News Briefs

██████ **MAXIM REPORTS RECORD REVENUES AND EARNINGS FOR THE
4TH QUARTER AND FISCAL YEAR 1997**

Maxim Integrated Products, Inc., (MXIM) reported record net revenues of $117 million for the fourth quarter of fiscal 1997 ending June 30, 1997, compared to $110 million for the same period a year ago. Net income increased to $36.9 million for the current quarter, compared to net income of $34.7 million for the same quarter in fiscal 1996. Income per share increased to $0.50 per share for Q497 from $0.49 per share in Q496. Sequentially, the results for Q497 showed an increase over Q397 net revenues of $111 million, and earnings per share of $0.48.

Maxim ended fiscal 1997 with net revenues of $433.7 million, net income of $137 million, and income per share of $1.88. Stockholders' equity grew to $465.6 million at June 30, 1997. Return on average stockholders' equity for the year was 34.6%. This return, one of the highest in the industry, confirms that the Company continues to make good product and capacity investment decisions with stockholders' assets.

During the quarter, Maxim's cash and short-term investments increased by $21.1 million after repurchasing $34.6 million of common stock and paying $14 million for capital expenditures. Depreciation expense of $4.1 million for Q497 remains one of the lowest in the integrated circuit industry, including analog companies.

During Q497, backlog shippable within the next 12 months increased to $152 million from the $124 million reported at the end of Q397 and the $103 million reported at the end of Q297 and Q197. Approximately 77% of the Q497 backlog consists of orders that were requested for shipment in Q198.

Turns orders received in Q497 were a record $49.1 million. (Turns orders are customer orders that are for delivery within the same quarter and may result in revenue within the quarter if the Company has available inventory that matches those orders.)

Net bookings increased 13% from Q397 levels to a record $156 million. While the Company experienced net bookings growth in all geographic segments, net bookings from direct OEM customers in the United States and Japan were the strongest. Maxim's growth continued in all product areas, particularly those products attractive to the very broad instrumentation, process control, networking, communications and portable equipment markets. The Company also believes that, due to the continuing need for new high-performance, low-cost analog integrated circuits to meet the needs of the tremendous growth in new equipment requiring analog IC solutions, older analog products are continuing to be designed into new equipment. We believe this could be increasing product life times for older IC products.

Gross margins for the fourth quarter increased slightly to 66.4% compared to 66.3% in Q397. Increases in production volume and manufacturing productivity continued in Q497. Research and Development expense increased $1.7 million to 12.7% of net revenues due to the Company's continued investment in new product development.

During Q497, the Company introduced 70 new products, continuing as the number one innovator of new analog products in the world. During fiscal 1997, the Company introduced over 40% more new products than it did in fiscal 1996. Historically, our future revenue growth rate has exceeded our increase in new product introductions over the long term.

Jack Gifford, Chairman, President and Chief Executive Officer, commented on the quarter and the year, "During fiscal 1997 and Q4, worldwide demand for Maxim's products continued to grow. We believe that in many respects, we outperformed our competitors during this period when inventory corrections were occurring. We attribute this to strong management throughout the Company and to the depth, breadth and proprietary nature of Maxim's product line."

Gifford continued, "We are pleased to report that one of our new products was honored by the industry's most influential magazine, *EDN*, as Analog Innovation of the Year. The two Maxim engineers who defined and designed it were also named Innovators of the Year. These awards reinforce what we hear from our customers worldwide: that Maxim inventions are innovative solutions to challenges faced by today's design engineer."

System-level issues in applying battery-charger ICs

The previous issue of Maxim's Engineering Journal (Vol. 27) discussed new developments in stand-alone battery chargers. This second article of a two-part series explores the system-level issues in applying battery-charger ICs.

Over the past five years, market pressures on portable equipment have transformed the simple battery charger into a sophisticated switch-mode device capable of charging an advanced battery in 30 minutes. This development also marks a departure from the self-contained, stand-alone charger ICs of only a few years ago. Some of those ICs included considerable intelligence: enough to handle the complex task of fast charging advanced batteries.

Maxim still manufactures stand-alone charger ICs, but market demand has changed recently. Today's battery-charger subsystems regulate charging voltage and current using the intelligence of an external microcontroller (μC), usually available elsewhere in the system. This approach achieves low cost in high-volume applications and allows the greatest flexibility in tailoring the charger to a specific application.

All necessary intelligence once resided in the battery-charger controller IC itself, but now the system designer must implement a charging algorithm and write the associated firmware. This article provides the information and background necessary to implement charger systems based on Maxim's wide range of battery-charger ICs for all popular chemistries.

The following discussion presents an overview of the requirements for charging common battery chemistries with Maxim battery-charger ICs. It addresses system-level trade-offs and firmware design tips, and lists World Wide Web resources available to designers. The discussion closes with design examples based on two common μCs: the 8051 and the Microchip PIC. Either example can serve as a base for further development of custom charger circuitry.

Overview of battery-charging techniques

Four rechargeable battery chemistries are in practical use today: Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Gelled Lead-Acid (PbSO4), and Lithium-Ion (Li+). The trade-offs to be made among these chemistries are beyond the scope of this article, but the *References* section provides access to such information.

Caution: consult the battery manufacturer for specific recommendations. The information presented here is intended only as an overview of charging requirements for various cell chemistries.

This section describes general charging techniques and limitations for the four common chemistries. For additional details and background, see the Maxim data sheets and other reference material cited at the end of the article.

Fast battery charging has several phases, as explained in the text and by the state diagram for a generic charger (**Figure 1**).

Initialization

Though not a part of the actual charging procedure, initialization is an important stage in the process. The charger initializes itself and performs its own self-test. A charge can be interrupted by a power failure and consequent reinitialization. Without a smart battery or some type of time-stamped, nonvolatile storage, such events can occur unnoticed. Most chargers reinitialize themselves fully after a power failure. If overcharging is an
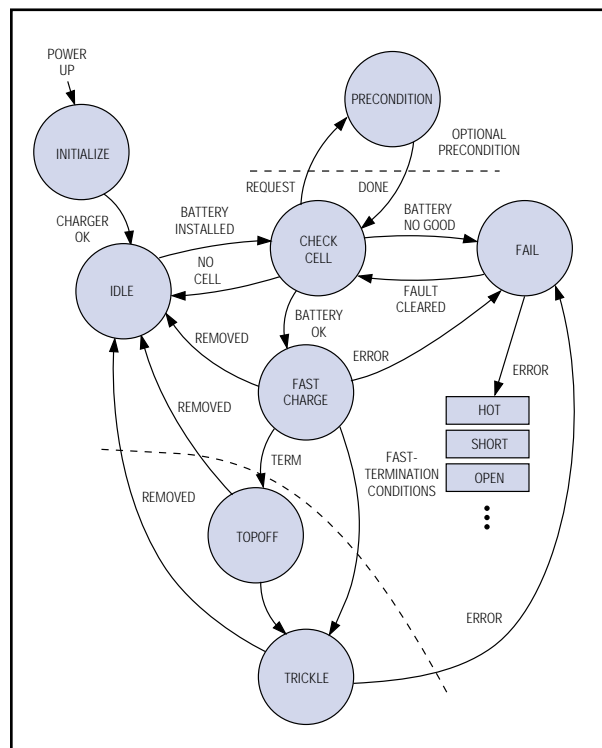

Figure 1. Generic charger-state diagram

issue, the charger can then execute a special self-test sequence to determine if the battery is already charged. A battery present on power-up, for example, should trigger such an action.

Several circumstances can allow this initialization to cause charging problems. A fixed-time charger, for example, applies charge to a battery for a fixed interval of four hours. If a power failure occurs three hours and 59 minutes into the charge, the charger starts another four-hour charge, giving the battery a four-hour overcharge. This treatment can damage the battery, and it is one reason fixed-time charging is seldom used. The example also shows why the charger should monitor battery temperature or use other termination methods as a backup measure.

Cell qualification

This phase of the charging procedure detects when a battery is installed and whether it can be charged. Cell detection is usually accomplished by looking for voltage on the charger terminals while the charger source is off, but that method can pose a problem if the cells have been deeply cycled and are producing little voltage. As an alternative, the charger often looks for a thermistor or shorting jumper rather than the cell itself. The presence of this hardware can also serve to identify the battery pack. Smart batteries, on the other hand, conduct a rich exchange of serial data with the battery pack, usually providing all the necessary charging parameters over a specialized I^2C™-like protocol called the System Management Bus (SMBus™).

Once the charger determines that a cell is installed, it must determine if the cell is good. During this subphase (qualification), the cell is checked for basic functioning: open, shorted, hot, or cold. To test whether or not a cell is chargeable, some chargers—lead-acid types especially—apply a light charging current (about one-fifth of the fast rate) and allow the cell a fixed amount of time to reach a specified voltage. This technique avoids the problem of false rejects for deeply cycled $PbSO_4$ batteries, and with the battery manufacturer's approval, it can be used for other chemistries as well.

A check of the ambient and cell temperatures is also a part of the qualification phase. When a charger detects high or low temperature, it usually waits a predetermined interval for the temperature to return to nominal. If this doesn't happen within the allotted time, the charger reduces the charging current. This action in turn reduces battery temperature, which increases efficiency. Finally, the cells are

SMBus is a trademark of Intel Corp.

I^2C is a trademark of Philips Semiconductor Corp.

checked for opens and shorts. Open cells are easily detected, but a shorted-cell indication requires confirmation in order to avoid false failure indications. If all of these checks are satisfactory, the cell can be charged, and the state is advanced as shown in Figure 1.

Preconditioning phase (optional)

Some chargers (primarily those for NiCd batteries) include an optional preconditioning phase in which the battery is fully discharged before recharging. Full discharge reduces each battery's voltage level to 1V per cell and eliminates dendritic formations in the electrolyte, which cause what is often falsely labeled the memory effect. This so-called memory effect refers to the presence of dendritic formations that can reduce the run life of a cell, but a complete charge and discharge cycle sometimes eliminates the problem.

Preconditioning can be accomplished before each charge, or it can follow an indication (by load test or other operation) that more than half of the cell's charge remains. Preconditioning can last from one to ten hours. Discharging a battery in less than one hour is not generally recommended. Fast preconditioning raises the practical problem of what to do with heat dissipated by the load resistor. Nor is preconditioning for longer than ten hours usually recommended unless it can be initiated manually upon detection of reduced capacity. Confusion and misunderstanding surround the NiCd "memory effect," so the designer should avoid putting a button on the charger to counteract it.

Fast-charge phase and termination

Fast-charge and termination methods used depend on cell chemistry and other design factors. The following discussion covers fast-charging techniques widely used for today's common battery chemistries. For specific guidelines and recommendations, consult the battery manufacturer's applications department.

NiCd and NiMH cells

Fast-charging procedures for NiCd and NiMH batteries are very similar; they differ primarily in the termination method used. In each case, the charger applies a constant current while monitoring battery voltage and other variables to determine when to terminate the charge. Fast-charge rates in excess of 2C are possible, but the most common rate is about C/2. Because charging efficiency is somewhat less than 100%, a full charge at the C/2 rate requires slightly more than two hours.

While constant current is applied, the cell voltage rises slowly and eventually reaches a peak (a point of zero slope). NiMH charging should be terminated at this peak (the 0ΔV point). NiCd charging, on the other hand, should terminate at a point past the peak: when the battery voltage first shows a slight decline (-ΔV) (**Figure 2**). Cell damage can result if fast charge continues past either battery's termination point.

At rates exceeding C/2 (resulting in a charge time of no more than two hours), the charger also monitors the cell's temperature and voltage. Because cell temperature rises rapidly when a cell reaches full charge, the temperature monitor enables another termination technique. Termination on this positive temperature slope is called ΔT termination. Other factors that can trigger termination include charging time and maximum cell voltage. Well-designed chargers rely on a combination of these factors.

Note: Because certain effects that appear when a cell first begins charging can imitate termination conditions, chargers usually introduce a delay of one to five minutes before activating slope-detection termination modes. Also, charge-termination conditions are difficult to detect for rates below C/8, because the voltage and temperature slopes of interest (ΔV/Δt and ΔT/Δt) are small and comparable to other system effects. For safety during a fast charge, the hardware and software in these systems should always err on the side of *early* termination.

Lithium-Ion cells

Li+ battery charging differs from the nickel-chemistry charging schemes. A top-off charge can follow to ensure maximum energy storage in a safe manner. Li+ chargers regulate their charging voltage to an accuracy better than 0.75%, and their maximum charging rate is set with a current limit, much like that of a bench power supply (**Figure 3**). When fast charging begins, the cell voltage is low, and charging current assumes the current-limit value.

Battery voltage rises slowly during the charge. Eventually, the current tapers down, and the voltage rises to a float-voltage level of 4.2V per cell (**Figure 4**).

The charger can terminate charging when the battery reaches its float voltage, but that approach neglects the topping-off operation. One variation is to start a timer when float voltage is reached, and then terminate charging after a fixed delay. Another method is to monitor the charging current, and terminate at a low level (typically 5% of the limit value; some manufacturers recommend a higher minimum of 100mA). A top-off cycle often follows this technique, as well.

The past few years have yielded improvements in Li+ batteries, the chargers, and our understanding of this battery chemistry. The earliest Li+ batteries for consumer applications had shortcomings that affected safety, but those problems cannot occur in today's well-designed systems. Manufacturers' recommendations are neither static nor totally consistent, and Li+ batteries continue to evolve.
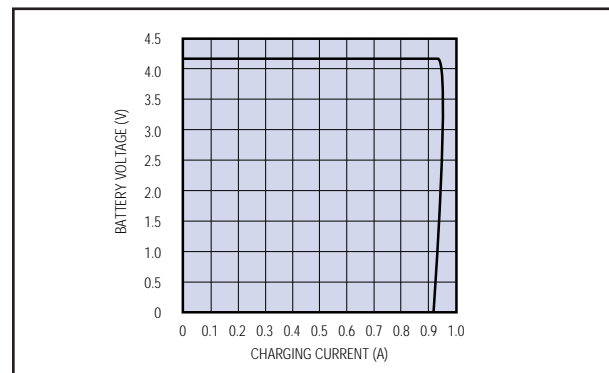

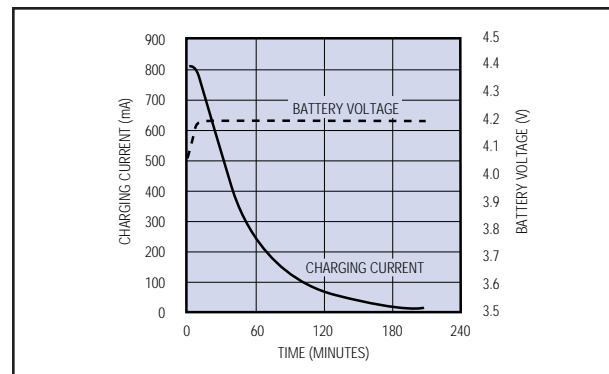*Figure 3. Li+ battery voltage vs. charging current*

Figure 2. NiCd battery-charging characteristics at C/2 rate

Figure 4. Li+ battery-charging profile

Lead-acid cells

PbSO4 batteries are usually charged either by the current-limited method or by the more common and generally simpler voltage-limited method. The voltage-limited charging method is similar to that used for for Li+ cells, but high precision isn't as critical. It requires a current-limited voltage source set at a level somewhat higher than the cell's float voltage (about 2.45V).

After a preconditioning operation that ensures that the battery will take a charge, the charger begins the fast charge and continues until it reaches a minimum charging current. (This procedure is similar to that of a Li+ charger). Fast charge is then terminated, and the charger applies a maintenance charge of V_{FLOAT} (usually about 2.2V). PbSO4 cells allow this float-voltage maintenance for indefinite periods (**Figure 5**).

At higher temperatures, the fast-charge current for PbSO4 batteries should be reduced according to the typical temperature coefficient of 0.3% per degree centigrade. The maximum temperature recommended for fast charging is about 50°C, but maintenance charging can generally proceed above that temperature.

Optional top-off charge (all chemistries)

Chargers for all chemistries often include an optional top-off phase. This phase occurs after fast-charge termination and applies a moderate charging current that boosts the battery up to its full-charge level. (The operation is analogous to topping off a car's gas tank after the pump has stopped automatically.) The top-off charge is terminated on reaching a limit with respect to cell voltage, temperature, or time. In some cases, top-off charge can provide a run life of 5% or even 10% above that of a standard fast charge. Extra care is advisable here: the battery is at or near full charge and is therefore subject to damage from overcharging.

Optional trickle charge (all chemistries except Li+)

Chargers for all chemistries often include an optional trickle-charge phase. This phase compensates for self-discharge in a battery. PbSO4 batteries have the highest rate of self-discharge (a few percent per day), and Li+ cells have the lowest. The Li+ rate is so low that trickle charging is not required or recommended. NiCds, however, can usually accept a C/16 trickle charge indefinitely. For NiMH cells, a safe continuous current is usually around C/50, but trickle charging for NiMH cells is not universally recommended.

Pulsed trickle is a variation in which the charger provides brief pulses of approximately C/8 magnitude, with a low duty cycle that provides a typical average trickle current of C/512. Because pulsed-trickle charging applies to both nickel chemistries and lends itself well to the on/off type of microprocessor (µP) control, it is used almost universally.

Generic charging system

Before looking at specific circuit implementations, designers should become familiar with generic blocks and features (**Figure 6**). All fast chargers should include these block functions in some form. The bulk power source provides raw dc power, usually from a wall cube or brick. The current and voltage controls regulate current and voltage applied to the battery. For less-expensive chargers, the regulator is usually a power transistor or other linear-pass element that dissipates power as heat. It can also be a buck switching supply that includes a standard freewheeling diode for average efficiency or a synchronous rectifier for highest efficiency.

The blocks on the right in Figure 6 represent various measurement and control functions. An analog current-control loop limits the maximum current delivered to the battery, and a voltage loop maintains a constant voltage
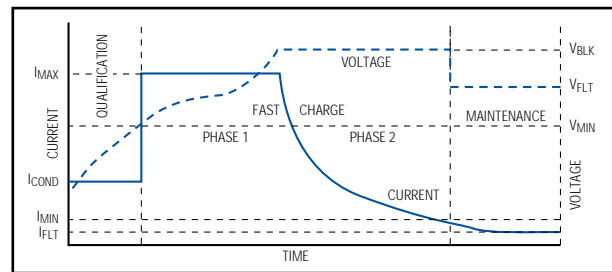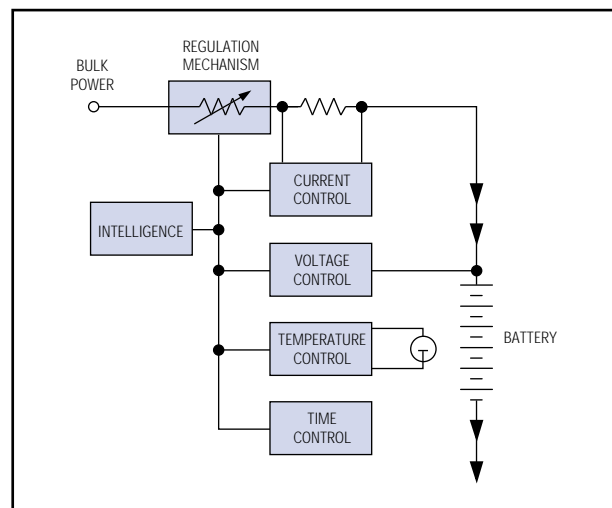

Figure 5. PbSO4 battery-charging profile

Figure 6. Generic charging—system block diagram

on the cell. (Note that Li+ cells require a high level of precision in the applied charging voltage.)

A charger's current-voltage (I-V) characteristic can be fully programmable, or it can be programmable in current only, with a voltage limit (or vice versa). Cell temperature is always measured, and charge termination can be based either on the level or the slope of this measurement. Chargers also measure charging time, usually as a calculation in the intelligence block.

This block provides intelligence for the system and implements the state machine previously described. It knows how and when to terminate a fast charge. Intelligence is internal to the chip in stand-alone charger ICs. Otherwise, it resides in a host µC, and the other hardware blocks reside in the charger IC. As mentioned previously, this latter architecture is the one preferred today.

Overview of Maxim's charger offerings

Maxim manufactures a broad selection of stand-alone and controller-type battery-charger ICs. The variety enables a system designer to make tradeoffs in performance, features, and cost. **Table 1** lists these ICs by the battery chemistry supported, in their order of introduction, with the most recent models at the top.

The choice between linear and switch-mode regulation constitutes a major design decision. Linear mode is less costly, but it dissipates power and gets hot. Heat may not be a problem in large desktop chargers, but it can be unacceptable in smaller systems such as a notebook PC. Synchronous switching regulators offer the highest efficiency (in the mid-90% range), which makes them suitable for the smallest systems, including cell phones. Some of the nonsynchronous switch-mode circuits listed also offer reasonable efficiency. In addition, most of the linear parts can be used in a moderately efficient hysteretic switching mode. (For details, consult the appropriate data sheet.)

The charger's level of autonomy poses another design decision. Stand-alone chargers, for example, are completely self-contained. The MAX712/MAX713 and MAX2003/MAX2003A have LED-control outputs for the user's end equipment as well.

Other devices can stand alone or can operate with a digital-to-analog converter (DAC) and µP. They include the MAX1640/MAX1641, MAX846A, and MAX745. The MAX1640, a voltage-limited current source intended primarily for charging nickel-chemistry batteries, includes a charge timer and pulse-trickle circuitry. It has

Table 1. Overview of Maxim's battery-charger ICs

PART	CONTROL METHOD*	STANDARD REGULATION MODE**	FEATURES	CHEMISTRY	CHARGE RATE	CHARGE-TERMINATION METHOD
MAX1647	µC control, SMBus	Synchronous switching	Smart-battery system, level 2 compliant, smart-battery charger with SMBus. Li+, independent I-V control	All	Programmed	Programmed
MAX1648	User	Synchronous switching	Analog-controlled version of MAX1647, high-accuracy switching, I/V source: Li+	All	Programmed	Programmed
MAX745	DAC or stand-alone	Synchronous switching	Advanced, low-cost, switch-mode Li+ charger, stand-alone, Li+ only	Li+	Constant voltage, Li+	Li+ float
MAX846A	DAC or stand-alone	Linear	Low-cost universal charger, accurate reference for Li+, external CPU support, reset and regulator	All	Constant voltage, Li+, programmed	Li+ float or programmed
MAX1640	DAC or stand-alone	Synchronous switching	Analog-controlled, switch-mode current source, Li+ or universal	Li+, NiCd, NiMH	Fast, trickle, pulse-trickle, top-off	Programmed or Li+ stand-alone
MAX2003A	Stand-alone	Linear or switching	Enhanced Bq2003, pulsed-trickle and top-off modes, smaller packages	NiCd, NiMH	Fast, trickle, pulse-trickle, top-off	0ΔV, -ΔV, ΔT, max voltage, max temperature, max time
MAX2003	Stand-alone	Linear or switching	Complete NiCd/NiMH charger with termination modes, LED outputs, discharge before charge. No Li+. Benchmarq Bq2003 second source.	NiCd, NiMH	Fast, trickle, top-off	0ΔV, -ΔV, ΔT, max voltage, max temperature, max time
MAX712	Stand-alone	Linear	Complete, low-cost NiMH with termination modes, max times, LED outputs. No Li+.	NiMH	Fast, trickle	0ΔV, max voltage, max temperature, max time
MAX713	Stand-alone	Linear	Complete, low-cost NiCd with termination modes, max times, LED outputs. No Li+.	NiCd	Fast, trickle	0ΔV, max voltage, max temperature, max time

The use of a DAC and µC is also possible with the DAC-input types.
**All linear types can be used in a hysteretic switching mode for higher efficiency.*

stand-alone features and operates with a high-efficiency synchronous switching regulator or (for lower cost applications) a standard switcher.

The MAX846A and MAX745 are both capable of stand-alone operation in charging Li+ batteries, and they include the high-accuracy reference and independent voltage and current control necessary for universal controllers. The MAX846A is a linear type, and the MAX745 is a synchronous-switching type. Though either can stand alone, they usually operate with a μC that provides limited control of the charging process. LED illumination and fast-charge termination are usually initiated by the software. The MAX846A includes a linear regulator and a CPU-reset output for the μC.

The least autonomous and most flexible devices are the MAX1647 and MAX1648. They are similar, except the MAX1647 has built-in DACs and an SMBus serial port, and the MAX1648 has analog inputs for voltage and current control. The MAX1647 is a complete, serially controlled DC power supply with independent voltage and current registers. Capable of SMBus communications with a smart battery, it provides Level 2 compliance with the Intel/Duracell smart-battery specification.

μC design tips

These charger ICs typically operate with a low-cost 8-bit controller such as the 8051, PIC, 68HC11, or 68HC05. The firmware can be written in assembly language or in C, either of which feature ready availability, low cost, and free tools. Third parties and manufacturers of these devices have assembled an impressive array of compilers, assemblers, emulators, and code libraries. Much of this source code is available on the World Wide Web, especially the toolbox routines for assembly language. The *Tips for charger program structure* section provides further information on these resources.

All common 8-bit μCs are suitable, but the selection of a specific μC is beyond the scope of this article. Peripherals such as analog-to-digital convertors (ADCs), DACs, and the SMBus serial interface are available in these μCs, and simpler μC versions that require external ADCs or DACs are also useful. Often, simpler μC versions that require external ADCs or DACs are more flexible and ultimately more useful.

The ROM and RAM requirements for charger applications are modest. In general, you can implement a single-chemistry charger in less than 0.5kbytes of code and 32 bytes of RAM (simple requirements for even a low-end PIC). With some ingenuity, you can implement a multi-chemistry charger with about 50% more code.

The simplest way to develop μC code is to start with a skeleton or a piece of similar code, and modify it to suit your needs. This approach gets a prototype working quickly by overcoming a lot of the blank-page, compiler/assembler-syntax problems. Unfortunately, only a limited amount of battery-charger firmware exists on the Web and in standard application notes. However, two design examples in the *Hardware and Software Examples* section provide a starting point. *See the Resources and references* section for more information on some of the more difficult toolbox routines, such as SMBus communications and math routines, and for examples of program designs that illustrate approaches to these designs.

Tips for charger-program structure

Writing battery-charger software is straightforward and best implemented with a state machine. Define a state variable or series of flags that represents the current state. The code then tends to be a large case statement that acts according to this state variable. The code modules modify the state variable according to the current conditions. Disallowed and undecodable states pose the only potential problems. All case statements must have a default case that picks up these disallowed or "impossible" states and corrects them. Always include a mechanism that detects these conditions and then takes intelligent action, such as stopping the charger.

Keep the code simple: avoid multiple interrupts and complex multitasking or queuing structures where possible. Using a single timer-tick interrupt is a very effective way to keep time. If the CPU has a timer with an interrupt, use it to maintain system-timer flags. This powerful technique is an exception to the no-interrupts rule. If no timer interrupt is available (as in the PIC16C5x), use the system timer (RTC) and poll it. Design the code so the timer cannot overflow between polls.

Avoid hardware interrupts. Instead, poll the hardware inputs at regular intervals set by the timer tick. Code execution takes place in real time, but it doesn't have to react immediately to stimuli. The 100ms required to determine whether the battery is installed is acceptable, considering that battery charging takes an hour. Typical performance for stand-alone chargers is usually one calculation per minute for termination.

A simple and workable structure for these programs is a paced loop. The main program is a loop that looks at

timer flags set by a timer interrupt-service routine or the loop itself, and calls subroutines that perform the multiple tasks required. Some routines run on each pass, and others run on every "nth" loop or tick. The basic tick time might be 100ms, for example. A blinking-light subroutine with a half-second period would be called to complement the LED every five ticks, and the temperature-limit detector would be checked on each pass through the loop. The result is a very robust structure.

For controllers that lack a timer interrupt, the paced loop can be implemented by the routines themselves, using their own execution times to maintain system timing. This technique is implemented in the next section by the code example for an 8-pin PIC controller. A simple flow chart of this structure (**Figure 7**) is described in greater detail in Reference 7.

Hardware fail-safe reminder

Before exploring some examples, one final recommendation is to consider the use of a μP supervisor with a watchdog timer and a hardware fail-safe system. The supervisor's reset function provides a clean system reset when the power comes up, and the watchdog timer can catch a stalled CPU or errant firmware stuck in a loop. Maxim also makes some simple temperature-
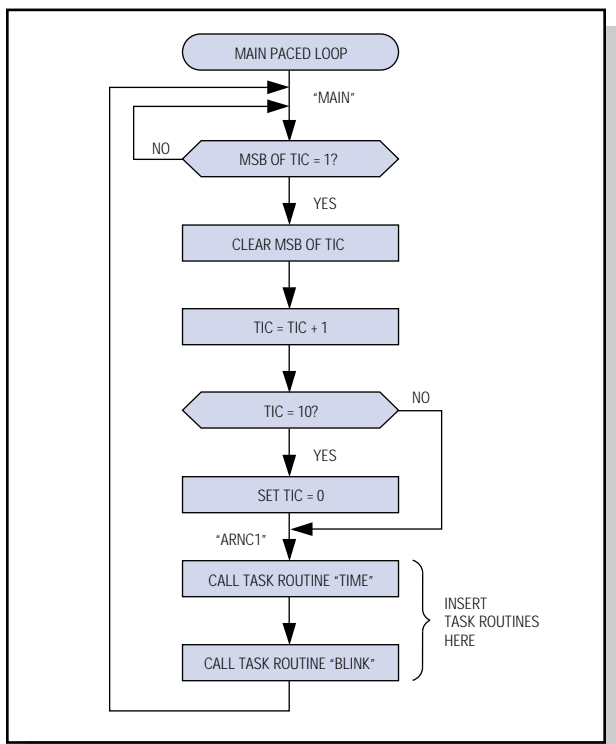
measurement/control products. The MAX6301 temperature switches make an especially good backup system. They are SOT23 devices that change their output level when a fixed temperature threshold is crossed.

Supervisors are especially important in charger applications, because the constant application and removal of power to the charger can confuse the CPU. If, for example, the processor stalls and fails to terminate a fast charge, the results can be catastrophic. The system should also include a temperature sensor or other hardware override that can end the fast charge without software intervention. Some of Maxim's SOT23-reset supervisors include a watchdog (see the MAX823).

Hardware and software examples

1) MAX846A Li+ charger with charge timer and LED-status outputs, controlled by an 8-pin PIC

In this example, a small external μP enhances the MAX846A, forming a complete desktop-charger system that includes user-interface functions such as the LEDs in **Figure 8** (to indicate the charge process and status). The MAX846A is designed for this type of operation. Its auxiliary linear regulator and μP-reset circuit (to support the external μC) reduces the cost of a typical desktop-charger application.

2) MAX1647-based, 2A Li+ charger with 8051 μC

The full-featured MAX1647 charger and 8051 μC form a full-featured Li+ charger (**Figure 9**). The Atmel 80C2051 controller shown (a nonexpandable 8051 in a small package) is typical of the controllers usually available in systems requiring a high-end charger. Source code for the application includes SMBus communications, a general state-machine structure, and other useful routines. Look for LI1647.doc and PIC846.doc under "Other Software." The charger status can be read out from the UART or by additional software residing in the μP.

3) Software examples for the MAX1647 and MAX846A chargers

Software for the MAX1647 and MAX846A examples (**Figure 9**) is available at Maxim's web site. MAX846A software for the 8-pin PIC12C508 controller is written in Microchip PIC assembly language. It implements an LED user interface and a timer that terminates the fast charge five minutes after reaching the Li+ voltage limit. This simple example does not include the state machine or the complexities of a full charger, because much of that capability is available in the nearly stand-alone MAX846A.

Figure 7. Main paced-loop flow chart
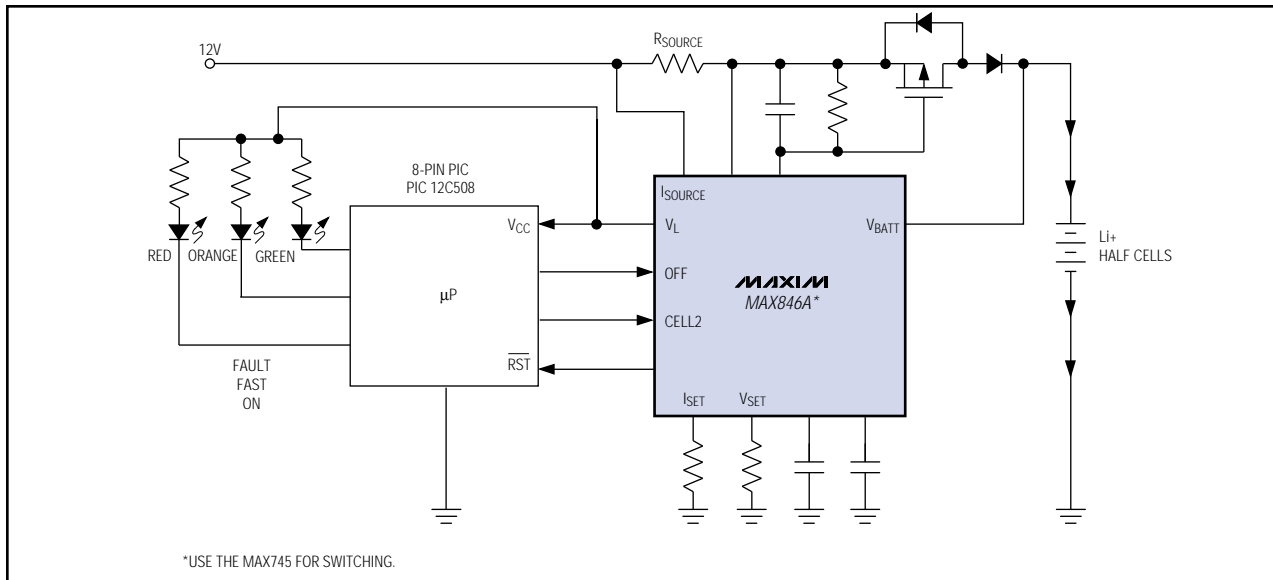
Figure 8. Li+ desk charger with LED status indicator

The example does rely on the paced-loop structure without interrupts, as described earlier.

The MAX1647 example is written in 8051 assembly code for Atmel's ATM80C2051, a 20-pin version of the 8051. This code includes a general state-machine structure and SMBus-driver routines for communicating with the MAX1647 internal registers. It also incorporates a paced-loop structure, but employs the 80C2051's timer interrupt to create a timer-tick basis for all timing. For further details, see the source-code documents at Maxim's Web site.

Figure 9. Full-featured Li+ charger

Resources and references

The following is a brief sampling of application notes and other resources available on the World Wide Web and from vendors. Most vendors publish their application notes on the web for easy access. Simply accessing the web and entering a μC part number into the AltaVista search engine usually yields more than 50 documents.
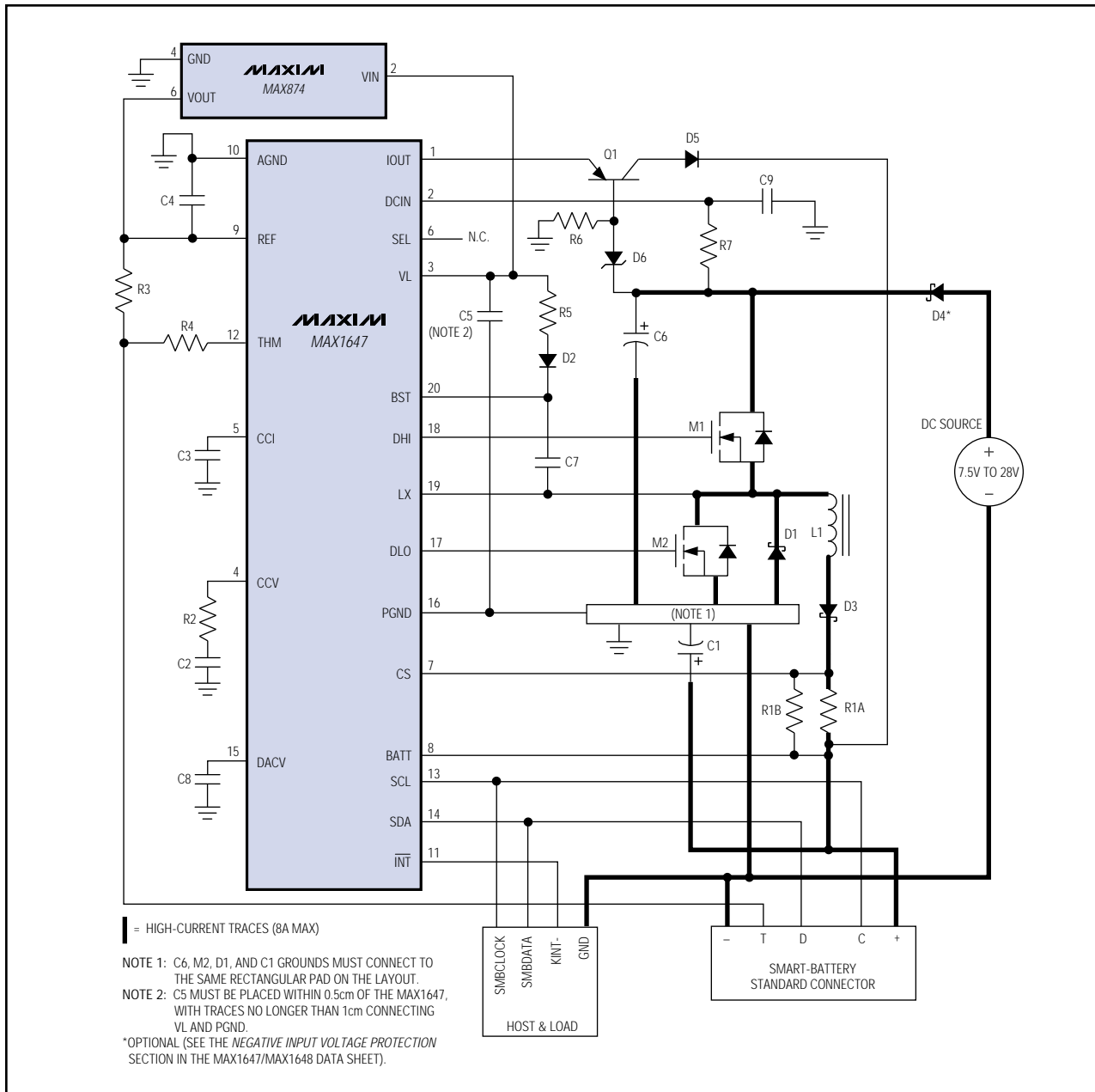
8051-derivative application notes

Philips Semiconductors: Web site and CD-ROM

AN422: Using the 8XC751 Microcontroller as an I²C Bus Master

AN428: Using the ADC and PWM of the 83C752/87C752

AN439: 87C751 fast NiCd charger

EIE/AN92001: Low RF-Emission Applications with a P83CE654 Microcontroller

Intel Corp.: Web site and CD-ROM

Atmel Corp.: Web site and CD-ROM

A Digital Thermometer Using the AT89C2051 Microcontroller

Interfacing 24CXXX Serial EEPROMs with AT89CX051 MCU

68HC05 application notes

AN1263: Designing for Electromagnetic Compatibility with Single-Chip Microcontrollers

AN1262: Simple Real-Time Kernels for HC05 MCUs

AN1256: Interfacing the HC05 MCU to a Multichannel D/A Converter

AN1241: Interfacing the HC05 MCU to Serial EEPROMs

AN1227: Using Serial EEPROMs with HC05 MCUs

AN477: Simple A/D Conversion for MCUs Without Built-In ADCs

PIC application notes

Microchip: Web site and CD-ROM

AN541: Using a PIC16C5X as a Smart I²C Peripheral

AN546: Using the A/D Converter in the PIC 16C73

AN554: Software Implementation of I²C Bus Master

AN577: PIC16C54A EMI Results

AN552: Implementing Wake-Up on Keystroke for the 16C54

AN585: A Real-Time Operating System for PIC16/17

AN606: Low-Power Design Using PIC16/17

AN520: A Comparison of Low-End 8-Bit Microcontrollers

Parallax: Third-party web site and tools

References

1. *How to Implement an SMBus Controller Using the 80C51SL KBC,* Intel Corp. application note, November 1994.

2. *Handbook of Batteries, by David Linden (Editor), 2nd Edition, McGraw Hill text, January 1995, ISBN: 0070379211*

3. *The System Management Bus Specification,* Versions 0.95a and 1.0, Intel Corp., February 1995.

4. *The Smart-Battery Data Specification*, Version 1.0, Duracell Inc. and Intel Corp., February 1995.

5. *The SMBus BIOS Specification*, Version 1.0, Intel Corp., February 1995.

6. *Smart-Battery Selector Specification*, Version 0.9, Intel Corp., April 1995.

7. *Understanding Small Microcontrollers,* by James Sibigtroth. Published by Motorola Inc., CSIC Division, circa 1990.

APD bias circuit
has adjustable output

The avalanche photodiode detector (APD) is used as a receiver in optical communications, as is the pin diode. The APD is more sensitive, but it must be biased properly to produce the appropriate electron flow for a given flux of photons. In **Figure 1**, an external digital-to-analog converter enables dynamic, computer-controlled adjustment of an APD bias generator.

To generate the bias voltage V_{OUT}, a boost converter (IC1, L1, and Q1) drives a diode-capacitor charge pump (D3/C4, D2/C3, and D1/C5). IC1 regulates V_{OUT} with respect to a set point established by the external control voltage V_{DAC}: as V_{DAC} ranges from 2V to zero, V_{OUT} varies from 28V to about 71V (**Figure 2**).

At 70V with a 0.5mA output current, the limitation on ripple is typically 0.5V (max) (0.7%). The circuit shown produces less than 0.3% ripple at 1mA, and its maximum output current is about 3mA. The output capacitor (C5) should be a low-ESR type.

A similar idea appeared in the 5/22/97 issue of EDN.
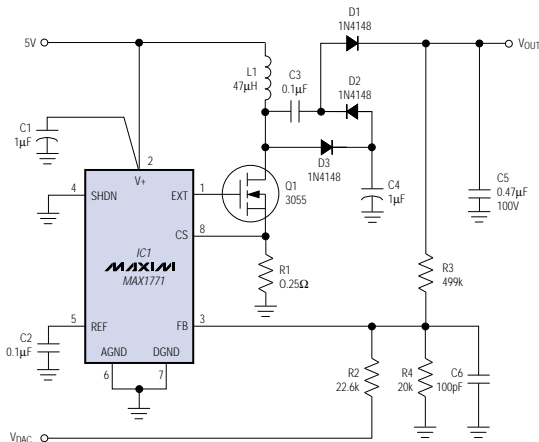
Figure 1. This APD-bias generator produces a regulated, computer-adjusted output in the 30V to 70V range.
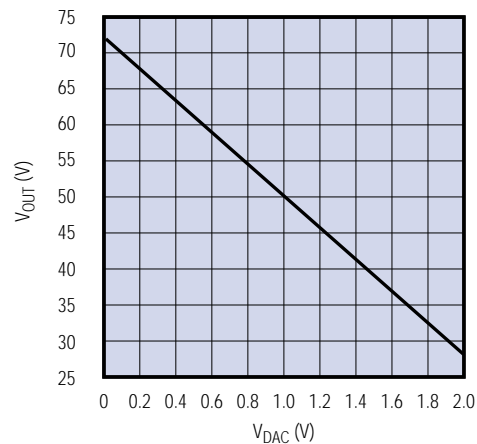
Figure 2. The dc-output level in Figure 1 is a linear function of the control-voltage V_{DAC}.

DESIGN SHOWCASE

Low-power 3V ADC is 0.05% linear

The simple 3V analog-to-digital converter (ADC) shown in **Figure 1** is very small, requires no negative supply or expensive precision components, and draws minimal supply current (10µA). A single conversion consists of 12,000 comparisons and takes about 300ms. The circuit operates as described in the following paragraph.

Following each comparison, the microcontroller (µC) closes one of two switches: IC2A (comparator high) or IC2B (comparator low). The switches connect either V_{REF} (1.2V) or ground to their "B" terminals, producing a pulse-width modulation (PWM) signal that is filtered by R3 and C1 and differentially integrated against V_{IN}. The result is compared against V_{REF}.

As this action integrates the error voltage up and down, the µC counts the number of comparisons for which the comparator output is high (IC2A switch closed). This count (N_H) divided by 12,000 equals the PWM duty cycle. The system is fully ratiometric, so the duty cycle equals $N_H / 12000 = V_{IN} / V_{REF}$. Rearranging and substituting $V_{REF} = 1.2V$ yields $V_{IN} = N_H / 10,000$.

Listing 1* enables the the LCD module to display voltage values directly, like a digital panel meter. The subroutine "DVM" produces the actual A/D-conversion values required in an embedded application. Setting the span constant (number of comparisons) to 12,000 yields a 300ms conversion with 4-1/2 digits of resolution and produces a 1.1999 full-

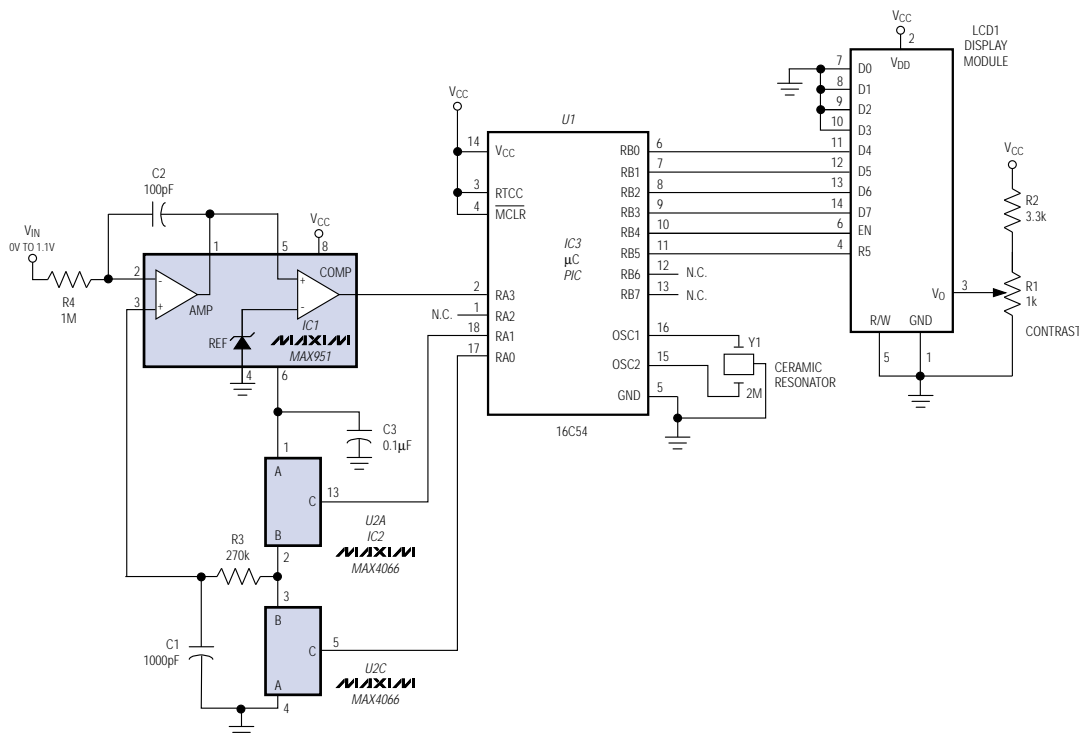**See article in the 6/19/97 issue of EDN or EDN's web site at www.ednmag.com.*

Figure 1. This inexpensive, 0.05%-linear ADC can be added to existing equipment or used to upgrade the converter included in certain µCs (such as the PIC 16C71).

scale display. You can speed the conversion to 30ms by setting the span constant to 1200, which produces a 3-1/2 digit display that reads 1.199 at full scale.

IC2's near-ideal switching characteristics account for the low 0.05% nonlinearity. A high-performance, 3V-specified version of the industry-standard 4066, IC2 is a quad analog switch that features 35Ω on-resistances and 0.1nA (max) off leakages. You can save space by replacing IC2 with the MAX323 dual analog switch: a 3V single-pole/single-throw device with specifications similar to those of the MAX4066. The MAX323 resides in an 8-pin μMAX package (versus a 14-pin SO for the MAX4066).

V_{CC} is limited to the maximum allowed by the μC (6V). IC1, which operates with V_{CC} as low as 2.8V over temperature, draws only 7μA of supply current. The voltage reference in IC1 is stable for capacitive loads smaller than 100pF or larger than 0.05μF. To ensure stability, the reference's external bypass capacitor (C3) should be kept large.

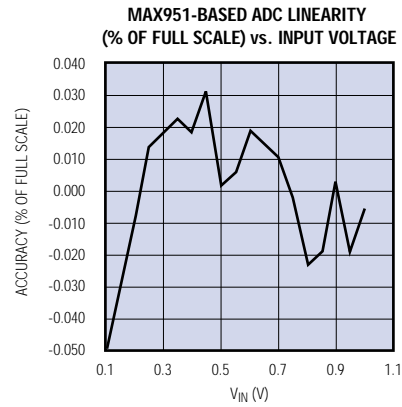*A similar idea appeared in the 6/19/97 issue of EDN.*

**MAX951-BASED ADC LINEARITY
(% OF FULL SCALE) vs. INPUT VOLTAGE**

Figure 2. In Figure 1, the output nonlinearity (as a percentage of full scale) varies as shown.

Step-up/step-down converter generates 3.3V from two or three cells

Generating 3.3V from two or three cells poses a challenge to design engineers. The regulator must step down when the cells are fresh, but it must also step up when the cells are semidischarged and weak. One solution to this problem is a flyback-transformer design, which requires that you select transformer ratios to ensure a constant output voltage under varying load conditions.

Alternatively, a single-ended primary-inductance converter (SEPIC) offers simpler circuitry (**Figure 1**). This circuit generates 3.3V at 400mA with 78% efficiency. Input voltage can range above and below the output, and a capacitor (C2) couples the output to the switching circuitry. This configuration offers two advantages over flyback-transformer circuits and step-up linear-regulator circuits: no output current flows during shutdown, and V_{OUT} remains well regulated as V_{IN} passes through the V_{OUT} level.

The two inductors in this circuit can be separate components or can be wound on a common core for convenience. They don't work as a transformer, so you can wind them without regard to coupling. Capacitors C2, C3, and C5 should have low equivalent series resistance for best efficiency. C2's voltage rating must exceed the maximum input voltage, and the external switch (Q1) must withstand the sum of $(V_{IN} + V_{OUT})$.

By capturing Q1's switching pulses, Schottky diode D2 boosts the V+ voltage to $(V_{IN} + V_{OUT})$. The resulting higher gate drive lowers the losses in Q1, especially for low input voltage, but it also limits V_{IN} to 12V (max). Output capabilities are 300mA at $V_{IN} = 2V$ and 400mA at $V_{IN} = 3V$, with efficiency versus load current as shown in **Figure 2**.

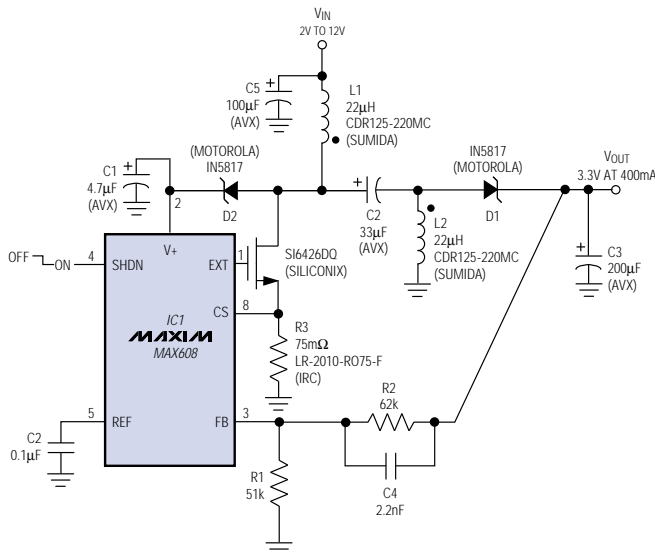*A similar idea appeared in the 11/21/96 issue of EDN.*

Figure 1. This SEPIC switching regulator maintains a 3.3V output for V_{IN} that ranges above and below 3.3V (as does the voltage from a 2-cell or 3-cell battery, for example).
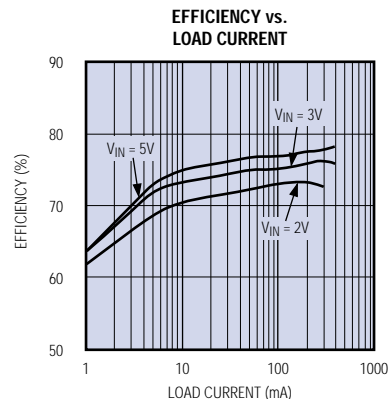

Figure 2. Efficiency for the Figure 1 circuit approaches 80%.

NEW PRODUCTS

2.7V, 12-bit/10-bit, 8-channel DAS have internal reference

The MAX146/MAX149 data-acquisition systems (DAS) combine an 8-channel multiplexer (mux), track/hold, 12-bit analog-to-digital converter (ADC), and 2.5V reference in a small, 20-pin SSOP. Small size, low power consumption (3.6mW at 133ksps), and low-current power-down (1μA) make the MAX146/MAX149 ideal for portable systems.

The MAX146 operates from a single +2.7V to +3.6V supply, and the MAX149 operates from a single +2.7V to +5.25V supply. Both devices allow programming of the eight analog inputs for unipolar/bipolar and differential/single-ended operation. Both also guarantee monotonic operation with an INL of ±1/2LSB over temperature.

The MAX146/MAX149 offer guaranteed dynamic specifications, internal/external-clock operation, and a reference buffer that provides a ±1.5% voltage-adjustment range. Their 3-wire serial interface is compatible with the SPI™/QSPI™ and Microwire™ synchronous-serial standards. A serial-strobe output enables direct connections to interrupt-driven processors and microcontrollers.

In addition to a $\overline{\text{SHDN}}$ pin and software-selectable power down, the MAX146/MAX149 can be programmed to shut down automatically after each conversion. They power up automatically in response to an access of the serial interface, and their quick turn-on times make this a practical power-saving feature: the MAX146/MAX149 draw less than 60μA of supply current at reduced sampling rates.

The MAX146/MAX149 are available in 20-pin DIP and QSOP packages, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $3.20 for the MAX149 and $6.25 for the MAX146 (1000 up, FOB USA).

SPI and QSPI are trademarks of Motorola, Inc.

Microwire is a trademark of National Semiconductor Corp.

Low-cost, 5V, multichannel 8-bit ADCs are the smallest available

The MAX1112/MAX1113 low-power, 8-bit ADCs include an analog input mux, 4V reference, serial interface, and clock. The 4-channel MAX1112 fits in a QSOP-16 package (same size as an 8-pin SO), and the 8-channel MAX1113 fits in a small, 20-pin SSOP.

Both of these low-power ADCs operate from 5V and sample to 50ksps, yet draw supply currents of only 135μA. For minimal power usage in battery-powered applications, they include a 2μA power-down mode that lowers power consumption considerably at slower sampling rates.

MAX1112/MAX1113 converters power down automatically at the end of each conversion. They power up automatically in response to an access of the SPI/QSPI and Microwire-compatible, 2MHz serial interface. Each device's analog inputs can be configured for unipolar/bipolar and single-ended/differential operating modes. Other features include a hard-wired $\overline{\text{SHDN}}$ input, an internal/external clock, an internal/external reference, and a serial-strobe output that provides the end-of-conversion signal.

The MAX1113 comes in 16-pin DIP and QSOP packages; the MAX1112 comes in 20-pin DIP and SSOP packages. Both are available in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $2.45 for the MAX1113 and $2.70 for the MAX1112 (1000 up, FOB USA).

12-bit TTL/ECL-compatible DACs handle update rates to 100MHz

The MAX5012/MAX5013 are 12-bit, 100Msps digital-to-analog converters (DACs) designed for direct digital synthesis, high-resolution imaging, and arbitrary-waveform generation. They offer improved performance over the pin-compatible AD9712: faster settling time (13ns) and lower glitch energy (15pV-s) result in an excellent spurious-free dynamic range of 72dBc at 20MHz clock and 5MHz f_{out}. MAX5012/MAX5013 applications include fast-frequency-hopping and direct-sequence spread-spectrum radios, microwave and satellite modems, and test/measurement instrumentation.

The TTL-compatible MAX5013 operates from +5V and -5.2V supply voltages, dissipates a nominal 640mW, and is capable of refresh rates to 80MHz. The ECL-compatible MAX5012 operates from a single -5.2V supply, dissipates 600mW, and is capable of refresh rates to 100MHz. Both include master-slave latches, an internal bandgap reference, and a 40MHz multiplying capability.

MAX5012/MAX5013 DACs are available in 28-pin plastic DIP and PLCC packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $30.00 (1000 up, FOB USA).
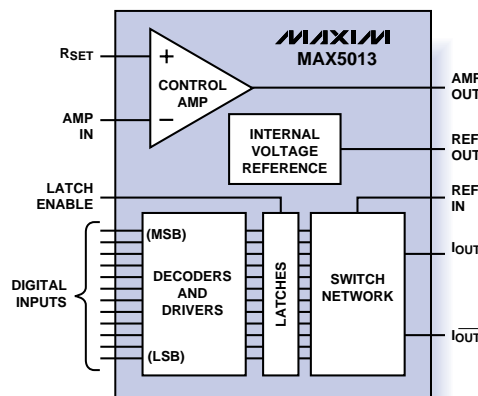
NEW PRODUCTS

10-bit, 20Msps/ 40Msps ADCs have TTL outputs

The MAX1160/MAX1161 10-bit analog-to-digital converters (ADCs) operate from +5V/-5.2V dual supplies and dissipate only 1W (typ) while converting at the maximum guaranteed rates: ≥20Msps (MAX1160) and ≥40Msps (MAX1161). An internal track/hold ensures excellent dynamic performance without the need for external components.

Low input capacitance (5pF typ) simplifies the analog drive requirements. The output data format is parallel straight binary, and an overrange output indicates when the analog input exceeds (by 1LSB) the positive full-scale value. The bipolar analog-input range is 80% of full scale ($\pm2V$ for $V_{REF} = \pm2.5V$). Digital inputs and outputs are TTL compatible.

Both converters have a 1MHz spurious-free dynamic range of 67dB. Signal-to-noise and distortion (SINAD) for the MAX1160 is typically 57dB at 1MHz, 55dB at 3.58MHz, and 47dB at 10MHz. For the MAX1161, typical SINAD is 54dB at 1MHz and at 3.58MHz, and 46dB at 10MHz. The effective number of bits (in dB, typical) for the MAX1160 is 9.2 at 1MHz, 8.8 at 3.58MHz, and 7.5 at 10MHz. For the MAX1161, these parameters are 8.7 at 1MHz, 8.7 at 3.58MHz, and 7.3 at 10MHz.

The MAX1160/MAX1161 come in 28-pin plastic DIP and SO packages, specified for the commercial temperature range (0°C to +70°C). Prices start at $29.00 for the MAX1160 and $42.00 for the MAX1161 (1000 up, FOB USA).

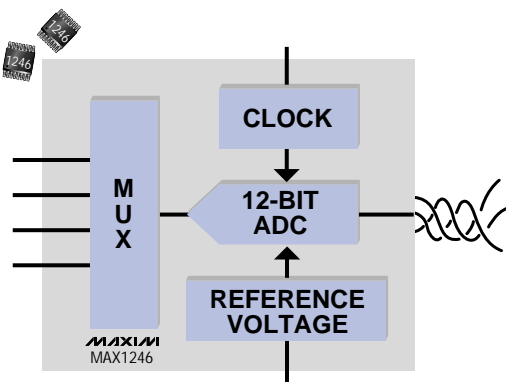## 2.7V, 12-bit/10-bit serial ADCs are the smallest available with internal V~REF~

The MAX1246 12-bit, 4-channel ADC with on-chip voltage reference comes in a small, 16-pin QSOP package (same size as an SO-8 package). This device is the smallest available multi-channel 12-bit ADC that includes a reference. Its small size, low power consumption (4mW at 133ksps), and low-current power-down (2µA) make it ideal for portable systems. Power-supply range is +2.7V to +3.6V.

The MAX1246's 3-wire serial interface, compatible with SPI™/QSPI™ and Microwire™ synchronous-serial standards, allows you to program the four analog inputs for unipolar/bipolar and differential/single-ended operation. The device guarantees monotonic operation and has an integral nonlinearity of ±1/2LSB over temperature. It offers guaranteed dynamic specifications, internal/external-clock operation, and an internal reference buffer.

The 10-bit MAX1248 operates from supply voltages between +2.7V and +5.25V. Pin- and software-compatible with the 12-bit MAX1246, it allows an easy migration between 10-bit and 12-bit applications. MAX1246/MAX1248 converters are available in 16-pin QSOP packages, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $6.15 for the MAX1246 and $3.40 for the MAX1248 (1000 up, FOB USA).

SPI and QSPI are trademarks of Motorola, Inc.

Microwire is a trademark of National Semiconductor Corp.

Dual, low-power, 6-bit ADCs sample at 60Msps/90Msps

The MAX1002/MAX1003 are dual, 6-bit ADCs. Each combines high-speed, low-power operation with an internal reference, clock oscillator, and user-selectable, full-scale input range. Each converts two analog input signals to two 6-bit, offset-binary-coded parallel outputs, at sampling rates as high as 90Msps (MAX1003) or 60Msps (MAX1002). Integral and differential nonlinearity are less than ±1/2LSB.

The MAX1002/MAX1003 converters can interface directly with baseband in-phase and quadrature signals, making them ideal for use in the QPSK demodulators used in direct-broadcast satellite applications. The input amplifiers feature true differential inputs with -0.5dB 55MHz analog bandwidths, and full scale, user-programmable input ranges of 125mVp-p, 250mVp-p, or 500mVp-p.

With AC-coupled input signals, typical channel matching is better than 0.1dB gain, 1/4LSB offset, and 0.5° phase. Effective resolution is 5.8 bits at 20MHz and 5.7 bits at 50MHz. The MAX1002 operates from a +5V supply and provides TTL-compatible digital outputs. The MAX1003 requires a +5V analog supply and a +3.3V digital supply, providing an easy interface to digital signal processors and microprocessors compatible with 3.3V CMOS logic. Power dissipation is a nominal 350mW.

The MAX1002/MAX1003 come in 36-pin SSOP packages specified for the commercial temperature range (0°C to +70°C). Prices start at $3.00 (1000 up, FOB USA).

NEW PRODUCTS

Ultra-high-speed DACs include complete video controls

The MAX5018 and MAX5140 8-bit video digital-to-analog converters (DACs) are monolithic devices that accept video data at 400Msps (MAX5140), 275Msps (MAX5018 "A" version), or 165Msps (MAX5018 "B" version). Each converter supports the RS-343-A standard with a complete set of video-control signals (sync, blank, reference white, and bright).

The MAX5018/MAX5140 operate from a single -5V supply. Their comple-mentary analog-current outputs directly drive doubly terminated 50Ω and 75Ω loads to standard composite-video levels (7.5IRE). The video-control and data inputs are ECL compatible and ESD protected. Both chips include data and control input registers, video control logic, a reference-voltage buffer, and signal-current switches. In addition, the MAX5140 includes a precision bandgap reference that is capable of driving two other MAX5140s in an RGB graphics system.

MAX5018/MAX5140 both have feedthrough control, a feature not available in comparable video DACs. Terminal FT allows the ECL-compatible control and data inputs to operate either without registers (FT high), or latched by the clock into a D-type internal register (FT low). Latching the video data acts as a barrier to feedthrough noise.

The MAX5018 is an improved, pin-compatible version of the HDAC10180 and TDC1018 DACs. Both the MAX5018 and MAX5140 are available in a 24-pin plastic DIP specified for the industrial temperature range (-20°C to +85°C). Prices start at $19.95 (1000 up, FOB USA).

300MHz, single-supply op amps offer rail-to-rail outputs and high-Z disable

The low-cost MAX4012 family of 300MHz, single-supply, Rail-to-Rail® op amps includes the single MAX4012, dual MAX4016, triple MAX4018, and quad MAX4020. All are unity-gain stable and operate from a +3.3V to +10V single supply or from ±1.65V to ±5V dual supplies.

Input common-mode ranges include ground, making these op amps ideal for single-supply applications. With a 2kΩ load, the outputs can swing to within 60mV of the rails. The MAX4018 has a disable mode, useful in multiplexing applications, that lowers the supply current to 200μA and places the outputs in a high-impedance state.

The combination of low power consumption, single-supply operation, rail-to-rail outputs, and wide bandwidth makes these op amps suitable for use in battery-powered instruments, video applications, CCD imaging, and high-speed analog-to-digital converter preamps.

Their voltage-feedback architecture employs current-feedback techniques to achieve a -3dB 300MHz bandwidth, 0.1dB gain flatness to 30MHz (6MHz guaranteed), slew rates of 600V/μs, quiescent supply currents of only 5.5mA per amplifier, and output current capabilities of ±100mA.

Inverting and noninverting inputs exhibit the same voltage noise ($10nV/\sqrt{Hz}$) and the same input-current noise ($1.3pA/\sqrt{Hz}$). In addition, these op amps offer low differential gain/phase errors of 0.02%/0.02°, a spurious-free dynamic range of -78dBc at 5MHz, and total harmonic distortion of -75dB at 5MHz.

The MAX4012 comes in a space-saving, 5-pin SOT23 package; the MAX4016 comes in 8-pin SO and μMAX packages; and the MAX4018/MAX4020 come in 14-pin SO and 16-pin QSOP packages. All are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.88 (1000 up, FOB USA).

Rail-to-Rail is a registered trademark of Nippon Motorola Ltd.

First ultra-high-speed, 3V/5V comparators offer rail-to-rail operation

The MAX961–MAX964 ultra-high-speed, single-supply comparators are the first in the world to guarantee propagation delays below 7ns (typically 4.5ns with 5mV overdrive) while operating from a single supply as low as +2.7V. The input common-mode range extends 100mV beyond the supply rails, and the outputs can sink or source 4mA to within 0.52V of V_{CC} and ground.

The MAX961/MAX963 feature complementary outputs that exhibit less than 300ps of propagation skew, which is an important consideration for digital communications. The MAX961/MAX963 also feature a latch-enable function that holds the output on command, and the MAX961/MAX963/MAX964 feature a logic-controlled shutdown that lowers the supply current to 270μA. All devices include hysteresis to ensure clean switching.

The single MAX961 and the dual MAX962 come in 8-pin SO and μMAX packages; the dual MAX963 comes in a 14-pin SO; and the quad MAX964 comes in a 16-pin SO or QSOP. All are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $2.50 (1000 up, FOB USA).
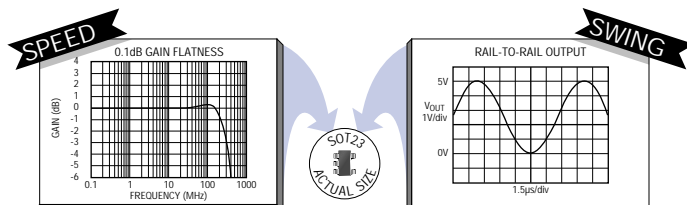
NEW PRODUCTS

High-speed, rail-to-rail comparators have SOT23 packages

The six-member MAX987 family of single/dual/quad micropower comparators is specified for single-supply operation from +2.5V to +5.5V, making them suitable for use in both 5V and 3V systems. They also operate from ±1.25V to ±2.75V dual supplies. Quiescent supply currents are typically 48μA per comparator, and propagation delays are only 110ns.

The common mode input-voltage range extends 250mV beyond each supply rail (V_{EE} - 0.25V to V_{CC} + 0.25V), and large output drivers enable rail-to-rail output swings with loads as high as 8mA. Typical input specifications include 0.5mV offset voltage and 1.0pA bias current. Internal hysteresis ensures clean output switching, even with slow-moving input signals.

The output stage's unique design limits supply-current surges while switching, virtually eliminating the supply glitches typical of many other comparators. The MAX987/MAX991/MAX995 have push/pull output structures that sink as well as source current. The MAX988/MAX992/MAX996 have open-drain output structures that can pull up to V_{CC} or to any level not exceeding V_{EE} +6V.

Package options include a 5-pin SOT23 or 8-pin SO for the single MAX987/MAX988, an 8-pin μMAX or SO for the dual MAX991/MAX992, and a 14-pin SO for the quad MAX995/MAX996. All are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.66 (1000 up, FOB USA).
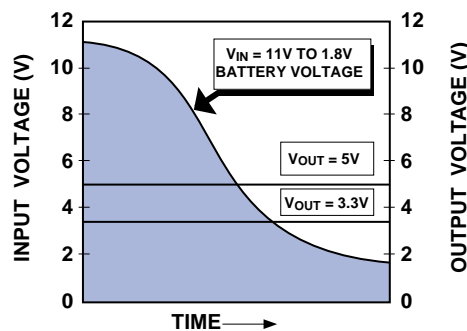
500mA DC-DC converters deliver constant 5V/3.3V from 3/4-cell batteries

The MAX710/MAX711 integrate a step-up DC-DC converter with a linear regulator, providing step-up and step-down voltage conversion with output currents to 500mA. They are optimized for use with 3-cell and 4-cell batteries, in applications for which the input voltage varies above and below the regulated output voltage. Their wide input range (1.8V to 11V) allows operation with a large assortment of batteries and wall-cube adapters.

The MAX710/MAX711 deliver long battery life. They feature low 100μA quiescent supply currents along with a 0.2μA logic-controlled shutdown that completely disconnects the input from the output. Their logic-controlled standby operation, which turns off the DC-DC converter but leaves the linear regulator active, extends battery life by reducing the supply current to 7μA. Also under logic control are the highest-efficiency vs. lowest-noise operating modes.

The MAX710 output is preset for 3.3V or 5V, and the MAX711 output is adjustable from 2.7V to 5.5V using two external resistors. Low-battery detectors are included on-chip. Both devices are available in 16-pin narrow SO packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $2.95 (1000 up, FOB USA).

Quad/dual bidirectional switches handle RF/video to 300MHz

The MAX4545/MAX4546/MAX4547 low-voltage, CMOS T-switches are designed for RF and video signals within the -3dB DC bandwidth to 300MHz. They are suitable for 50Ω and 75Ω applications in RF switching, video-signal routing, high-speed data acquisition, and automatic test equipment.

The MAX4545 contains four normally open (NO) single-pole/single-throw (SPST) switches. The MAX4546 contains two dual SPST switches: one NO and one normally closed (NC). The MAX4547 contains two single-pole/double-throw (SPDT) switches. The "T" configuration of each switch ensures excellent performance: for 50Ω systems at 10MHz, crosstalk and off isolation are both -80dB, and the 50Ω insertion loss at 100MHz is -1dB. All of these switches handle rail-to-rail analog signals in either direction.

On-resistances are 20Ω (max) with ±5V supplies, matched to within 1Ω (max) between switches, and flat to within 0.5Ω (max) over the specified signal range. Off-leakage currents are only 5nA at +25°C and 50nA at +85°C. These switches operate from a +2.7V to +12V single supply, or from ±2.7V to ±6V dual supplies.

When using 5V or ±5V supplies, the logic thresholds for all digital inputs (0.8V and 2.4V) ensure compatibility with TTL/CMOS logic. These switches are pin compatible with the industry-standard DG540, DG542, and DG643 switches and provide more than 2kV of ESD protection (per MIL-STD-883, Method 3015.7).

The MAX4545 comes in 20-pin DIP, SO, and SSOP packages, and the MAX4546/MAX4547 come in 16-pin DIP, SO, and SSOP packages. All are available in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $1.62 (1000 up, FOB USA).

NEW PRODUCTS

Dual-output DC-DC converters power amplifier and radio in cellular phones

The MAX1705/MAX1706 low-noise, dual-output DC-DC converters are optimized for wireless-handset applications. They have high-power outputs that drive power amplifiers directly, delivering up to 5.5V at 800mA from a battery of one to three cells. In addition, they include a low-dropout linear regulator that provides a low-noise, 200mA output for radio-baseband and logic circuits. Small size, high efficiency, and low noise make these devices ideal for use in cellular phones, cordless phones, personal communicators, and other battery-powered applications.

The MAX1705/MAX1706 feature a synchronous-rectifier pulse-width-modulation (PWM) boost topology, with internal switches and efficiencies as high as 95%. Each accepts inputs as low as 0.7V, and provides outputs adjustable from 2.5V to 5.5V. For maximum efficiency, their tracking mode maintains the linear regu-lator's output voltage just below the dropout level. For higher efficiency at light loads, the fixed-frequency, low-noise PWM operation can be switched to pulse-frequency-modulation (PFM) operation using logic control. Quiescent supply current—180µA in PWM low-noise mode—drops to 100µA in PFM low-power mode and to 1µA in shutdown mode.

To minimize interference with 455kHz IF circuitry, the internal clock runs at a fixed frequency of 300kHz ±14% in PWM mode. An external clock can synchronize internal switching for 200kHz to 400kHz frequencies. The MAX1705 has an internal, 1A, n-channel MOSFET switch capable of delivering output currents to 800mA. The MAX1706 has a 0.5A switch that allows smaller inductors at lower output currents. Two shutdown-control inputs provide push-on/push-off logic via a momentary-on pushbutton switch. Each device includes an uncommitted comparator for use as a voltage monitor.

The MAX1705/MAX1706 are available in space-saving, 16-pin QSOP packages (same board area as an 8-pin SO). Both are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $2.96 (1000 up, FOB USA).
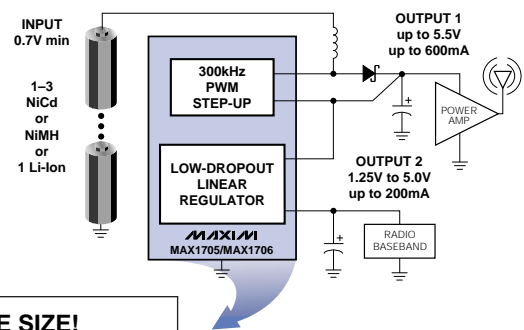
SAME SIZE! MORE FEATURES!

8-PIN SO   16-PIN QSOP

High-accuracy current sources remain cool while fast charging

The high-efficiency MAX1640/MAX1641 are switch-mode current sources that generate regulated currents as high as 2A with an accuracy of 2% (MAX1641) or 5% (MAX1640). Intended for use with a microcontroller in battery-charging applications, they allow the use of external resistors in setting the switching frequency; maximum charging voltage; and fast-charge, top-off, and trickle-charge currents. Each device includes a 2%-accurate set point for maximum termination voltage.

To achieve tighter current regulation, the MAX1641 senses current on the low side of the load, between battery and ground. The MAX1640 senses current on the high side (between current source and battery), thereby avoiding the potential ground-differential problems associated with low-side sensing.

Input voltage range is 5.5V to 24V, and the output range extends from 2V to the input voltage. Each device employs fixed-frequency PWM to control an external p-channel power switch. For higher efficiency, the devices also control an optional n-channel MOSFET operating as a synchronous rectifier. Switching frequencies extend to 300kHz, enabling the use of small external components, and PWM duty cycles to 100% enable very-low-dropout operation.

The MAX1640/MAX1641 are available in compact, 16-pin QSOP packages (same size and shape as a standard 8-pin SO), specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $2.75 (1000 up, FOB USA). For both devices, a preassembled evaluation kit (MAX1640 EVKIT) is available to speed designs.
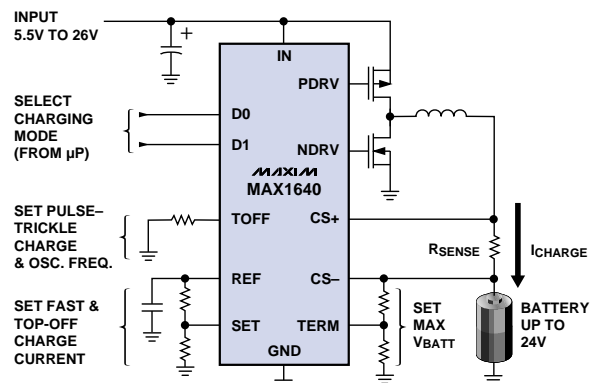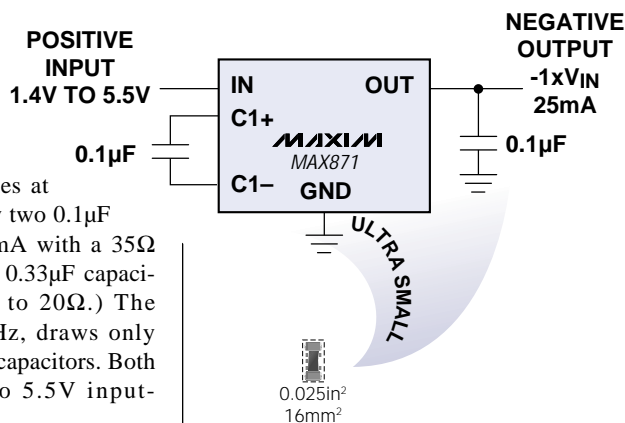

16-pin QSOP (same size as 8-SO)

NEW PRODUCTS

Charge-pump DC-DC converters use 0.1µF capacitors and occupy only 0.025in²

The MAX870/MAX871 DC-DC charge-pump inverters, which convert positive voltages into negative, are ultra-small. An entire MAX871 circuit, for instance, (SOT23-5 package and two 0805-size ceramic capacitors) occupies less than 0.025in² (16mm²). The MAX870/MAX871 bias GaAsFET power amplifiers in wireless-handset applications, and they also provide analog power and biasing for analog measurement and signal-processing circuits.

The MAX871 switches at 500kHz and requires only two 0.1µF capacitors to deliver 25mA with a 35Ω output impedance. (With 0.33µF capacitors, impedance drops to 20Ω.) The MAX870 runs at 125kHz, draws only 0.7mA, and requires 1µF capacitors. Both devices have a 1.4V to 5.5V input-voltage range.

The MAX870/MAX871 require less room than does the industry-standard 7660 charge pump. Their 5-pin SOT23 package is one-fourth the size of the 7660's 8-pin SO, and the 7660's 10µF capacitors are 100 times larger than the MAX871's 0.1µF ceramic capacitor.

The MAX870/MAX871 inverters are available in 5-pin SOT23 packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $1.30 (1000 up, FOB USA).

SMALLEST DC-DC INVERTER FITS IN 0.025in²

POSITIVE INPUT 1.4V TO 5.5V

NEGATIVE OUTPUT -1xV_{IN} 25mA

IN   OUT
C1+
MAXIM
MAX871
C1−   GND

0.1µF

0.1µF

ULTRA SMALL

0.025in²
16mm²

3V, 1GHz RF amplifiers have shutdown and bias control

The MAX2630–MAX2633 broadband RF amplifiers provide -3dB bandwidths greater than 1GHz while operating from a +2.7V to +5.5V single-supply voltage. Supply currents are 6.6mA (typ), and the MAX2631/MAX2633 feature a shutdown mode that lowers the supply current to 1µA.

Their 13.4dB gain and 3.7dB noise figure make the MAX2630–MAX2633 amplifiers suitable for use in receiver, buffer, and transmit-IF circuitry operating at frequencies from VHF to microwave. Applications include global positioning systems, wireless LANs, cordless and cellular telephones, TV tuners, and set-top boxes.

The MAX2630/MAX2631 have internal bias circuitry that eliminates the need for external bias resistors or inductors. For the MAX2632/MAX2633, the internal bias current is adjustable with a single external resistor that allows users to customize output power and gain for specific applications. The only other external components necessary are the input/output blocking capacitors and a V_{CC}-bypass capacitor. All amplifiers have 50Ω input and output ports.

The MAX2630 is available in a 4-pin SOT143 package, the MAX2631/MAX2632 in 5-pin SOT23 packages, and the MAX2633 in a 6-pin SOT23. All are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.66 (1000 up, FOB USA).

Smallest 1-cell DC-DC converters have built-in synchronous rectifier

The MAX1642/MAX1643 high-efficiency, 1-cell, step-up DC-DC converters are the smallest available. Their internal synchronous rectifiers save space and reduce cost. Compared with a standard Schottky diode, the synchronous rectifier also provides up to 15% more efficiency at low output voltages.

For pagers and other applications powered by 1V batteries, the MAX1642/MAX1643 save space while providing the longest battery life possible. They deliver the best combination of ultra-low quiescent supply current (40µA) and high efficiency (to 85%) to maximize battery life whether idling or active. Start-up voltage is guaranteed at 0.88V.

The MAX1642/MAX1643 save board space. Each is available in the small µMAX package (half the size of an 8-pin SO and only 1.11 mm high). The synchronous rectifier is internal, so the only external components required are two capacitors and one inductor.

The MAX1642 conserves battery life with a low-battery detector and a 2µA logic-controlled shutdown. The MAX1643 replaces the shutdown control with a second low-battery detector, enabling measurements of both "battery low" and "battery dead." Both devices have a 0.7V to 1.6V input range. Output voltages are preset at 3.3V ±4%, but can be adjusted from 2V to 5.2V using two external resistors. Output current capability is about 25mA.

The MAX1642/MAX1643 are specified for the extended-industrial temperature range (-40°C to +85°C), and prices start at $1.76 (1000 up, FOB USA). A pre-assembled evaluation kit (MAX1642 EVKIT) is available to speed designs.

NEW PRODUCTS

622Mbps, SDH/ SONET 1:8 deserializer has TTL outputs and draws 265mW

The MAX3680 deserializer is a bipolar IC that includes input/output buffers, an 8-bit shift register, and an 8-bit parallel-output register. Designed to convert 622Mbps serial data to 8-bit-wide, 77Mbps parallel data, the MAX3680 is suitable for use in SDH/SONET transmission systems, ATM/SONET access nodes, add/drop multiplexers, and digital cross connects.

The MAX3680 operates from a single 3.3V supply and consumes 265mW (typ) in normal operation. It accepts PECL-compatible serial clock and data inputs and delivers TTL-compatible outputs. It also includes a TTL-synchronization input that enables data realignment and framing as part of the interface to external, high-speed digital circuitry.

The MAX3680 comes in a 28-pin SSOP specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $34.45 (1000 up, FOB USA).

## 622Mbps, 4:1 SDH/SONET serializer has LVDS inputs, PLL clock synthesizer

The MAX3691 4:1 serializer is designed for converting 155Mbps parallel data to 622Mbps serial data in 622Mbps SDH/SONET applications. Operating from a 3.3V supply, it provides a high-speed digital interface by accepting low-voltage differential-signal clock and data inputs and delivering a 3.3V differential-PECL serial-data output.

The MAX3691 includes a fully integrated phase-locked loop (PLL) consisting of phase/frequency detector, loop filter/ amplifier, and voltage-controlled oscillator, which synthesizes an internal 622Mbps serial clock from a low-speed crystal-reference clock. By locking onto a 155.52MHz external reference, the PLL generates an internal 622Mbps for clocking the output shift register. A TTL loss-of-lock output indicates whether the PLL is operating properly.

Along with the MAX3667* laser driver, the MAX3691 is part of a complete, two-chip solution for 622Msps SDH/SONET applications. Their 3.3V power supplies, PECL input (MAX3667), and PECL output (MAX3691) simplify the design of 622Msps transmission systems.

The MAX3691 is available in a 32-pin TQFP package specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $55.00 (1000 up, FOB USA).

*Future product—contact factory for availability.
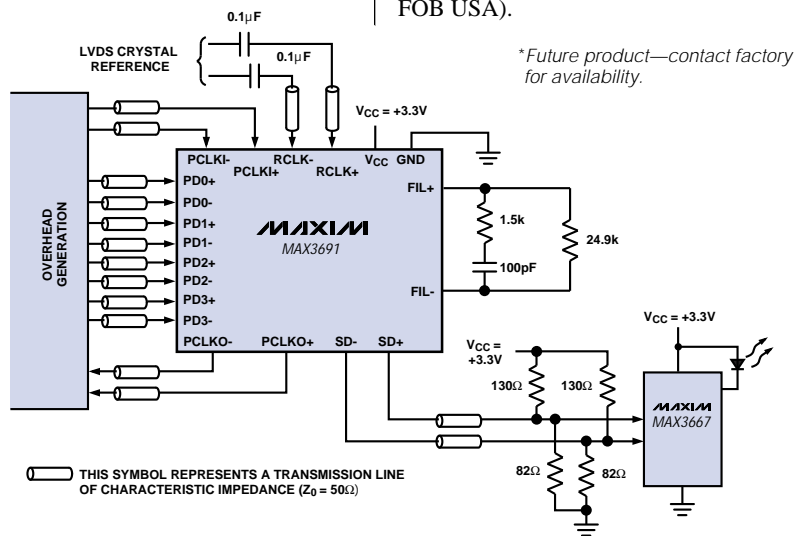
SPI-compatible UART offers the lowest power and smallest size

The MAX3100 is a universal-asynchronous receiver transmitter (UART). Operating from a +2.7V to +5.5V supply, it has a host-system interface compatible with SPI™ and Microwire™ synchronous-serial standards. It offers an asynchronous serial-data output suitable for use in RS-232, RS-485, IR, and opto-isolated data links. Applications include intelligent instrumentation, small HVAC and building-control networks, computer/peripheral IR data links, and hand-held instruments.

An internal baud-rate generator (whose oscillator is stabilized by an external crystal) produces all the common baud rates from 300 baud to 230,000 baud, and an Infrared Data Association timing mode enables communication over IR links. The MAX3100 shutdown mode (invoked by hardware or software) lowers quiescent operating current (0.5mA max at 1.8MHz) to only 10µA (max). Internal circuitry for detecting incoming receiver signals remains active during shutdown.

To minimize processor overhead on high-speed data links, the MAX3100 includes an 8-word-deep FIFO buffer. It generates an interrupt in response to four different conditions, one of which is ideal for address recognition on 9-bit networks. Each type of interrupt can be internally masked in response to one of four control-word configurations. Two general-purpose programmable lines are included: the active-low input clear to send ($\overline{CTS}$), and the active-low output request to send ($\overline{RTS}$). To support an optocoupler interface, the MAX3100 features inputs with Schmitt-trigger conditioning and outputs with 25mA sink capability.

The MAX3100 comes in 14-pin plastic DIP or 16-pin QSOP packages, in versions tested for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $2.80 (1000 up, FOB USA).

SPI is a trademark of Motorola, Inc. Microwire is a trademark of National Semiconductor Corp.

THIS SYMBOL REPRESENTS A TRANSMISSION LINE OF CHARACTERISTIC IMPEDANCE ($Z_0 = 50\Omega$)