX195EVKIT-DIP	DIP		††
ANALOG FILTERS				
MAX274	MAX274EVKIT-DIP	DIP		20.00
MAX275	MAX274EVKIT-DIP	DIP	MAX275BCPP	20.00
POWER SUPPLIES				
MAX619	MAX619EVKIT-SO	SO		††
MAX639	MAX639EVKIT-DIP	DIP		20.00
	MAX639EVKIT-SO	SO		20.00
MAX640	MAX639EVKIT-DIP	DIP	MAX640CPA	20.00
	MAX639EVKIT-SO	SO	MAX640CSA	20.00
MAX649	MAX649EVKIT-SO	SO		††
MAX651	MAX649EVKIT-SO	SO	MAX651CSA	††
MAX652	MAX649EVKIT-SO	SO	MAX652CSA	††
MAX653	MAX639EVKIT-DIP	DIP	MAX653CPA	20.00
	MAX639EVKIT-SO	SO	MAX653CSA	20.00
MAX654	MAX655EVKIT-DIP	DIP	MAX654CPD	20.00
MAX655	MAX655EVKIT-DIP	DIP		20.00
MAX657	MAX655EVKIT-DIP	DIP	MAX657CPD	20.00
MAX662	MAX662EVKIT-SO	SO		20.00
MAX712	MAX712EVKIT-DIP	DIP		40.00
MAX713	MAX712EVKIT-DIP	DIP	MAX713CPE	40.00
MAX716	MAX716EVKIT-SO	SO		50.00
MAX717	MAX718EVKIT-SO	SO	MAX717CSE	30.00

*Some kits are used to evaluate more than one device. In this case, order the closest-fitting EV kit and a free sample of the device you wish to evaluate.
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Evaluation Kit Ordering Table (continued)

Part Number	EV Kit	Package Type	Order Free Sample*	EV Kit Price† ($)
MAX718	MAX718EVKIT-SO	SO		30.00
MAX719	MAX718EVKIT-SO	SO	MAX719CSE	30.00
MAX722	MAX722EVKIT-SO	SO		30.00
MAX723	MAX722EVKIT-SO	SO	MAX723CSE	30.00
MAX730	MAX738EVKIT-DIP	DIP	MAX730CPA	20.00
	MAX738EVKIT-SO	SO	MAX730CSA	20.00
MAX731	MAX731EVKIT-DIP	DIP		20.00
MAX732	MAX752EVKIT-DIP	DIP	MAX732CPA	20.00
	MAX732EVKIT-SO	SO		20.00
MAX733	MAX752EVKIT-DIP	DIP	MAX733CPA	20.00
MAX734	MAX734EVKIT-SO	SO		20.00
MAX736	MAX739EVKIT-DIP	DIP	MAX736CPD	20.00
MAX737	MAX739EVKIT-DIP	DIP	MAX737CPD	20.00
MAX738	MAX738EVKIT-DIP	DIP		20.00
	MAX738EVKIT-SO	SO		20.00
MAX739	MAX739EVKIT-DIP	DIP		20.00
MAX741D	MAX741DEVKIT-SO	SSOP		50.00
MAX741U	MAX741UEVKIT-SO	SSOP		50.00
MAX743	MAX743EVKIT-DIP	DIP		20.00
MAX746	MAX746EVKIT-SO	SO		††
MAX747	MAX747EVKIT-SO	SO		††
MAX748	MAX738EVKIT-DIP	DIP	MAX748CPA	20.00
	MAX738EVKIT-SO	SO	MAX748CWE	20.00
MAX749	MAX749EVKIT-SO	SO		††
MAX750	MAX758EVKIT-DIP	DIP	MAX750CPA	20.00
	MAX758EVKIT-SO	SO	MAX750CSA	20.00
MAX751	MAX731EVKIT-DIP	DIP	MAX751CPA	20.00
MAX752	MAX752EVKIT-DIP	DIP		20.00
MAX756	MAX756EVKIT-SO	SO		††
MAX757	MAX756EVKIT-SO	SO	MAX757CSA	††
MAX758	MAX758EVKIT-DIP	DIP		20.00
	MAX758EVKIT-SO	SO		20.00
MAX759	MAX759LCDKIT-SO	SO		30.00
	MAX739EVKIT-DIP	DIP	MAX759CPD	20.00
MAX763	MAX738EVKIT-DIP	DIP	MAX763CPA	20.00
	MAX738EVKIT-SO	SO	MAX763CSA	20.00
MAX777	MAX777EVKIT-SO	SO		††
MAX778	MAX777EVKIT-SO	SO	MAX778CSA	††
MAX779	MAX777EVKIT-SO	SO	MAX779CSA	††
MAX781	MAX781EVKIT-SO	SO		††
MAX782	MAX782EVKIT-SO	SO		††

* Some kits are used to evaluate more than one device. In this case, order the closest-fitting EV kit and a free sample of the device you wish to evaluate.
† Prices provided are for design guidance and are FOB USA. International prices will differ due to local duties, taxes, and exchange rates.
††Future product - contact factory for pricing and availability.

MAXIM

Appendix F
New Releases

2-Cell (1.8V) to 5V Step-Ups Maximize Battery Life

DC-DC Converters Have 88% Efficiency, 150μA I_Q, and 20μA Shutdown

The MAX756 and MAX757 step-up DC-DC converters extend battery life with the world's best combination of high efficiency and low quiescent current. Efficiency is 85% to 88% when delivering 5V from a 2.5V input. And that's for loads from 10mA to 300mA—a 30:1 ratio. For the same conditions, quiescent current is just 150μA when operating, and only 20μA when in logic-controlled shutdown. The internal power MOSFET switches at up to 500kHz, allowing use of a small 22μH inductor. In addition, they are guaranteed to start up with inputs as low as 1.8V (2 battery cells), and operate with inputs from 1.1V to V_{OUT}.

3.3V & 5V STEP-UP CONVERTERS PROVIDE LONGER BATTERY LIFE

Low-voltage step-up converters save battery life with high efficiency and low quiescent current.

The MAX756 has a pin-selectable 3.3V or 5V output. The MAX757 has an adjustable 2.7V to 5.5V output. Both come in 8-pin DIP and SO packages. A complete surface-mount evaluation kit is available.

Fast-Charge NiCd & NiMH Batteries in Under 1 Hour

Safe and Reliable Solution Needs Only Low-Cost Components

4A SWITCH-MODE APPLICATION USES FEWEST COMPONENTS
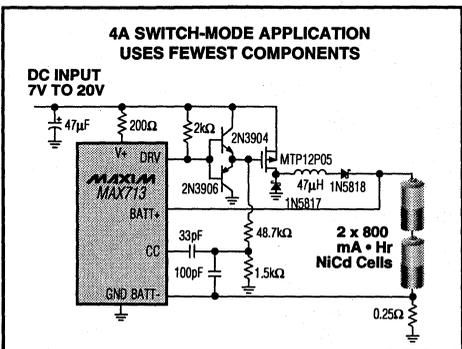
This switch-mode current-regulation scheme uses the minimum number of external components, all of which are low cost and easily obtainable.

The MAX712 and MAX713 are complete battery charging systems in a single IC. Each contains an A/D converter, analog power-control circuitry, and all the intelligence necessary to safely and reliably fast-charge and trickle-charge nickel-cadmium (NiCd) or nickel-metal-hydride (NiMH) batteries. Automatic switchover from fast-charge to trickle-charge protects batteries; so do user-set charge rates, temperature detection points, and timeout periods. Both come in 16-pin narrow SOIC and DIP packages.

The MAX712 and MAX713 charge from 1 to 16 cells connected in series. They use a combination of voltage-slope, temperature, and timeout detection to terminate charging. The MAX712 detects zero voltage-slope; the MAX713 detects negative voltage-slope. They can fast-charge at rates of 4C to C/3, (20 minutes to 4 hours) or trickle-charge at a C/16 rate. Through-hole evaluation kits are available.

The MAX712/MAX713 can be configured using either a linear regulator or a switch-mode regulator to control the charging current. Each application is designed to use low-cost components. For example, the linear application needs only a PNP transistor, diode, and low-cost passives.

Dual-Output, 3.3V and 5V Notebook Power Supplies Provide Up to 50W with >90% Efficiency

80% to 95% Efficiency for Loads from 5mA to Full-Load

The MAX782, MAX783, and MAX786 controller ICs incorporate a 3.3V supply, a 5V supply, and two precision comparators for voltage monitoring—all in a single shrink small-outline package (SSOP). The MAX782/MAX783 also include dual PCMCIA analog-control outputs and a third comparator. All devices accept inputs from NiCd or NiMH battery stacks of 6 to 14 cells (5.5V to 30V).

The MAX782/MAX783/MAX786 use synchronous rectification with low-cost, N-channel MOSFET switches to achieve 90% efficiency over a wide range of loads. Even at 5mA, efficiency is 80%. Only 70μA quiescent current is needed in standby mode, extending battery life in both suspend and run modes. Each output is configurable for loads from 5W to 50W, and each can be shut down independently.

Fixed-frequency PWM control allows easy filtering for wireless systems and helps prevent interference in pen-based computers. Filtering requires only 30μF of output capacitance per ampere of load—far less than that required by conventional PWM controllers.

The MAX782/MAX783 support dual PCMCIA slots with integral VPP outputs and three high-side drivers for V$_{CC}$ control. VPP control is compatible with industry-standard digital PCMCIA controllers. VPP outputs are programmable to 12V, 5V, 0V, or high-Z. The MAX783 is optimized for six-cell operation. The MAX786 is configured for applications that do not require PCMCIA compatibility. Complete, surface-mount evaluation kits are available for the MAX782 and MAX786.
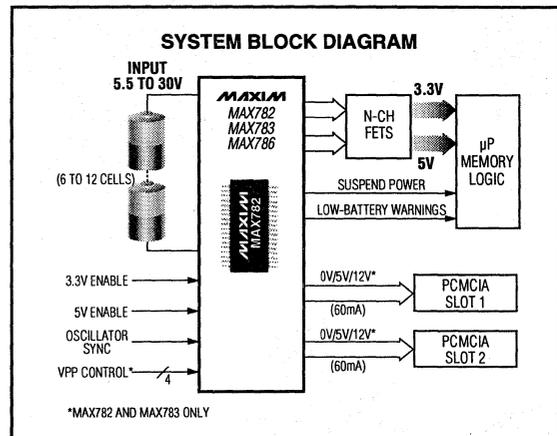

The MAX782/MAX783/MAX786 deliver 3.3V and 5V outputs, power dual PCMCIA card slots, and operate from 5.5V to 30V inputs.

3.3V- or 5V-Output Step-Downs Are 91% Efficient for Load Currents Ranging from 1mA to 225mA

Compact Switcher Draws Only 10μA Quiescent Current

The MAX639/MAX640/MAX653 switching regulators extend battery life by providing ultra high-efficiency step-down regulation, especially in applications with dynamic load-current requirements. Efficiency with 5V outputs is greater than 90% for output currents from 1mA to 225mA—a dynamic range exceeding two orders of magnitude! The regulators' unique "constant peak current" design draws only 10μA of quiescent current and allows the use of external components that are smaller than those in typical switch-mode converters.

These step-down converters save space, requiring only four external components and fitting in $0.5in^2$. The MAX639 has a preset 5V ±4% output. The MAX640 and MAX653 have preset 3.3V and 3.0V outputs, respectively. Maximum input voltage is 11.5V. Complete surface-mount or through-hole evaluation kits are available.
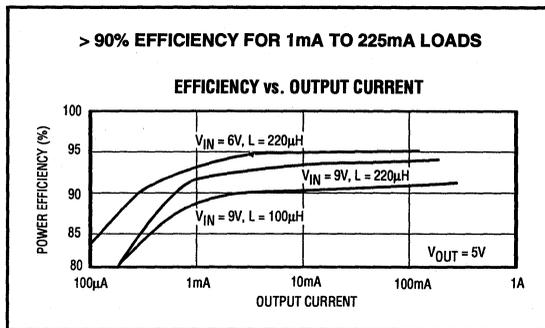
The MAX639 exhibits > 90% efficiency over loads that vary by two orders of magnitude. Outputs can also be adjusted from 1.3V to V_{IN}.

3.3V DC-DC Converters Deliver 2.5A with 85% to 95% Efficiency

Build a Complete 2.5A Converter in < $0.9in^2$

The MAX746 and MAX747 are fixed-frequency PWM controllers for low-noise step-down applications requiring up to 2.5A of output current. They have 85% to 95% efficiency over a wide load range (50mA to 2.5A), thanks to a dual-mode control scheme that minimizes switching losses by reducing switching frequency at light loads. The devices maximize battery life whether your system is running at full power or is in standby mode. Quiescent supply current is 1mA, or only 20μA in shutdown (both max over temperature). The controllers include a precision low-battery detector, soft-start, and cycle-by-cycle current limiting.

The MAX746 is configured to drive an external, N-channel power MOSFET on the high side, whereas the MAX747 is configured to drive P-channel power MOSFETs. The MAX746 comes in 16-pin DIP and narrow SO packages; the MAX747 comes in 14-pin DIP and narrow SO packages. And to save valuable time, a surface-mount evaluation kit is available.
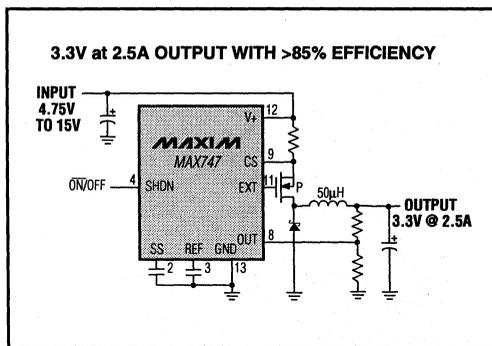
Save battery life and board space with the MAX746/MAX747. They fit into < $0.9in^2$ and have 85% to 95% efficiency.

Step-Down Switching Regulators Have 5A or 2A Internal Switch

Save Space: Few External Components Needed

The MAX724 and MAX787/MAX788/MAX789 5A, switch-mode, step-down DC-DC regulators feature a wide 8V to 40V input range (to 60V for the high-voltage "H" versions). The MAX726-MAX729 output 2A. All of these devices require few external components, since the power switch, oscillator, and control circuitry are on chip.

Though optimized for step-down applications, these versatile regulators can also be configured as inverters, negative boost converters, or flyback converters, with input voltages as low as 5V. Fixed outputs are 5V (MAX727/MAX787), 3.3V (MAX728/MAX788), and 3V (MAX729/MAX789); the MAX724 and MAX726 are adjustable from 2.5V to 40V (to 60V for the "H" version). All devices have a preset 100kHz internal oscillator, which can also be adjusted to 200kHz in the MAX724 and MAX726. Cycle-by-cycle current limiting protects against overcurrent faults and short-circuit output faults. Quiescent current is 8.5mA.

These easy-to-use pulse-width-modulating (PWM) switching regulators are available in 5-pin TO-220, 7-pin TO-220, and 4-pin TO-3 packages.
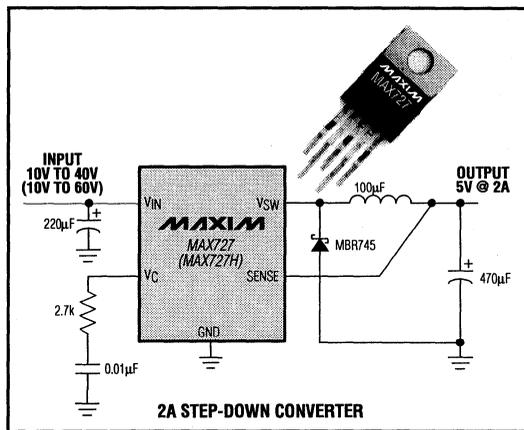
The MAX727 outputs 2A at a fixed 5V output, while requiring only 6 external components.

Step Down to 5V or 3.3V Outputs with 90% Efficiency & Low Noise

Small PWM DC-DCs Deliver Guaranteed 750mA, Require No Design
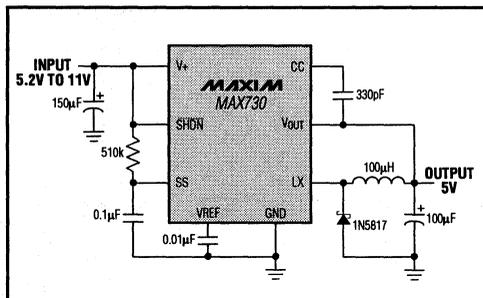
This MAX730 step-down circuit can deliver up to 1A at 5V and fits in 0.5in².

The MAX730/MAX738 fixed 5V-output, MAX763A/MAX748A fixed 3.3V-output, and MAX750/MAX758 adjustable-output (from 1.25V up to V_{IN}) step-down converters extend battery life and save space in portable applications. They provide high-efficiency (85% to 95%) step-down regulation and fit into less than $0.5in^2$ of board space. Quiescent current is 1.7mA in normal operation and 6μA in logic-controlled shutdown. Preselected component values (including only one 100μH inductor value for all applications) and evaluation kits greatly simplify design work and component gathering.

The MAX730, MAX763A, and MAX750 are guaranteed over temperature to deliver 300mA at 3.3V or 5V for inputs up to 11V. The MAX738, MAX748A, and MAX758 deliver 750mA at 3.3V or 5V, guaranteed for inputs up to 16V. All devices are capable of supplying up to 1A. The output of the MAX750 and the MAX758 is set using a resistor divider.

High-frequency 160kHz pulse-width-modulation (PWM) current-mode control provides easy-to-filter, fixed-frequency output ripple, allowing use in cellular phone applications.

Dual-Output Palmtop Power Supplies Step Up from 1.8V Batteries

Power μP and Program Flash Memories with 87% Efficiency

The MAX717-MAX721 dual-output switching regulators provide an unbeatable combination of high efficiency (87%), low supply current (60μA quiescent, 20μA in shutdown), and small size (16-pin narrow SO package). They fit perfectly in palmtop and other battery-powered microprocessor applications, and start up from inputs as low as 1.8V, guaranteed over temp. And they continue to operate for inputs down to 0.9V. Integrated features include low output voltage warning, automatic switchover between battery power and wall-adapter power, logic-signaling when wall adapter is in use, and a mini backup switcher powered by the backup battery to keep alive memory and clock. Outputs are logic controlled. An evaluation kit for the MAX718 is available.

DUAL-OUTPUT REGULATOR
POWERS μP & PROGRAMS FLASH MEMORY

The MAX718 generates both 3.3V/5V AND 5V/12V outputs from battery inputs down to 0.9V, and it starts up from inputs as low as 1.8V, guaranteed.

| Part	Main Output (V)	Aux. Output	Wall-Adapter Detect Signal	Backup Keep-Alive Switcher	Total Shut-down
MAX717	3.3	FLASH	YES	YES	NO
MAX718	3.3 or 5	FLASH	NO	YES	NO
MAX719	3.0 or 5	FLASH	NO	YES	NO
MAX720	3.3 or 5	FLASH	YES	NO	YES
MAX721	3.0 or 5	FLASH	YES	NO	YES

Single IC Powers μP and Negative-Voltage LCD from 1.8V

The MAX722 and MAX723 feature the same small size, high efficiency, and low supply current as the MAX717-MAX721. They step up from 1.8V batteries to power 3V and 5V microprocessors, and also invert down to -40V for LCDs. Their high switching frequency (up to 500kHz) allows the use of tiny surface-mount magnetics (22μH, <5mm diameter). Supply current is a low 60μA due to CMOS construction and a unique constant-off-time pulse-frequency-modulation (PFM) control scheme. Efficiency is 87% (10% better than low-voltage bipolar regulators). An evaluation kit is available for the MAX722.

DUAL-OUTPUT REGULATOR
POWERS μP & NEGATIVE LCD

MAX722 and MAX723 integrated features include low-voltage warning and automatic switching between battery power and wall-adapter power.

Part	Main Output (V)	Aux. Output	Wall-Adapter Detect Signal	Backup Keep-Alive Switcher	Total Shut-down
MAX722	3.3 or 5	LCD	NO	NO	YES
MAX723	3.0 or 5	LCD	NO	NO	YES

Program 12V Flash Memories Without Inductors!

World's Lowest Cost and Smallest Solution Fits in Only 0.2in^2

FLASH MEMORY PROGRAMMER

INPUT 4.75 TO 5.25V

0.1μF

4.7μF

4.7μF

OUTPUT 12V 30mA

ON/OFF ►

0.22μF

0.22μF

MAXIM
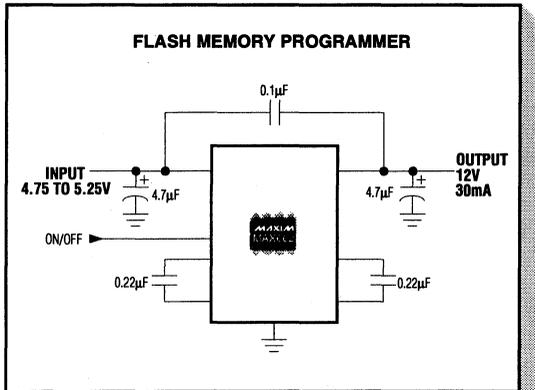
This entire MAX662 circuit, including external components, cost less than $2.10 (10,000 pc. pricing) and fits in less than 0.2in^2.

The MAX662 is the world's first charge-pump flash memory programming supply. It uses only low-cost capacitors to provide a regulated 12V ±5% output. Output current is guaranteed to be 30mA over the commercial temperature range (0°C to +70°C) for inputs from 4.75V to 5.5V.

While operating, quiescent supply current is 320μA. In shutdown mode, the output drops to 5V and the quiescent current drops to 70μA. Programming control is directly enabled via the logic-controlled shutdown pin.

This compact and low-cost solution requires only a handful of capacitors that total about 35¢ and, along with the MAX662, fit into about 0.2in^2 of board space. The MAX662 evaluation kit is available to speed design cycles.

Guaranteed 120mA, 12V-Output Flash Memory Supply Fits in 0.3in^2

8-Pin SOIC is 88% Efficient, Steps Up from 4.75V

The MAX734 delivers 120mA at 12V ±5%, guaranteed over temperature, from inputs as low as 4.75V. It saves space and battery life in palmtop and notebook computers and other systems using flash memory.

Also, the MAX734 can be configured in a bootstrapped application that delivers 12V at 120mA from inputs down to 1.9V. Typical efficiency for that application is 80%.

Available in 8-pin SO and DIP packages, it uses only a diode, an 18μH inductor, and two 33μF capacitors. The entire circuit is completely surface-mountable and fits into less than 0.3in^2.

Battery-saving features include 88% efficiency, 1.2mA quiescent supply current, 70μA shutdown supply current, and controllable soft-start to reduce surge currents at start-up. Shutdown and programming control can be easily and directly interfaced with a microprocessor using the logic-controlled shutdown pin.

FLASH MEMORY PROGRAMMER GUARANTEES 12V AT 120mA OUTPUT

INPUT 4.75V TO 12V

33μF

18μH

OUTPUT 12V ±5% 120mA

SHDN

V+

V$_{PP}$

Vpp PROGRAMMING CONTROL (DIRECT FROM MICROPROCESSOR)

LX

1N5817

FLASH MEMORY

MAXIM MAX734

V$_{OUT}$

CC

0.001μF

33μF

GND

The MAX734 is an 8-pin SO that steps up from a 4.75V input to a 12V output at 120mA and fits into < 0.3 in^2.

The MAX734 is an 8-pin SO version of the popular MAX732 flash memory programming supply. The MAX732 comes in a 16-pin wide SO package and delivers a guaranteed 150mA from a 4.5V input. Evaluation kits for both the MAX734 and the MAX732 are available.

Palmtop, Cell Phone, Disk Drive Power Supply Starts Up from 1.8V

Surface-Mount IC Draws Only 1.6mA, Delivers 5V at 1A

The MAX741U's unique pairing of low start-up voltage (as low as 1.8V) and low 1.6mA quiescent current (50μA in shutdown) makes it the best choice for battery-operated and portable power-supply designs that require high currents from low input voltages. Efficiency is typically above 85%. Its pulse-width-modulated (PWM) control scheme keeps output ripple at an easy-to-filter fixed frequency, making the MAX741U particularly well suited for cellular phone and radio designs. Other applications include stepping up to 5V at 1A to power disk drives in 3V-only systems, and delivering 5V at 500mA from 3V battery inputs in palmtop computers.

The device integrates many useful pin-programmable features, such as an external oscillator sync pin, which allows the output ripple frequency to be adjusted outside the transmission band for cellular phone applications. Other features include preset 5V, 12V, 15V, or adjustable ±4% outputs.

The MAX741U evaluation kit demonstrates a typical 2.7V input/5V at 1A output step-up application and shows off the tiny 20-pin SSOP package.
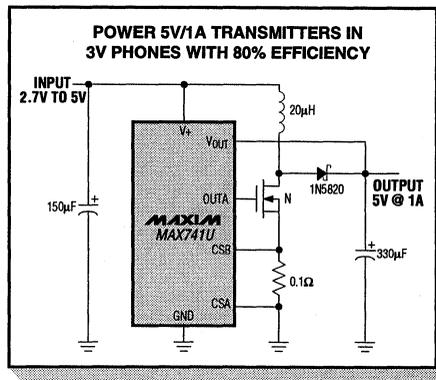
The MAX741U steps up to 5V at 1A from inputs as low as 2.7V. It features 1.6mA quiescent current and a tiny 20-pin SSOP package. (This simplified drawing shows only major components.)

Linear Regulator Powers 200mA Load with 150mV Dropout & 5mA Supply Current

Best Combination of Low Supply Current and Low Dropout

The MAX667 low-dropout linear regulator offers an unbeatable combination of low dropout voltage and low quiescent current for prolonging useful battery life in portable applications. In addition, it also has 0.2μA shutdown supply current for saving the battery when the system is not in use. It delivers 200mA at 5V with an input as low as 5.15V—a useful capability in 5V systems powered by 5-cell NiCd or 3-cell lead-acid batteries. Short-circuit protection prevents output currents greater than 450mA.

In normal mode, the MAX667's no-load supply current is 20μA. For 200mA loads, the device consumes just 5mA. The output is preset to 5V ±4%, guaranteed over temperature, but it can be adjusted from 1.3V to 16V with two resistors. The MAX667 requires only a 10μF output capacitor. The regulator features an on-chip low-battery input/output comparator and a "dropout" indicator that signals when the PNP pass transistor is about to saturate.

The MAX667 outperforms typical bipolar linear regulators with its unique combination of low supply current and low input/output voltage differential.

Flash Programming & DC-DC Converter Modules Use 6x Less Space than Comparable Modules

No External Components or Design Work Needed

The MAX1732 flash memory programming supply and MAX1738 step-down DC-DC converter fit in miniature 14-pin DIP modules measuring just 0.27" long x 0.77" wide x 0.29" high (6.86mm x 19.57mm x 7.37mm), using only 0.25in^2 (1.6cm^2) of board space. No external components or design work are required, since all components are contained in a single module.

The MAX1732 programs 12V, 120mA flash memories: 120mA output current and ±4% output voltage regulation are guaranteed over temperature for inputs from 4.5V to 6V. The MAX1738 performs 5V, 500mA step-down conversions, and accuracy is guaranteed over all specified conditions of line, load, and temperature. Typical efficiencies exceed 85% (MAX1732) or 86% (MAX1738). No-load supply current is 1.7mA for both devices, and reduces to just 70µA (MAX1732) or 60µA (MAX1738) in logic-controlled shutdown mode.

The MAX1743 is a complete DC-DC module that converts a +5V input to a dual ±12V or ±15V output: It supplies 125mA at ±12V, or 100mA at ±15V. Positive and negative outputs are independently regulated to within ±4% over all specified conditions of line, load, and temperature. This 24-pin DIP module measures 0.57" long x 1.27" wide x 0.345" high. Typical efficiencies are 82%. On-board cycle-by-cycle current sensing, soft-start, and undervoltage lockout ensure reliable operation.

STEP DOWN TO +5V

MAXIM
MAX1738

14-Pin DIP Only 0.29" High
0.27" x 0.77" x 0.29"
(6.86mm x 19.57mm x 7.37mm)
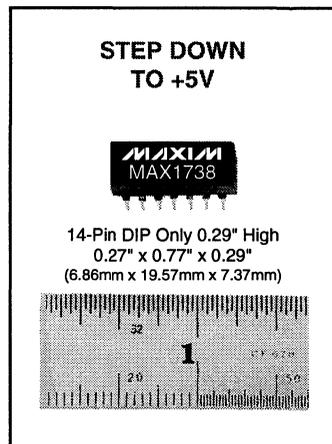
Appendix G
Future Products

100mA Step-Up Converters Have 85% Efficiency, 150μA I_Q, and 20μA Shutdown

The MAX856 and MAX857 step-up DC-DC converters feature low quiescent currents and high efficiencies. From 2V inputs, the MAX856 delivers 100mA at 5V or 150mA at 3.3V. The output voltage is pin-selectable. The MAX857 has an adjustable output from 2.7V to 5.5V. The MAX856/MAX857 are designed for applications requiring small size and long battery life. These pulse-skipping converters have a 400mA switch current limit, which permits the use of very inexpensive and extremely small surface-mount inductors. Minimum start-up voltage is guaranteed to be 1.8V, and the devices will remain operating with inputs down to 1.1V. Both devices are available in 8-pin DIP and SO packages. A complete, surface-mount evaluation kit is available. (Release Date: September 1993)

Step-Up, Step-Down & Inverting Battery-Powered DC-DC Converters Have High Efficiency, Low I_Q, 8-Pins

Maxim's new family of step-up, step-down, and inverting DC-DC converters lengthen battery life. These compact and easy-to-use converters feature quiescent currents under 100μA, shutdown currents under 5μA, and efficiencies of 80% to 95%. Efficiency stays constant, even over loads ranging from 1mA to 1A, thanks to a unique current-limited pulse-skipping control scheme. Minimal component count and 300kHz switching frequencies keep external circuitry small, saving space. All devices are available with internal power switches or as controllers using external power switches. Outputs are preset or adjustable. Preassembled surface-mount evaluation kits and free samples will be available to speed designs. Refer to the product tables at the end of the Design Guide for specific information. (Release Date: October 1993)

MAX639*/MAX640/MAX653	5V/3.3V/3V, Step-Down DC-DC Converters
MAX649/MAX651/MAX652	5V/3.3V/3V, Step-Down DC-DC Controllers (P-Channel External Switch)
MAX756/MAX757	3.3V or 5V/Adjustable, Step-Up DC-DC Converters
MAX761/MAX762	12V/15V, Step-Up DC-DC Converters
MAX770-MAX773	5V/12V/15V/Adjustable, Step-Up DC-DC Controllers (N-Channel External Switch)
MAX764/MAX765/MAX766	-5V/-12V/-15V, Inverting DC-DC Converters
MAX774/MAX775/MAX776	-5V/-12V/-15V, Inverting DC-DC Controllers (P-Channel External Switch)

* Available now

1V-Input DC-DC Converters
Step Up to 5V or 3.3V at 100mA

The new MAX777, MAX778, and MAX779 DC-DC converters step up 1V to 6V inputs to outputs of 3V, 3.3V, or 5V (or are adjustable from 2.7V to 6V). They require only two external components (a 100µF output capacitor and a 22µH inductor) to deliver over 100mA from 1V inputs. From 2V inputs, they deliver up to 240mA, guaranteed over temp. An on-chip synchronous rectifier takes the place of the external catch diode, and permits true shutdown by placing a high resistance in the DC path from the input to the output.

Battery life is lengthened due to 85% typical efficiencies and a 310µA (max over temp.) quiescent supply current, which is further reduced to 30µA in shutdown. A complete, preassembled surface-mount evaluation kit is available. (Release Date: September 1993)

DC-DC Converter Gives Constant
3.3V or 5V Output from 1V to 6V
Input, without a Transformer

The new MAX877, MAX878, and MAX879 step-up/step-down DC-DC converters provide a regulated output from input voltages above, below, and equal to the output. They come in 8-pin DIP and SO packages, and require only an input capacitor, output capacitor, and 22µH inductor. They have a 1V to 6V input range and deliver up to 300mA. An on-chip synchronous rectifier takes the place of the external catch diode, and permits true shutdown by placing a high resistance in the DC path from the input to the output.

Battery life is lengthened due to 85% typical efficiencies and a 310µA (max over temp.) quiescent supply current, which is further reduced to 30µA in shutdown. Typical applications include 3.3V or 3V outputs from one lithium battery or two or three NiCd batteries, and delivering 5V from four alkaline cells. The MAX877 has a 5V output, the MAX878 has a pin-selectable 3V or 3.3V output, and the MAX879 has an adjustable 2.7V to 6V output. An evaluation kit is available. (Release Date: October 1993)

200mA Linear Regulators Have Ultra-Low 5μA Quiescent Current and Low, 100mV Dropout Voltage at 200mA Outputs

The new MAX682-MAX685 family of linear regulators features a P-channel MOSFET pass transistor, which reduces quiescent supply currents to just 5μA. And, because there are no base currents like those found in conventional PNP bipolar linear regulators, the supply current stays low, independent of output current. In shutdown, the supply current drops even more—to less than 1μA (max over temp.). The low dropout voltage further ensures maximum battery life.

The input supply range is 2.7V to 12V. Output accuracies are ±4% over line, load, and temperature. The MAX682 has an adjustable output from 2.7V to V_{IN} and an LBI/LBO low-battery detector. The MAX683, MAX684, and MAX685 have 5V, 3.3V, and 3V outputs, respectively. They have two LBI/LBO low-battery detectors. All devices come in 8-pin DIP and SO packages, and require only 0.33μF of output capacitance. (Release Date: September 1993)

Charge Pump Delivers 5V from 2V – Needs No Inductors

The new MAX619 charge-pump voltage converter delivers 15mA (guaranteed over temp.) at 5V from one lithium battery cell or two NiCd or alkaline battery cells (2V to 3.6V), without using inductors. It comes in 8-pin DIP and SO packages, and uses only two inexpensive 0.22μF capacitors and a 10μF output capacitor. The device fits in less than 0.33in^2 (2.1cm^2), and is ideal for generating 5V logic supplies and analog biases in portable, battery-powered instruments.

Quiescent current is only 150μA (max over temp.) when operating, and less than 10μA in shutdown. The output is regulated to 5V ±4% over line, load, and temperature. (Release Date: January 1994)

Maxim U.S. Sales Representatives

Alabama
M-Squared, Inc.
(205) 830-0498

Arizona
Techni Source, Inc.
(602) 497-0711

California
Mesa
(619) 278-8021
Pro Associates, Inc.
(408) 248-5300
Centaur Corporation
(818) 591-1655
(714) 261-2123

Colorado
Component Sales, Inc.
(303) 779-8060

Connecticut
Comp Rep Associates
(203) 230-8369

Delaware
TAI Corporation
(609) 778-5353

Florida
Sales Engineering Concepts
(305) 426-4601
(407) 830-8444

Georgia
M-Squared, Inc.
(404) 447-6124

Idaho
E.S. Chase
(503) 292-8840

Illinois
Heartland Technical
Marketing, Inc.
(708) 358-6622

Indiana
Technology Marketing Corp.
(317) 844-8462
(219) 432-5553

Iowa
JR Sales Engineering, Inc
(319) 393-2232

Kansas
Delltron
(816) 436-6445

Louisiana
BP Sales
(214) 234-8438

Maryland
Micro-Comp, Inc.
(410) 644-5700

Massachusetts
Comp Rep Associates
(617) 329-3454

Michigan
Micro Tech Sales, Inc.
(313) 459-0200

Minnesota
Mel Foster Technical Sales,
Inc.
(612) 941-9790

Mississippi
M-Squared, Inc.
(205) 830-0498

Missouri
Delltron
(314) 839-0033
(816) 436-6445

Montana
E.S. Chase
(503) 292-8840

Nebraska
Delltron
(816) 436-6445

Nevada
(Reno, Tahoe area only)
Pro Associates
(408) 248-5300

New Hampshire
Comp Rep Associates
(617) 329-3454

New Jersey
Parallax
(516) 351-1000
TAI Corporation
(609) 778-5353

New Mexico
Techni Source, Inc.
(505) 268-4232

New York
Parallax
(516) 351-1000
Reagan/Compar
(607) 754-2171

North Carolina
M-Squared, Inc.
(Corporate office)
(919) 836-1350
(Sales office)
(919) 851-0010

Ohio
Lyons Corporation
(513) 278-0714
(216) 659-9224
(614) 895-1447

Oklahoma
BP Sales
(214) 234-8438

Oregon
E.S. Chase
(503) 292-8840

Pennsylvania
(Pittsburgh area)
Lyons Corporation
(614) 895-1447
(Philadelphia area)
TAI Corporation
(609) 778-5353

South Carolina
M-Squared, Inc.
(919) 851-0010

Tennessee
M-Squared, Inc.
(East TN)
(404) 447-6124
(West TN)
(205) 830-0498

Texas
BP Sales
(214) 234-8438
(713) 782-4144
(512) 346-9186

Utah
Luscombe Engineering Co.
(801) 268-3434

Virginia
Micro-Comp, Inc.
(804) 239-2626

Washington
E.S. Chase
(206) 823-9535

Wisconsin
Heartland Technical
Marketing, Inc.
(414) 789-6860

Maxim International Sales Representatives

Argentina
YEL SRL
(1) 372 7163

Australia
Veltek Pty., Ltd.
(03) 808 7511

Austria
Allmos Electronics
(02) 682 67 561

Belgium
Master Chips
(02) 219 5862

Brazil
Intectra
(415) 967-8818

Canada
Tech-Trek
(604) 276-8735
(416) 238-0366
(613) 599-8787
(514) 337-7540

Canada/Distributor
Arrow
(514) 421-7411
(613) 226-6903
(418) 871-7500
(416) 670-7769
(604) 421-2333
Hamilton Hallmark
(604) 420-4101
(416) 564-6060
(514) 335-1000
(613) 226-1700

China
Components Agent
China, Ltd. (HK)
(852) 420 1125
(Beijing)
1-491 1529
(Shenzhen)
(755) 228 0692

Denmark
Exatec A/S
98633311
31191022

Finland
Yleiselektroniikka Oy
(0) 452 621

France
Maxim France
(1) 30 60 91 60

France/Distributors
Maxim France
(1) 30 60 93 39
ASAP

Germany
Maxim GmbH
(089) 898 13 70

Germany/Distributors
Maxim GmbH
(0130) 82 79 25
Spezial Electronic KG
(057) 22 20 30

Hong Kong
Components Agent, Ltd.
487 8826
Dynax Electronics, Ltd.
481 0223

India
Irys
21253136

Ireland
FMG Electronics
(035) 66 40 02

Israel
Tritech, Ltd.
09-917 277

Italy
Consystem S.r.l.
(02) 99041977-8

Italy/Distributor
Esco Italiana Electronics Supply
(02) 24 09 241
(02) 24 09 251

Japan
Maxim Japan Co., Ltd.
(03) 3232-6141

Japan/Distributors
Easton Co., Ltd.
(03) 3279-1939
Internix, Inc.
(03) 3369-1105
Microtek, Inc.
(03) 3371-4071
Sil-Walker, Inc.
(03) 3341-3651

Korea
Hanaro Corporation
(02) 558 1144

Netherlands
Koning En Hartman
(015) 60 99 06

New Zealand
Power Factor NZ, Ltd.
(9)81 86478

Norway
Odin Electronics A/S
6 387 0300

Poland
Uniprod, Ltd.
(48) 32376459

Singapore/Malaysia
Thailand
Electronic Resources Pte., Ltd.
(Singapore)
283 0888
Electronic Resources Pte., Ltd.
(Thailand)
538 4600
Electronic Resources (M)
SDN BHD (Kuala Lumpur)
703 8498
Electronic Resources (M)
SDN BHD (Penang)
882 895

South Africa
Fairmont Electronics (Pty), Ltd.
(011) 886 2920

Spain
ADM Electronics S.A.
1-5304121

Sweden
Egevo AB
(08) 795 9650

Switzerland
Laser & Electronic Equip.
(01) 422 3330

Taiwan
Solomon Technology Corp.
(02) 760 5858
Maxim Integrated Products
(35) 777659

Turkey
Interex (U.S.A.)
(415) 574-0767

U.K.
Maxim Integrated Products
(U.K.), Ltd.
(0734) 845255

U.K./Distributors
Maxim Integrated Products
(U.K.), Ltd.
(0734) 845255
2001 Electronic Components
(0438) 742001
HB Electronic
(0204) 25544

Maxim U.S. Franchised Distributors

Allied Electronics
(800) 433-5700

Arrow Electronics
(516) 391-1300

Bell Industries
(310) 826-2355

Hamilton Hall-Mark
(214) 343-5000

Digi-Key Corp
(800) 344-4539

Nu Horizons
(516) 226-6000

Maxim Corporate Headquarters

Maxim Integrated Products
120 San Gabriel Drive
Sunnyvale, CA 94086