Maxim Engineering Journal

Volume Fifteen

News Briefs

TEKTRONIX AND MAXIM FINALIZE AGREEMENT

WILSONVILLE, Ore., April 1, 1994 – Tektronix, Inc. (NYSE:TEK) and Maxim Integrated Products, Inc. (NASDAQ:MXIM) announced today that they have signed the agreements by which Maxim will acquire Tektronix' Integrated Circuits Operation. The agreements also provide that the two companies will operate Tektronix' Hybrid Circuit Operations as a corporate joint venture. Terms of the agreements were not disclosed. Completion of the transactions is subject to other conditions, and upon satisfaction of those conditions, the complete transaction is expected to close within 60 days.

The integrated circuit transaction involves the purchase of assets and facilities, and a long-term agreement for Maxim to supply components to Tektronix. Maxim will continue to supply integrated circuit products to existing Tektronix customers. The hybrid circuits corporate joint venture will also supply products to Tektronix and other customers.

"Entering into these agreements is a win-win situation for all involved. Tektronix is pleased to align itself with Maxim, a company with a reputation as a high-quality component manufacturer," said Jerome J. Meyer, Tektronix chairman and chief executive officer. "Maxim is a world class supplier when it comes to meeting customers' needs."

John F. Gifford, Maxim chairman, president and chief executive officer said, "In addition to contributing significant growth potential, this alignment strengthens Maxim's long-term strategic plan and product market direction. We are extremely happy to join forces with Tektronix, a company of both technical and market significance."

Headquartered in Sunnyvale, California, Maxim designs, develops, manufactures, and markets a broad range of linear and mixed-signal integrated circuits for use in a variety of electronic products throughout the world.

Tektronix is a portfolio of measurement, computer graphics and video systems businesses dedicated to applying technology excellence to customer challenges. Tektronix is headquartered in Wilsonville, Oregon and has operations in 23 countries outside the United States. Founded in 1946, the company ranks 305th in the Fortune 500 and had revenues of $1.3 billion in fiscal 1993.

MAXIM LEADS IN VITAL PARTS FOR NEW PORTABLE ELECTRONICS

(Investor's Business Daily—Abridged)

With the increasing use of portable computers, cellular phones, and other equipment that must interact with people, demand is growing for devices that convert signals from analog to digital and digital to analog.

"The prediction was that the world would go digital, and analog would be dead. The reality is that the world is analog—we just digitize things because computers are digital," explains John Marren, an analyst at Alex Brown & Sons.

By developing new chip sets to handle the power management and space problems of the new portable generation of battery-powered and handheld communicators, Maxim should remain a formidable analog competitor well into the next century.

Analog ICs for 3V systems

Three-volt digital ICs have quickly become popular for the power savings they offer in portable equipment. And to complement these digital ICs, the industry has created a new generation of low-voltage analog ICs, also offering the benefit of lower power consumption.

Single 3V operation is available for many op amps, comparators, and microprocessor supervisors, and for some RS-232 interface ICs. For A/D and D/A converters, analog switches, and multiplexers—which often require minimum supply voltages of 5V or ±5V—the choice is more limited. You can, however, easily provide the required voltages with a local switching regulator or charge-pump converter.

Though 3V designs are beginning to appear across the board, the switch to low voltage is most notable in systems for which size, weight, and power consumption are especially critical—palmtop computers and wireless phones, for example. And, with the increasing demand for small size and longer battery life, it is likely that blood analyzers, barcode scanners, data loggers, and other portable equipment will also follow suit.

The switch from 5V to 3V also benefits line-powered systems, because the lower power dissipation associated with 3V operation allows smaller power supplies, heatsinks, and fans. The change from 5V to 3V also means that higher-density, higher-speed logic can operate at the same level of power dissipation.

The following discussion covers 3V analog ICs, the power savings inherent in their operation, and the problems associated with low-voltage operation. It also presents methods for generating 5V from 3V, and methods for generating 3V from inputs that range above and below 3V (such as the terminal voltage of a 3-cell alkaline battery).

Power savings from 3V operation

The power saved by lowering V_{CC} from 5V to 3.3V can be dramatic. For resistive and capacitive loads, power saved is proportional to the voltage squared: $1 - (3.3/5)^2 = 56\%$. For constant-current loads such as references and op amps, the savings is linear: switching from 5V to 3.3V saves 34%. For constant-power loads such as hard-disk drives, the switch to 3V doesn't save power; it merely requires the device to operate at a lower input voltage.

Many new op amps, microprocessor supervisors, and interface ICs (along with a handful of A/D and D/A converters, voltage references, and switches) are now specified for 3V operation. The following sections discuss these product types in detail.

Interface transceivers

As design improvements reduce the overall power required by a system, power dissipated by the serial-data interface becomes increasingly significant. Fortunately, the serial interface is an area that is still amenable to power reduction in most cases. One need only switch from the old RS-232 serial-interface standard to the newer EIA/TIA-562 standard.

RS-232 appeared in the days of mainframe and mini computers, at a time when ±12V power supplies were common in such systems. Not surprisingly, the first RS-232 transceivers required ±12V for operation. Voltage drops internal to the IC reduced the output swing to about ±9V, so the required minimum was set still lower, at ±5V. Now (32 years later), the RS-232 standard is still around, with the official name of EIA/TIA-232-E (or 232E for the sake of brevity).

The advent of portable and low-voltage equipment has spawned a new serial-interface specification that can replace the 232E standard. Called EIA/TIA-562 (562 for brevity), this new standard became effective in 1991. The 562 and 232E standards are electrically compatible, so the new 562 designs will mate with existing 232E equipment and vice versa.

For a comparison of certain 232E and 562 specifications, see **Table 1**. Note that the driver output swings differ (±5V vs. ±3.7V), but the receiver input thresholds are the same (±3V). The 562 devices' ±3.7V minimum output swings allow them to communicate with 232 receivers, which have input thresholds of ±3V. The noise margin, however, is only 0.7V. By comparison, the 232 drivers' ±5V minimum swings guarantee a noise margin of 2V.

The 562 standard cuts power consumption by specifying a minimum output swing of ±3.7V (vs. ±5V for 232E). The resulting power consumption for 562 drivers is only 55% of that required for 232E drivers. Note that line drivers (not the receivers) consume most of the power. Therefore, a palmtop computer containing 562 interface ICs provides power savings whether it connects to a 562 receiver or a 232E receiver.

Maxim has four 3V interface ICs that comply with the 562 standard. Each includes a charge-pump converter for generating the required output-voltage levels. The charge pump doubles V_{CC} to create the positive level, then inverts that voltage to create the negative level. For a given IC, the required external charge-pump capacitors (a set of four) have values of either 0.1µF or 1.0µF, with the larger value supporting a larger number of drivers and receivers.

The MAX563, for example, has two drivers and two receivers, and operates with four 0.1µF capacitors. Its 116k bits per second (116kbps) data rate makes it compatible with LapLink™ software. It also provides a 10µA shutdown mode in which the receivers remain active.

This feature—active receivers during shutdown—extends battery life in portable applications. It enables the computer to monitor external devices such as the ring indicator of a modem, via the serial interface, with minimal power consumption. In remote data gathering, for example, the computer may spend much of its time waiting for a ring signal or other external stimulus. If the computer and the interface IC have no access to AC power, both can remain shut down until "awakened" by the external signal.

Maxim also offers RS-232 transceivers that operate from 3V. These chips include special high-efficiency DC-DC converters for generating the higher output swings specified by EIA/TIA-232E. High efficiency is attractive because RS-232 loads can consume several hundred milliwatts at high data rates.

Table 1. Comparison of 232E and 562 Interface Standards

PARAMETER		EIA-232E	EIA-562
Mode of operation		Single ended	Single ended
Allowed number of transmitters and receivers per data line		1 Tx, 1 Rx	1 Tx, 1 Rx
Maximum cable length		C ≤ 2500pF	C ≤ 2500pF for data rates ≤ 20kbits/sec, C ≤ 1000pF for data rates > 20kbits/sec
Maximum data rate		20kbits/sec	64kbits/sec
Driver output voltage, loaded	minimum	±5V	±3.7V
	maximum	±15V	±13.2V
Maximum driver short-circuit current		500mA	60mA
Transmitter load impedance		3kΩ to 7kΩ	3kΩ to 7kΩ
Instantaneous slew rate		<30V/µs	<30V/µs
Receiver input threshold (sensitivity)		±3V	±3V
Receiver input resistance		3kΩ to 7kΩ	3kΩ to 7kΩ
Receiver input range		±25V	±25V

™LapLink is a trademark of Traveling Software.

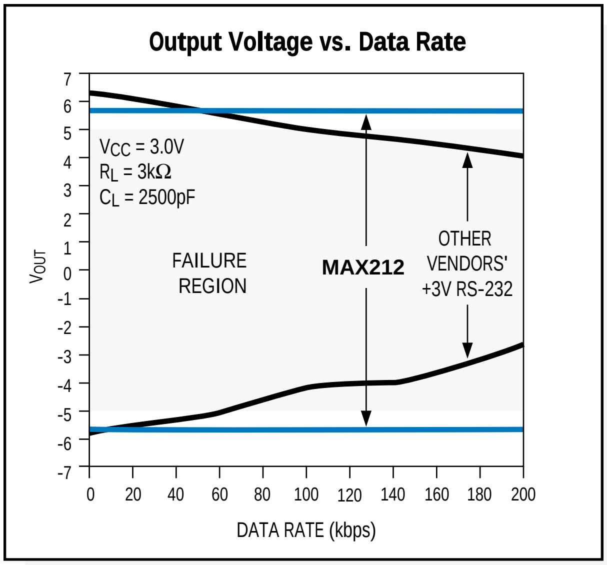


Figure 1. Maxim's 3V RS-232 transceivers, which derive their output-signal levels from a low-cost switching regulator, maintain valid levels at high data rates. Those with charge-pump triplers (from other vendors) do not.

Some manufacturers include charge-pump voltage triplers in their 3V interface ICs, but these ICs dissipate considerable power, and are unable to sustain the ±5V minimum outputs at higher data rates. Though effective in compensating for voltage drops in themselves and in their driver-output stages, voltage triplers are less efficient than the doublers used in 5V ICs. Miniature on-chip switching regulators are the most efficient at generating RS-232 voltages. That's why the new 3V RS-232E transceivers from Maxim contain efficient switching regulators rather than voltage triplers.

Switchers draw 50% less current than do charge-pump triplers. They also provide outputs suitable for powering mice and supporting high data rates (such as 116kbps for LapLink™). Other vendors' charge-pump-tripler ICs can't necessarily meet the drive requirements of a mouse (10mA at 5V and 5mA at -5V). Nor can they necessarily provide the minimum output levels (±5V) required by 232E at high data rates **(Figure 1)**.

Because many receivers have TTL voltage thresholds, it may be acceptable for an RS-232 output to fall below 5V while transmitting to another RS-232 device. Sub-5V RS-232 levels for the mouse, however, may cause it to fail. The mouse steals power from the RS-232 line to supply an internal microcontroller, whose minimum supply voltage in most cases is slightly below 5V.

The components used in the switcher and charge-pump-tripler approaches are equivalent in cost and size.

The 3V MAX212, an RS-232 transceiver with three drivers and five receivers in a 24-pin package, produces ±6.5V with a single-inductor, double-duty switching regulator. The MAX218 employs a different approach. This two-driver/two-receiver IC produces a positive output level with a boost switching regulator, and a negative output level with an inverting charge pump **(Figure 2)**.

The MAX218 operates from 3V V_{CC} or a 2-cell battery (minimum voltage 1.8V), with a guaranteed data rate of 120kbps. Its two receivers remain active during the 1µA shutdown mode, enabling the chip to monitor external devices while consuming small amounts of power. Packages include 20-pin DIPs, SOs, and SSOPs.

A/D converters

Low power consumption is a critical attribute for A/D converters operating in portable equipment. These applications often require high speed as well, but high speed and low power tend to be mutually exclusive. Accordingly, manufacturers have produced a new type of A/D converter—one that draws moderate supply currents while acquiring data, but very low currents while in shutdown. The result is a power savings for converters that operate intermittently.

The MAX152, for example, is a half-flash A/D converter whose 1.8µs conversion time produces a throughput of 400k samples per second (400ksps). Operating on 3V or

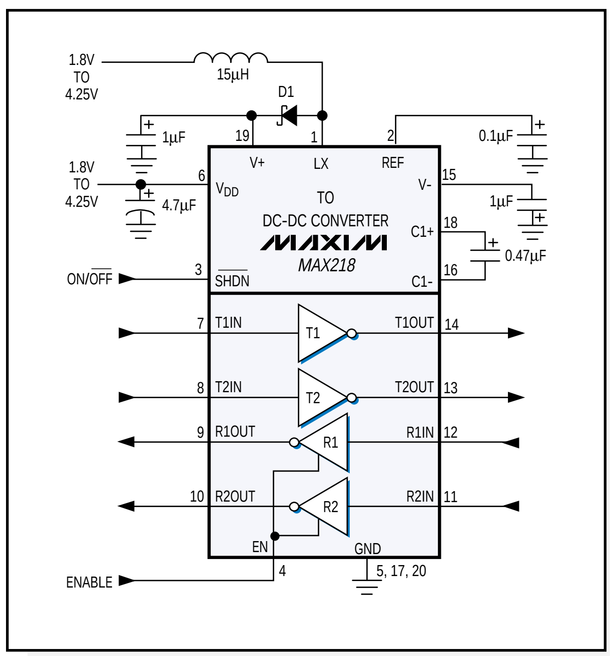


Figure 2. This low-voltage interface IC includes a high-efficiency DC-DC converter, which generates the voltages required for RS-232 communications.

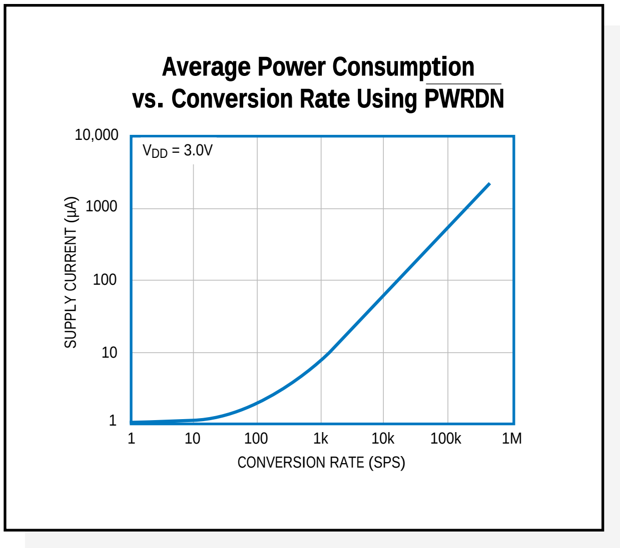


Figure 3. By entering a 1µA power-down mode between conversions, the MAX152 8-bit A/D converter offers a dramatic reduction in supply current.

±3V, it accepts unipolar or bipolar inputs. The 1.5mA operating current drops to 1µA in shutdown mode. Because the MAX152 returns from shutdown to full operation with the first acquired sample in less than 900ns, it can offer a large power savings for applications in which the sampling is intermittent **(Figure 3)**.

One such application is the measurement of received signal strength in cellular telephones (RSSI: received signal-strength indicator). The MAX152 digitizes the signal at 2ksps while drawing a mere 15µA from the 3V supply. Total unadjusted error (the sum of offset, integral nonlinearity, and gain errors) less than 1LSB is guaranteed, and SINAD (signal-to-noise and distortion) less than 45dB is guaranteed. The MAX152's 20-pin SSOP or DIP is ideal for space-sensitive applications.

D/A converters

New ICs also allow 3V digital systems to generate analog outputs. Intended for portable applications, these ICs require very little power and board area. The low-cost MAX513, for instance, is an 8-bit, voltage-output, triple D/A converter. Its low operating current (1mA) and low shutdown current (1µA) are ideal in portable applications, and its serial-data control allows it to fit into 14-pin DIP and SO packages.

The MAX513 operates from single or dual supplies, and its outputs swing to within 500mV of the rails. It has two buffered outputs plus a third, unbuffered output that allows the user to achieve higher precision. The MAX513 is attractive for low-cost applications such as trimming offset voltages, setting the bias point for adjustable current (or voltage) sources, and setting the regulation point in other circuits **(Figure 4)**.

Op amps

In op amps, reduced-supply operation lowers the signal-to-noise ratio (SNR) by curtailing the output-voltage swing. Many low-voltage op amps, therefore, offer rail-to-rail output swings as a means of preserving the SNR. For the same reason, many feature an input-voltage range that includes one or both supply rails.

Three-volt operation not only reduces the signal range, it puts an additional squeeze on SNR by raising the noise floor. Low-voltage amplifiers typically draw low supply current, which leads to higher levels of amplifier noise. In addition, the feedback resistors have higher values (to limit system supply currents), which also adds noise to the system.

To further complicate matters, high-impedance nodes are more likely to pick up noise from high-speed digital signals via capacitive coupling. You should, therefore, keep high-impedance traces short and physically distant from high-speed digital traces.

Noteworthy features for the new 3V op amps include ultra-low supply current (1µA), low offset voltage (60µV), and high speed (10MHz). Devices in the MAX492 series, for example, combine a 600kHz gain-bandwidth product and 200µV offset voltage with a low 130µA supply current. Input ranges are rail-to-rail, and outputs swing within 150mV of either rail. These characteristics make the MAX492 op amps useful as instrumentation amplifiers in low-voltage, battery-powered systems **(Figure 5)**.

The instrumentation amplifier of Figure 5 illustrates the larger dynamic range available with a wider output-voltage swing. Gain is $100(V_{IN}+ - V_{IN}-)$ and the rails are 3V and 0V, so the maximum differential input voltage (28.5mV) produces a full-scale output of 2.85V. (The 10kΩ pull-down resistor allows V_{OUT} to swing within 15mV of the negative rail.) Without pull-up or pull-down resistors, the output voltages are guaranteed to swing only within 150mV of either rail, so the input voltages have a similar restriction.

Among the newest 3V op amps are the first available monolithic, bidirectional, high-side current-sense amplifiers—the MAX471 and MAX472. These devices minimize grounding problems by eliminating current-

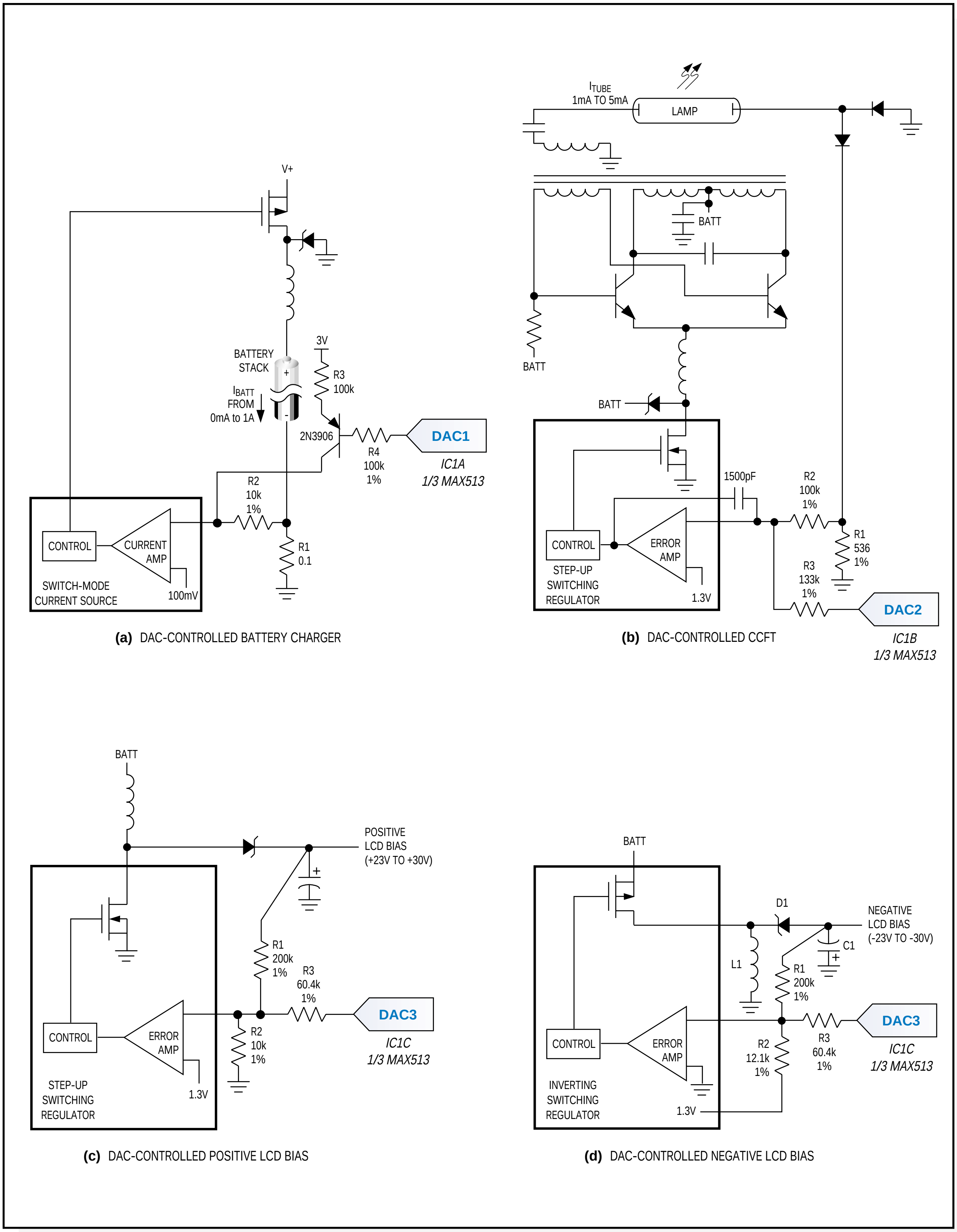


*Figure 4. The MAX513 triple, 8-bit D/A converter single-handedly controls three notebook-computer functions: battery charger **(a)**, bias for cold-cathode flourescent tube (CCFT) **(b)**, and positive **(c)** or negative **(d)** bias for the liquid-crystal display.*

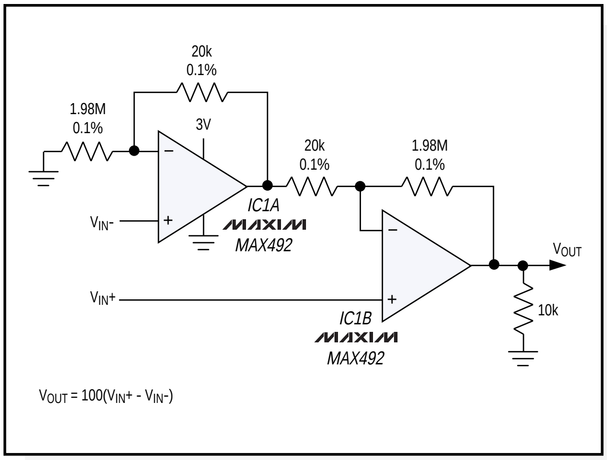


Figure 5. A wide output-voltage swing and precision (200µV offset) make this dual op amp a good choice for low-power instrumentation amplifiers.

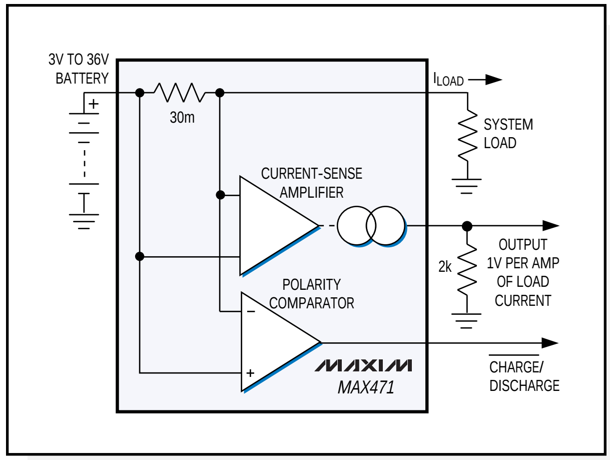


Figure 6. The MAX471 is the first available monolithic, bidirectional current-sense amplifier. With the addition of a gain-setting resistor, it forms a complete current-to-voltage converter.

sense resistors in the low-side ground returns of portable PCs, handiterminals, and other battery-powered systems **(Figure 6)**. Both come in 8-pin packages.

The MAX471's 30mΩ internal current-sense resistor enables current measurements in the range 30mA to 3A. The gain components shown provide an output of 1V/A, and the on-board polarity comparator indicates whether the batteries are being charged or discharged.

Thus, the MAX471 can monitor charge the way a gas gauge monitors gas, yielding a so-called battery gas gauge: connecting an A/D converter to the MAX471 output allows a microcontroller to track the battery's status by monitoring incoming and outgoing charge. The MAX472, similar to the MAX471, adds design flexibility with a user-specified external current-sense resistor. Both devices operate on 3V to 26V, draw less than 100µA, and conserve power with a 12µA shutdown mode.

For portable applications that must conserve every microamp, some 3V micropower op amps offer remarkably low supply currents. At 1.2µA maximum, the MAX406/MAX407/MAX409 and MAX417–MAX419 devices offer the lowest power consumption available anywhere. Outputs swing from the negative rail to within 1.1V of the positive rail, and input ranges include the negative rail.

The MAX406 (single), MAX407 (double), and MAX418 (quad) op amps are unity-gain stable with 8kHz gain-bandwidth products. The MAX409 (single), MAX417 (dual), and MAX419 (quad) devices are stable for gains 10V/V and higher, and have 150kHz gain-bandwidth products. All of these low-power devices operate between 2.5V and 10V or between ±1.25V and ±5V.

Low-voltage data-acquisition systems often require a negative reference voltage. Placing a positive reference in the feedback path of a MAX406 op amp, for example, produces a -2.50V reference **(Figure 7).** The op amp and positive reference are low-power devices, so the total current drain is only 11µA. This arrangement eliminates the feedback resistors and associated errors found in a standard inverting configuration.

Also, driving the load with an op amp eliminates any degradation of the reference voltage by load-regulation errors. The amplifier's input common-mode range determines the minimum required positive supply voltage, and the reference dropout voltage determines the minimum negative supply. These supply voltages need not be carefully regulated; the positive one can fall as low as 1.1V, and the negative one can rise as high as -2.7V.

Comparators

Like 3V op amps, the new 3V comparators include products separately optimized for high speed, low supply current, and low offset voltage. The MAX941–MAX943 family, for example, offers the first high-speed comparators capable of operating from a single 3V supply. Supply currents are only 350µA per comparator. These devices offer 80ns propagation delays, 1mV offsets, outputs that swing within 200mV of the supply rails, and a common-mode range that extends beyond the rails. Internal hysteresis ensures clean output switching, regardless of the input signal's rate of change.

The MAX941's combination of low voltage and high speed is without parallel—it excels, for example, as an overcurrent monitor in 3V systems **(Figure 8)**. The

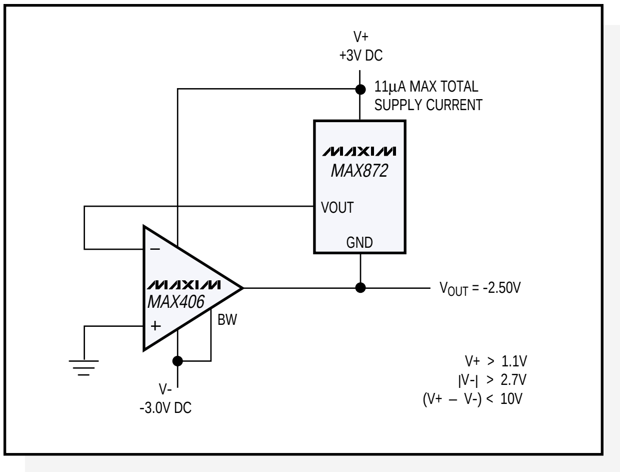


Figure 7. This negative reference, obtained by placing a positive reference in the feedback path of an op amp, draws only 11µA.

circuit of Figure 8 monitors load current through the low-side current-sense resistor R1, and compares it with a 100mV reference developed by IC1 and resistors R2 and R3. When the R1 voltage exceeds 100mV, the comparator output goes high and turns off the Q1 power MOSFET. The comparator remains latched in this state because it drives its own latch input (pin 5). A positive pulse at the base of Q2 unlatches the circuit.

Some applications—monitoring a power supply's output voltage, for instance—require ultra-low power consumption rather than high speed. Maxim has designed a family of low-power comparators for this purpose.

The MAX931–MAX934 comparator/reference ICs, for example, draw supply currents of only 3µA per comparator. Each device includes a voltage reference and one or more comparators with programmable hysteresis. The dual-comparator MAX932, for example, can implement an ultra-low-power microprocessor supervisory circuit **(Figure 9)**.

Other µP-supervisor ICs—even the lowest-power types that draw supply currents of 25µA to 100µA—may not be acceptable in applications that extend battery life by conserving every microamp of supply current. The MAX932 provides an accurate V_{CC} monitor and power-on reset while drawing only 6µA. It also generates an interrupt ($\overline{\text{INT}}$) that precedes $\overline{\text{RESET}}$ by 100µs. $\overline{\text{INT}}$ gives the processor an early warning that allows the system to perform necessary housekeeping chores before resetting the hardware.

For the early warning to work, V_{CC} must not fall too sharply during the 100µs window between $\overline{\text{INT}}$ and $\overline{\text{RESET}}$ (as it

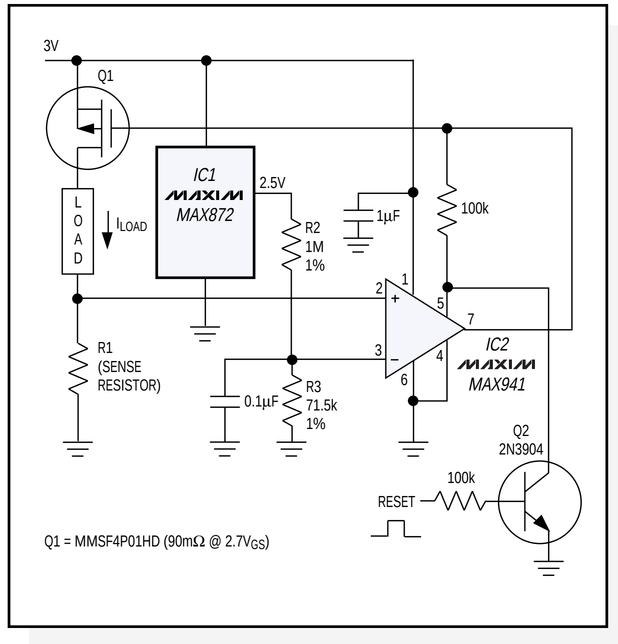


Figure 8. Low-voltage operation and speed (80ns propagation delay) make this comparator suitable as an overcurrent monitor in 3V systems.

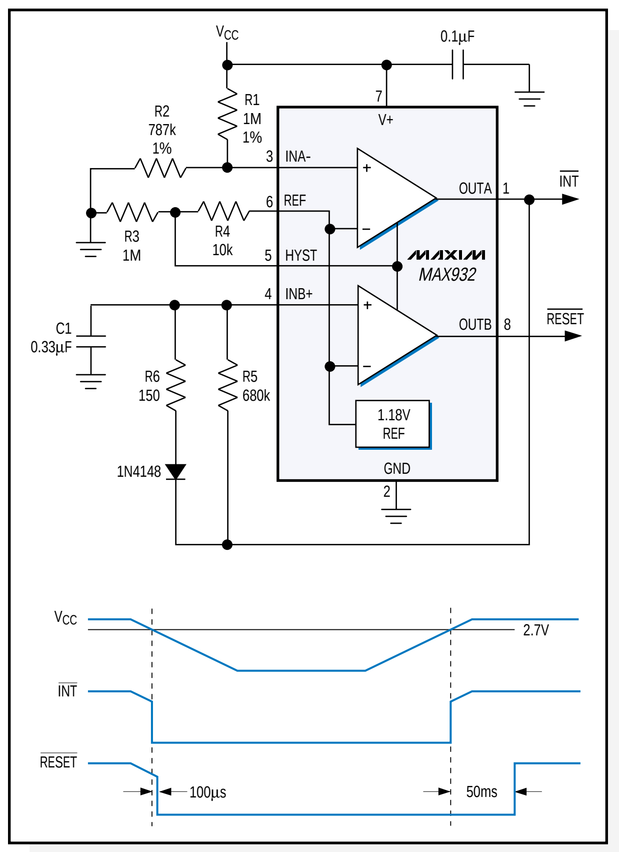


Figure 9. The MAX932—a reference and dual-comparator IC requiring only 6µA supply current—implements a micropower RESET generator. $\overline{\text{INT}}$ goes low 100µs before the reset is issued.

may if the battery is removed abruptly). You should, therefore, bypass V_{CC} with a capacitor to support the rail until the processor can execute a clean shutdown. The capacitor value depends on the load current. For 10mA loads, a 10µF capacitor allows V_{CC} to drop only 0.1V during the 100µs interval.

Microprocessor supervisory circuits

All microprocessor systems require some form of "supervision" to guard against erratic operation. The supervisor can be as simple as a reset generator, which ensures known start-up conditions by issuing a system reset following the application of power. But many include other functions as well, such as backup-battery management, memory-write protection, and "watchdog" timers for monitoring software execution.

Backup batteries, for example, ensure an uninterrupted flow of power to critical circuits (like the CMOS memory and real-time clock) when V_{CC} is absent. By monitoring V_{CC}, the µP supervisor decides when to switch the system over to the backup battery. Three-volt operation, however, presents an engineering problem that doesn't exist in 5V systems.

Five-volt systems simply compare V_{CC} with the backup voltage and switch to backup whenever V_{CC} is lower. But, this approach can cause false switchovers in a 3.3V (or 3V) system: lithium backup batteries measure as high as 3.6V when fresh, which is higher than the 3.0V limit for V_{CC} in a 3.3V system.

Maxim supervisory circuits avoid this problem by allowing the backup voltage to exceed V_{CC}, and initiating a switchover only when V_{CC} falls below 2.4V. Circuits of this type are the MAX690R/S/T, MAX704R/S/T, MAX802R/S/T, and MAX804–806R/S/T. (R, S, and T suffixes denote different V_{CC} monitor thresholds.) All come in 8-pin DIP and SO packages. On-board functions include backup-battery switchover, reset generation, watchdog timing, power-fail warning, and manual reset.

Power-fail comparators for the MAX802R/S/T, MAX804R/S/T, and MAX806R/S/T ICs have ±2% accuracy, enabling them to monitor both the 3V and 5V V_{CC} voltages in a dual-voltage system **(Figure 10)**. In this circuit, the main V_{CC} comparator monitors the 3V supply, and the power-fail (PFI) comparator monitors the 5V supply.

Internal circuitry issues a reset when the 3V V_{CC} goes out of tolerance. The 5V V_{CC}'s trip threshold (4.527V to

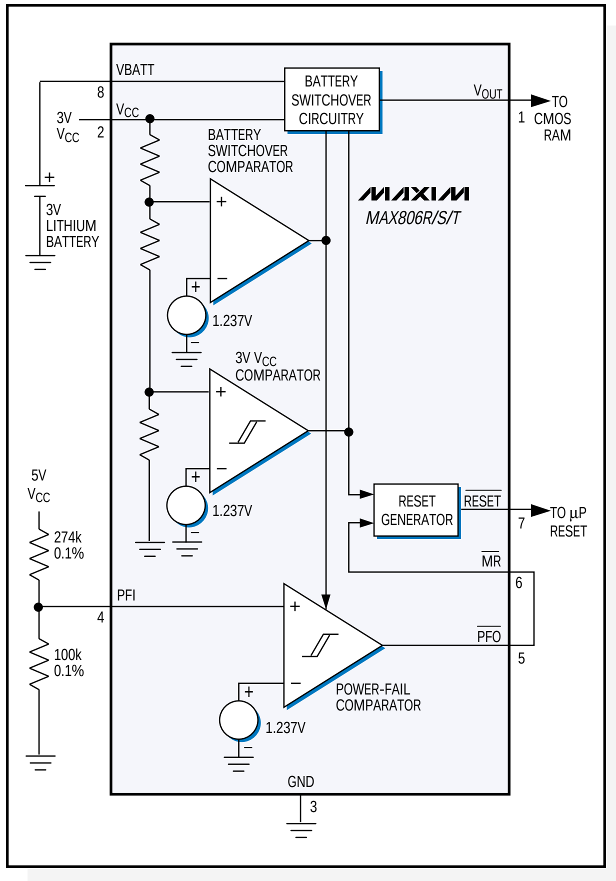


Figure 10. Configured as shown, this microprocessor supervisor monitors 5V and 3V V_{CC} in a dual-voltage system.

4.726V) is set by 0.1% resistors; when 5V falls out of tolerance, the PFI-comparator output (PFO) pulls down the manual-reset input (MR). Thus, an out-of-tolerance condition for either V_{CC} causes the chip to issue a reset.

Other 3V supervisors from Maxim protect the memory ICs with chip-enable (CE) gating. CE gating enables the supervisor to protect the memory by blocking read and write operations during power faults. The MAX792 and MAX820, for example, feature CE gating with a propagation delay through the supervisor of only 10ns. (Short delays allow slower, cheaper memories because the CE delay takes less of the memory cycle time.) These devices also offer manual reset, power-on reset, power-fail warning, and watchdog timing.

For extremely cost-sensitive applications, the MAX709 supervisor is available at $0.70 each for 25k pieces, direct from the factory. It comes in an 8-pin DIP or SO package. The MAX709 replaces the TL7705, including an external resistor and capacitor necessary for setting the TL7705's timeout period.

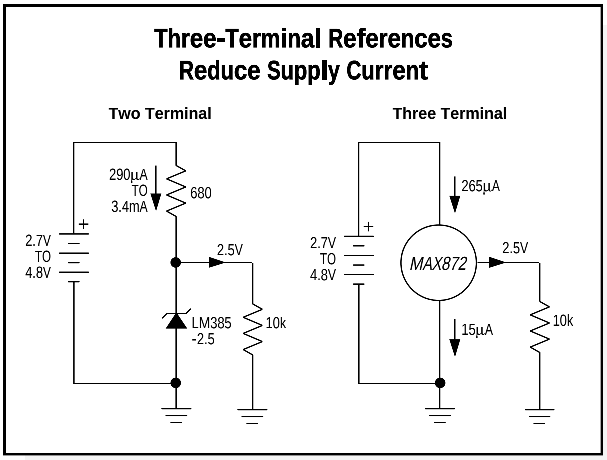


Figure 11. A 3-terminal voltage reference, unlike a 2-terminal type, draws constant supply current as the input voltage varies.

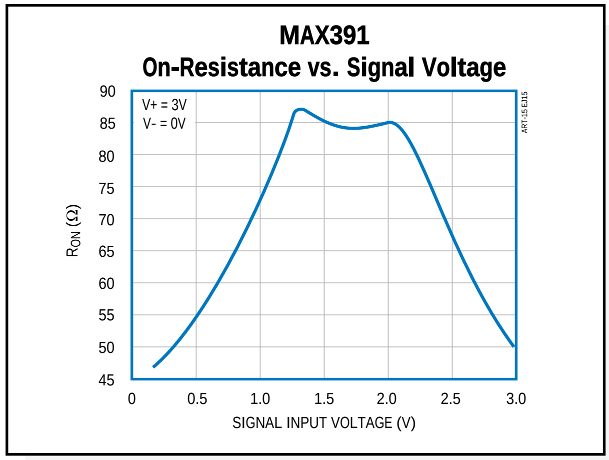


Figure 12. On-resistance for the MAX391 is superior to that of other low-voltage switches.

Voltage references

When a precision, low-voltage reference with minimal supply current is specified, you should choose a three-terminal bandgap type. Output voltage should be as high as possible for maximum signal-to-noise ratio; the input-to-output voltage should therefore be low. A 2.5V reference powered from 3V ±10%, for example, must operate with headroom as low as 200mV. Maxim's MAX872—a precision 2.5V reference—is the only bandgap type that meets this stringent requirement. It accepts inputs as high as 20V, and draws only 15µA of supply current.

The MAX872 can source or sink 500µA, with a corresponding guaranteed load regulation of 0.5mV/mA (source) and 12mV/mA (sink). Temperature drift is 40ppm/°C, and line regulation is 80µV/V over the 2.7V to 5.5V input range. For 5V operation, Maxim offers a wider selection of voltage references, along with the 3V-to-5V DC-DC converter that may be required.

Three-terminal references generally allow lower operating currents than do the two-terminal types based on zener diodes. The three-terminal MAX872 draws 15µA, for instance, and the two-terminal LM385-2.5 draws 30µA. But, the operating currents can vary greatly according to the application—particularly if the input voltage varies, as it does for many battery-powered products **(Figure 11)**.

When connected between a 10kΩ (250µA) load and a 3-cell battery (whose terminal voltage declines with discharge from 4.8V to 2.7V), the circuit's supply current remains constant at 265µA—15µA for the MAX872 and 250µA for the 10kΩ load. A two-terminal reference, on the other hand, requires a series resistor that allows adequate current at 2.7V. At higher voltages, therefore, it draws more current (3.4mA) than the reference needs.

Analog switches

Low-voltage analog switches with guaranteed precision have not been available until recently. The MAX391 family of quad single-pole/single-throw (SPST) analog switches operate from single (3V to 15V) or dual (±3V to ±8V) supplies. As expected, 3V operation yields somewhat higher on-resistance and somewhat lower switching speeds than are available with higher-voltage supplies.

MAX391 parts are fabricated in a (relatively) low-voltage process whose thin gate oxides allow tight control of the gate threshold voltage (about 0.6V). The resulting internal MOSFETs are fully enhanced at 1.2V, and therefore function well at 3V **(Figure 12)**.

DC/DC converters

Maxim has scores of regulators that generate 3V or convert 3V to other levels. They include linear regulators, switched-capacitor charge-pump converters, and switching regulators.

Linear regulators are simple, but they require an input voltage greater than the output. Charge-pump converters use capacitors for energy storage, and therefore provide small, low-cost, DC-DC conversion circuits. Die-size limitations, however, restrict the use of charge-pump converters to low-power applications.

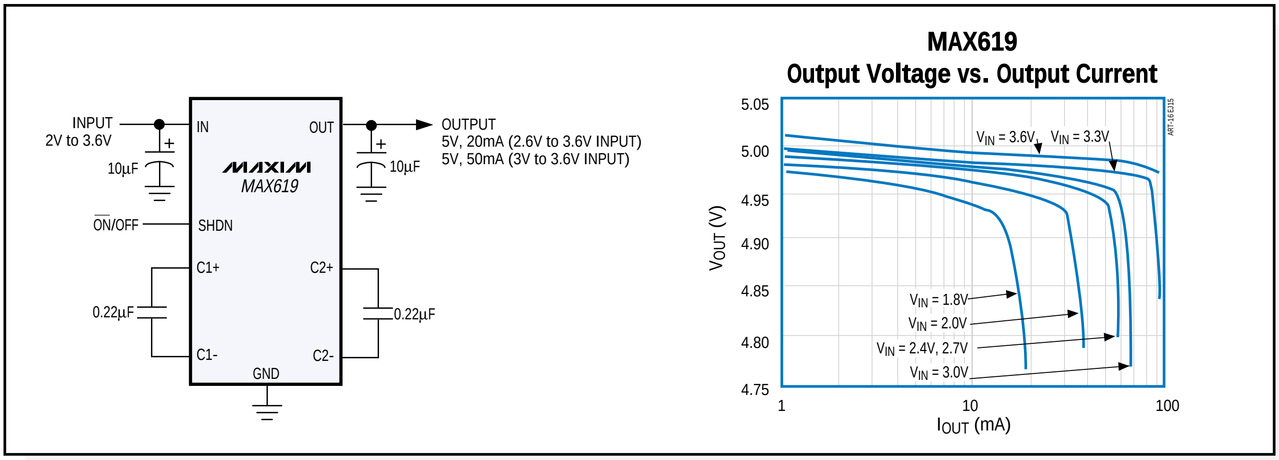


Figure 13. Occupying less than 0.1in.² of area, the MAX619 regulated charge-pump converter generates 20mA at 5V ±4% for inputs of 2V to 3.6V. (From 3V to 3.6V, the output capability is 50mA.)

Switching regulators provide single or multiple outputs, controlled by PFM (pulse-frequency modulation), PWM (pulse-width modulation), or both, depending on the output power level. PFM (or pulse-skipping) control schemes, which allow high efficiency with light loads, allow the regulator to operate with quiescent supply currents as low as 10µA. PWM schemes consume more power, but they allow a fixed-frequency operation that yields high efficiency with heavier loads. Some converters provide excellent efficiency for both light and heavy loads by switching between the two control schemes according to the load-current level.

For low-current applications, the simplest solution for boosting 3V to 5V is a capacitor-based *regulating* charge pump **(Figure 13)**. The industry-standard 7660 and most other charge pumps don't regulate V_{OUT}, but the MAX619 includes an analog reference and error amplifier whose output controls a set of internal switches connected to external capacitors. The switch/capacitor network can double or triple V_{IN}, and the MAX619 regulates by switching between these modes of operation. As indicated, this circuit produces 20mA at 5V ±4%, for inputs that range between 2V and 3.6V. For inputs between 3.0V and 3.6V, the output-current capability is 50mA.

Small size makes the Figure 13 circuit ideal for portable applications. The MAX619 comes in an 8-pin DIP or SO package, and the entire circuit (including the four external capacitors) occupies less than 0.1in.² of board area. Operating current is 150µA, and shutdown current is only 1µA maximum. Input and load are disconnected during shutdown. To generate more supply current, you can opt for an auxiliary switching regulator such as the MAX761.

Systems that handle bipolar signals usually require a negative supply, which can be generated locally if necessary. Again, the simplest solution is a charge pump such as the MAX660 or ICL7660. To provide more supply current, however, you need a switching regulator such as the MAX774. And if noise is a problem, you might consider shutting the regulator down at critical moments **(Figure 14)**.

Shutdown control is available on many switching regulators. It comes in handy on the negative supply for an A/D converter, for instance. You can avoid the regulator's noise by simply shutting it down during conversions. The output capacitor supports the negative supply voltage during those intervals.

Deriving 3V from higher input voltages requires either a linear regulator or a step-down (buck) switching regulator. Linear regulators are simpler, less noisy, and less expensive, but they dissipate more power (and generate more heat) as the applied input voltage rises. Linear regulators, however, can be quite efficient for applications with a low input-to-output differential (efficiency equals V_{OUT}/V_{IN}).

A new family of linear regulators (MAX882/MAX883/MAX884) incorporates several features of concern in the design of portable equipment: small size, low dropout, and low supply current. They supply 300mA of output current, and come in high-power SO packages that can dissipate up to 1W (vs. 450mW for conventional packages). Output voltages are 3.3V, 5.0V, and 3.3V, respectively.

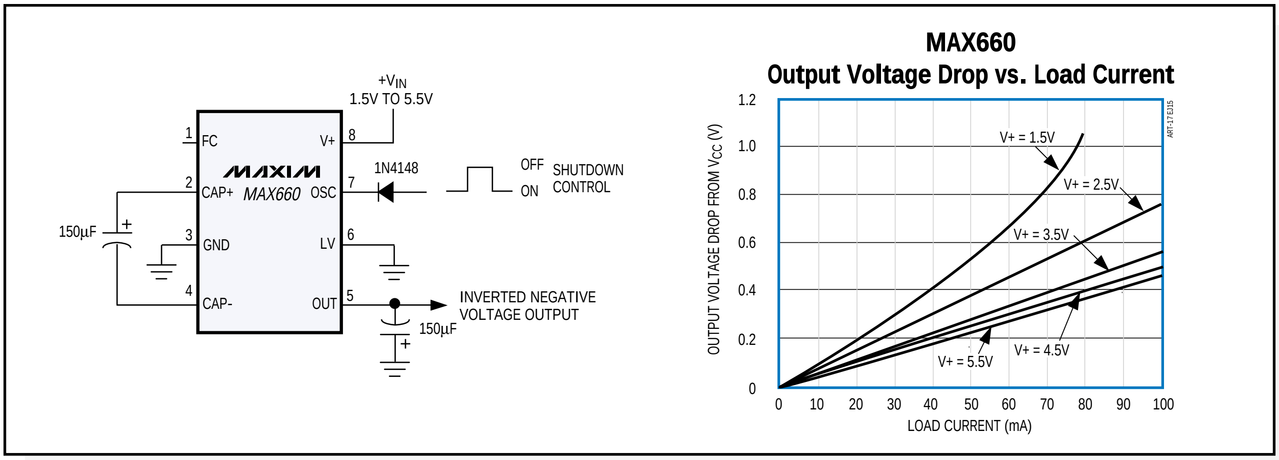


Figure 14. To eliminate noise in a downstream A/D converter, the MAX660 inverting charge-pump converter can be shut down between conversions (the output capacitor supplies current during that time).

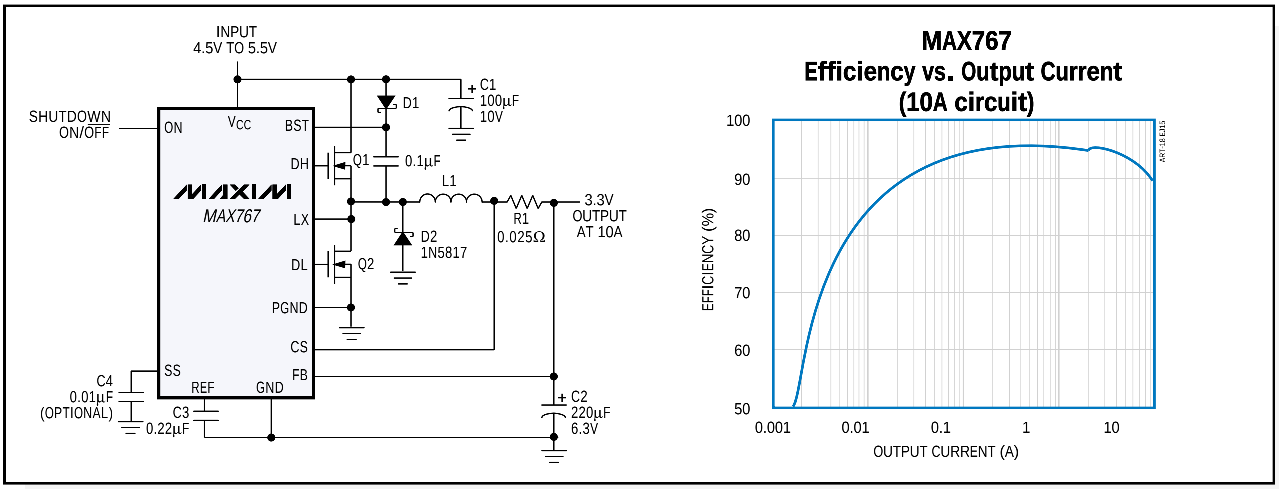


Figure 15. The MAX767 switching regulator converts 5V to 3.3V with efficiency greater than 90%. It supplies output currents to 10A, depending on the external components used.

The p-channel-MOSFET pass transistors in MAX882/MAX883/MAX884 devices help to achieve low supply current. Unlike the pnp-bipolar pass transistor found in conventional regulators, the MOSFET has no base-current overhead. MOSFETs also avoid the massive base-current losses contributed by pnp transistors when the regulator's input-to-output differential is low. Other features include a low-battery detector, an 8µA standby mode that turns off V_{OUT} but keeps the low-battery detector active, and an off mode that turns off everything, lowering the supply current to less than 1µA.

Linear regulators are efficient for low values of (V_{IN} - V_{OUT}), but for many applications the input voltage is considerably higher than the output voltage. Efficiency dictates a switching regulator in those cases, but switchers generate noise. RF applications such as radios and cellular phones, for example, must not include switching regulators that introduce noise at the sensitive IF frequency.

An ideal choice for these RF applications is the MAX748A switching regulator. It delivers 500mA at 3V from inputs of 3.3V to 16V, with efficiencies that range from 85% to 92%. The output voltage is guaranteed to be free of subharmonic noise, and guaranteed limits on the internal oscillator frequency (159kHz to 212.5kHz) assure an absence of noise in the vicinity of 455kHz—an IF frequency found in radios and cellular telephones.

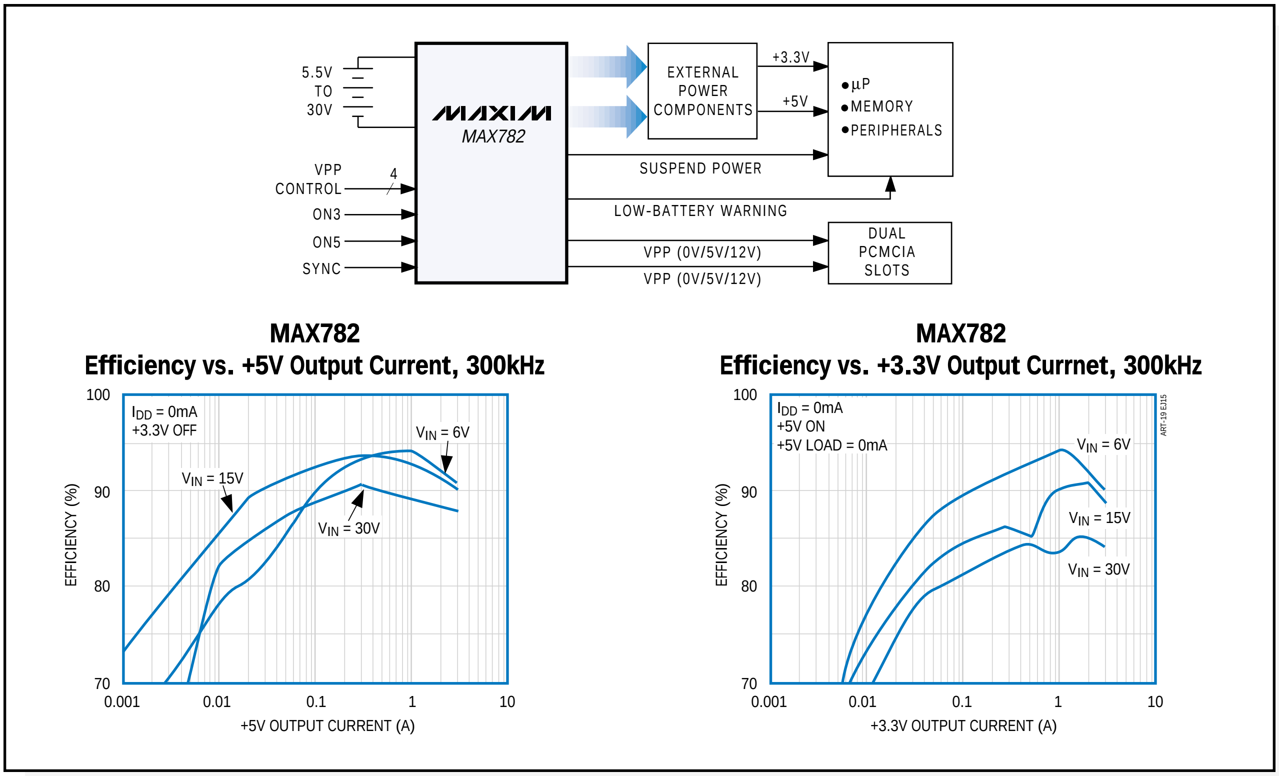


Figure 16. The MAX782 switching regulator generates dual 5V/3.3V outputs with efficiency greater than 90%. It also includes three precision comparators and a backup supply for RAM, and it generates dual V_{PP} (PCMCIA) outputs.

An efficient buck regulator is also a good choice for upgrading an existing logic board to accommodate lower-voltage, lower-power ICs. Typically, these boards have 5V available but require a 3V supply for the new low-voltage logic. A linear regulator can easily convert 5V to 3V, but for higher load currents the power dissipation is prohibitive. At 10A, for instance, the linear regulator would dissipate 20W and require a heatsink. High-efficiency switchers such as the MAX767 **(Figure 15)** deliver 30mA to 10A with efficiencies exceeding 90%, thereby eliminating the need for heatsinks.

For external power control, the MAX767 employs low-cost n-channel switching MOSFETs instead of the lossier and more costly p-channel ones. Synchronous switch Q2 reduces loss in the Schottky diode (D2) by turning on when the diode conducts, but with a smaller forward-voltage drop. Because the diode drop would otherwise be a large percentage of 3.3V, Q2 greatly increases the regulator's efficiency.

The MAX767 comes in a space-saving 20-pin SSOP package, and has an input range of 4.5V to 5.5V. Its quiescent operating current drops from 750µA to only 125µA in standby mode. High switching frequency (300kHz) allows the device to operate with small, low-cost surface-mount components. The 2.5µH inductor, for instance, is much smaller than that specified for competing ICs.

Dual-output switching regulators are intended for systems designed from the beginning to operate with dual 5V and 3V supplies. Applications such as the generation of V_{CC} voltages in a notebook computer, for example, are well served by the MAX782, which generates both of the regulated supply voltages **(Figure 16)**.

In addition to V_{CC}, the MAX782 generates dual V_{PP} (PCMCIA) outputs via a flyback winding on the 5V output. Other on-board functions include three precision comparators for low-battery detection, and dual, low-dropout linear regulators that supply backup voltages for the CMOS RAM and real-time clock.

The greatest power consumption in notebook computers usually occurs in the 5V and 3V supplies, but this consumption varies over several decades according to the mode of operation: 5W to 15W during normal operation, and 25mW to 250mW during standby. The converter that generates these voltages, therefore, must maintain efficiency for a wide range of load currents. The MAX782 (Figure 16) does just that.

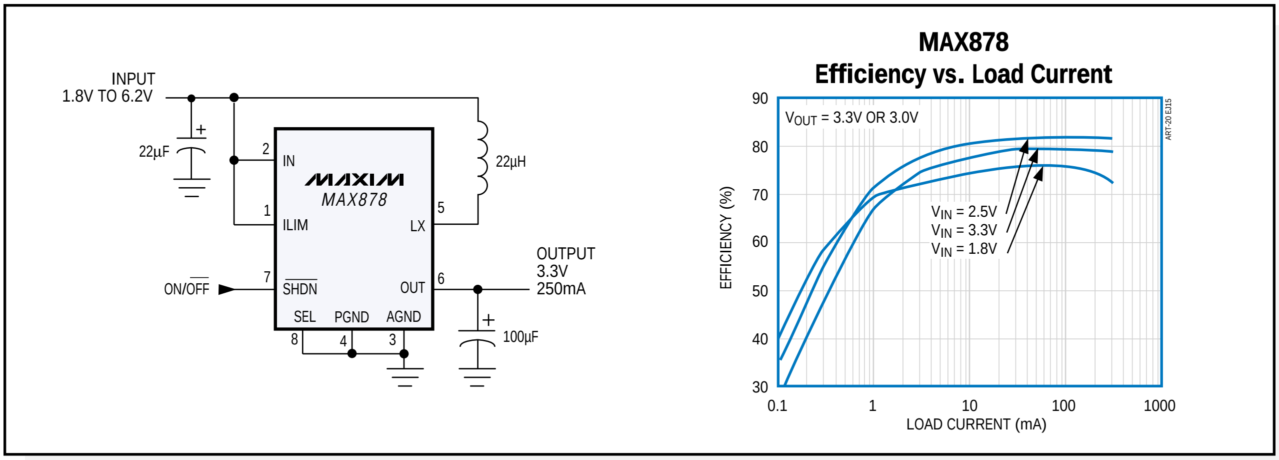


Figure 17. The MAX878 switching regulator's Active Rectifier™ enables it to deliver 250mA at 3.3V, from inputs that range above and below the output voltage.

The MAX782 achieves high efficiency with a combination of PFM (for light loads), PWM (for heavy loads), and synchronous rectification. PWM allows continuous current (an AC component superimposed on a DC offset) in the external inductor, which lowers the peak current and its associated I^2R loss.[1]

At lighter loads, the converter reverts to the PFM mode and skips most of the oscillator pulses. By reducing the pulse frequency, it dramatically reduces the switching losses associated with the charge and discharge of gate capacitance in the external MOSFETs. The result is high efficiency at light loads.

Many low-power applications require a V_{CC} of 3V, obtained from a lower voltage or from a 3-cell stack (in that case, the input voltage ranges above and below V_{CC}). MAX877 and MAX878 switching regulators excel in these applications **(Figure 17)**. The MAX877/MAX878 incorporate an internal Active Rectifier™ that ensures regulation whether the input voltage is above or below V_{CC}. The Active Rectifier™ also provides a complete disconnect between input and output when the regulator is shut down. (In most step-up DC-DC converters, the rectifying diode provides a direct connection between input and output when the input voltage is higher.)

The MAX877 and MAX878 deliver 240mA at 3.3V, with input voltages from 1.5V to 6.2V. Efficiencies can be as high as 85%, and the 220µA quiescent supply current drops to a low 20µA during shutdown. These parts operate with small and inexpensive external components (an inductor and two capacitors) because the switching frequency is a high 300kHz.

Other low-power applications require a switching regulator that starts (and operates) with a 1V input. MAX778/MAX779 devices meet this requirement; they start at 1V with a 10mA load, and require only three external components. Each part has an internal npn power switch. They can deliver as much as 300mA at 3V or 3.3V, and their low supply current (190µA) lets them achieve efficiencies as high as 80%.

For low-voltage systems that must also generate PCMCIA or LCD voltages, you should choose from the MAX717–MAX723 family of dual switching converters. And to implement a stand-alone LCD controller, choose the MAX749 in an 8-pin DIP or SO package: it operates from 2V to 6V, draws only 60µA, and provides a digitally adjustable negative output.

[1] Vargha, Douglas, "Extend battery life while minimizing size in portable equipment power supplies," Part I, *PCIM Magazine*, March 1993, p.31.

™Active Rectifier is a trademark of Maxim Integrated Products.

DESIGN SHOWCASE

Switching-regulator output is lower than V_{REF}

For typical switching regulators, the feedback arrangement does not allow regulated outputs lower than the reference voltage. If you lower the output by modifying the feedback network, the recommended compensation components may no longer stabilize the regulator's error amplifier.

The external reference voltage in **Figure 1** helps to overcome these problems. The IC regulates by maintaining the FB voltage (pin 1) equal to the internal V_{REF}. (V_{REF} normally sets a lower limit of 2.21V for V_{OUT}.) The FB voltage usually comes from a resistive divider connected between V_{OUT} and ground, but this circuit connects the divider between V_{OUT} and the higher-voltage, shunt-regulator output of zener diode D2. As you adjust R5, the resulting output voltage ranges from 2.21V down to about 1.2V:

$$V_{OUT} = V_{FB}(R1 + R2)/R2 - V_Z(R1/R2),$$

where $V_{FB} = V_{REF} = 2.21V$,
and V_Z = zener voltage = 7.5V.

Because the IC's error amplifier is inherently stable, the simple compensation components R1 and C1 assure stability following this feedback modification. You can set V_{OUT} lower than 1.2V if you also modify the compensation network. And, the feedback modification shown in this circuit can allow other regulators to produce outputs lower than V_{REF}, if you can stabilize their error amplifiers.

The highest input voltage allowed for this IC is 40V. (The MAX742H allows inputs to 60V.) If V_{IN} differs significantly from 40V, adjust R2 as necessary to return the zener current to approximately 1.5mA. R3 is an optional load resistor that prevents the otherwise unloaded output from approaching the zener voltage.

The circuit can supply 5A. It offers 0.75%/V line regulation for inputs between 30V and 40V, and 0.4%/A load regulation for output currents between 0.1A and 5A.

Losses occur in the Schottky diode (D1)—which drops about 0.2V—and in the inductor, whose series resistance is about 0.06Ω. Together, these components consume about 2W at 5A. Other sources of power consumption include output capacitor C5 and the internal, power-Darlington power transistor. At light loads, the efficiency is degraded by a relatively high supply current **(Figure 2).** The levels at DC—8.5mA in the IC and 1.5mA in the zener—increase somewhat with the switching frequency.

The MAX724's internal Darlington switch drops about 1.8V. For higher efficiency at lower load currents, choose the 2A MAX726, whose internal single-npn switch drops only 1.2V.

A related idea appeared in EDN, March 17, 1994, p 74.

(Circle 2)

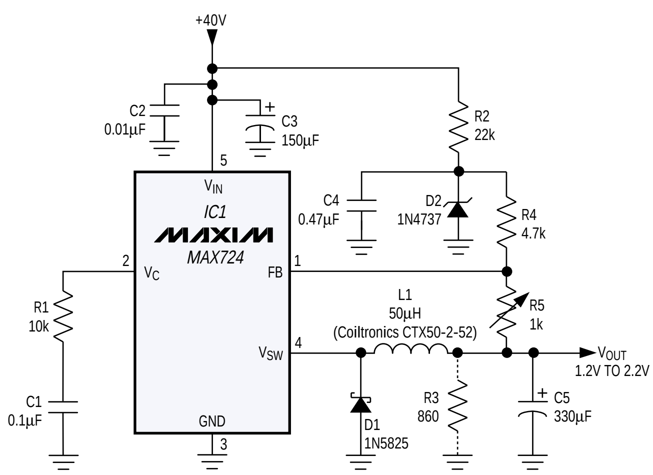


Figure 1. Connecting the R4-R5 feedback network to 7.5V (instead of 0V) enables this switching regulator to produce a regulated output lower than its internal reference voltage.

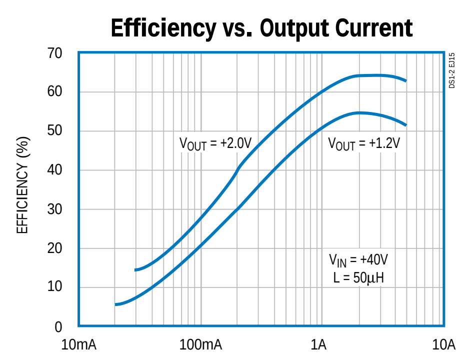


Figure 2. Substantial quiescent currents in the Figure 1 circuit lower the DC-DC conversion efficiency at low output currents.

DESIGN SHOWCASE

Switch-mode supply charges battery while serving load

In the portable-system power supply of **Figure 1**, L2 and Q2 are part of an unorthodox battery-charger configuration for the auxiliary switch-mode output (which normally generates a negative bias voltage for LCDs). Combining the battery charger with a 5V V_{CC} supply offers three advantages over alternative circuits. First, the battery can be recharged without interrupting the system. Second, the high-side current-sense resistor dissipates power only during the charge cycle (conventional low-side sense resistors remain in the ground-return path for all modes of operation). Third, the efficient switch-mode operation requires no heatsink, allowing an all-surface-mount construction.

V_{CC} power is normally obtained from a wall cube or other unregulated DC source, via the linear-regulator action of Q1. When this voltage source is removed, IC1 automatically activates an external switching regulator (L1 and D2), which maintains an uninterrupted output by boosting the battery voltage to 5V.

Battery-charger operation depends on intervention by the microprocessor that normally controls such circuits. The µP monitors battery voltage (via an on-board or external A/D converter) and, when necessary, pulls NEGON high (pin 2) to command a charging sequence. IC1 then toggles Q1 at approximately 300kHz, such that the average current through R3 is about 2A. When the µP senses full charge (indicated by a change in slope of the charging voltage), it terminates the charge by driving NEGON low.

Charging current is regulated indirectly by an internal comparator that causes Q2 to switch off (for 1µs) when the voltage across R3 exceeds a threshold of 200mV. Higher wall-cube voltage causes a steeper inductor-current ramp, producing a steeper sense-

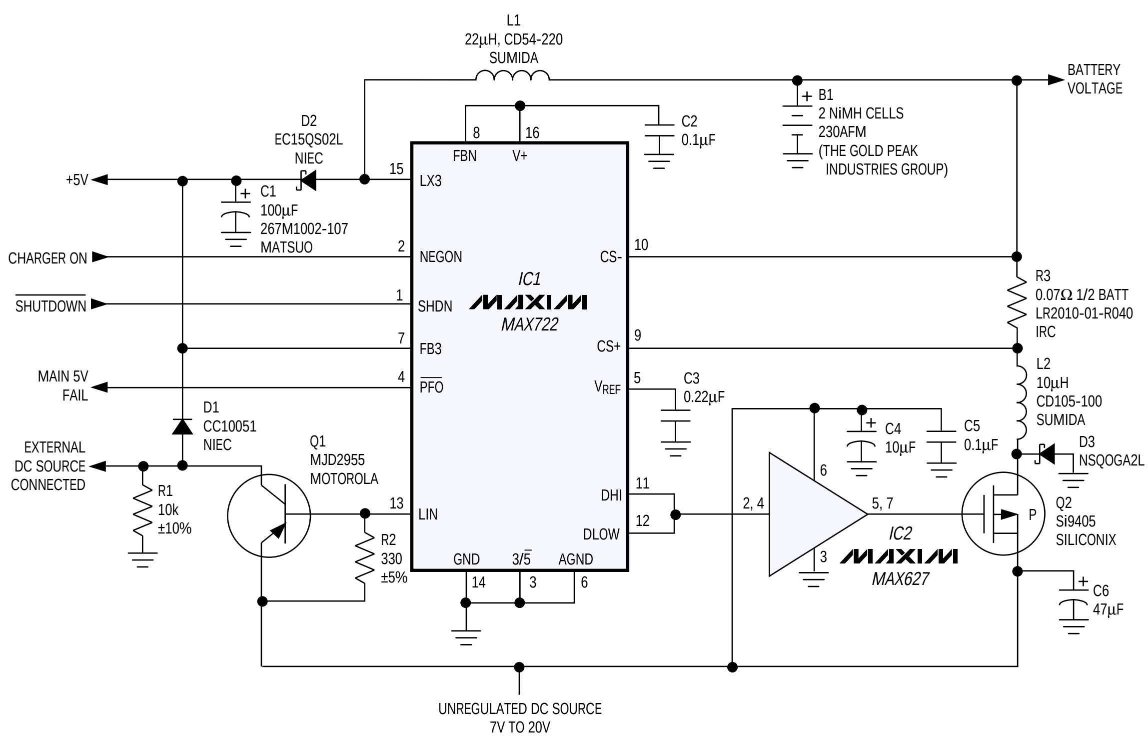


Figure 1. Suitable for palmtop computers and other portable systems, this power supply can recharge the battery while maintaining an uninterrupted 5V V_{CC}.

resistor voltage ramp, which allows higher peak inductor currents (I_{PEAK}) during the comparator's fixed propagation delay. The result is a slight increase in average charging current with the applied DC voltage **(Figure 2)**.

Charging current is more strongly influenced by the inductor (L2) and current-sense resistor (R3). The equation for I_{CHARGE} is simplified by the inductor's continuous-conduction mode of operation (inductor current remains non-zero during each cycle):

$$I_{CHARGE} = I_{PEAK} - \tfrac{1}{2} t_{OFF}(V_{BATT} + V_{DIODE})/L2,$$

where $t_{OFF} = 1\mu s$ and $I_{PEAK} = 0.2/R1$.

In Figure 1, therefore:

$$I_{CHARGE} = 0.2/0.09 - \tfrac{1}{2} 10^{-6}(2V + 0.45V)/10^{-6} = 2.09A.$$

A related idea appeared in EDN, December 9, 1993, p 64.

(Circle 3)

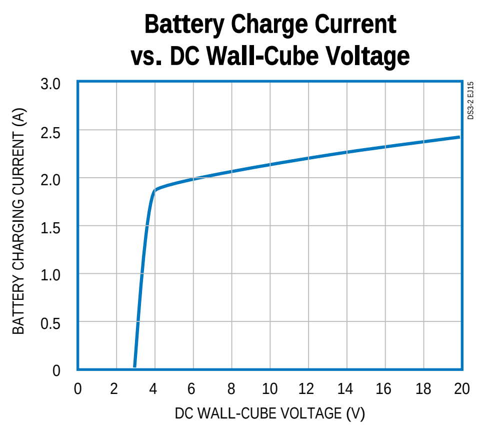


Figure 2. Available charging current increases slightly with the applied DC voltage in Figure 1.

DESIGN SHOWCASE

Boost converter has high efficiency at light loads

In most DC-DC converters, the normal supply currents do not allow high efficiency at low load currents. The circuit in **Figure 1**, however, contains micropower components that enable it to maintain 90% efficiency for load currents as low as 1mA. IC1 (a quad Schmitt-trigger NAND gate) draws maximum quiescent currents of only 0.25µA, and IC2 (a combination voltage reference and comparator) draws only 2.5µA.

IC2 compares its own reference voltage against the circuit output, V_{OUT}. The resulting comparator output (pin 8) is high when V_{OUT} is above its threshold and low otherwise. The quad NAND gate is configured as an oscillator, a set/reset latch, and a buffer inverter. The latch blocks oscillator pulses when the comparator output is high. When it goes low, the pulses pass through to Q1's gate and activate the boost regulator.

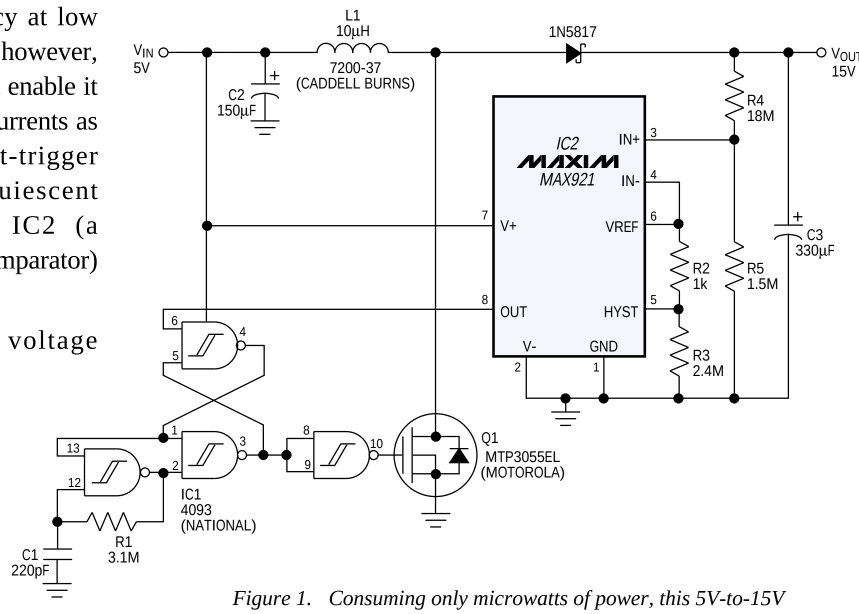


Figure 1. Consuming only microwatts of power, this 5V-to-15V boost converter provides low load currents with high efficiency.

R4 and R5 help determine the circuit's DC output level: $V_{OUT} = V_{REF}(1 + R4/R5)$. The output voltage ripple for light loads depends on the comparator's hysteresis. With R3 = 2.4MΩ, the hysteresis in millivolts equals the value of R2 in kilohms. Then, the ripple in millivolts equals $V_{REF}(1 + R4/R5)(R2)$, where R2 is in kilohms. For this circuit, ripple = 1.182V(1 + 18/1.5)(1) = 15.4mV.

(Circle 4)

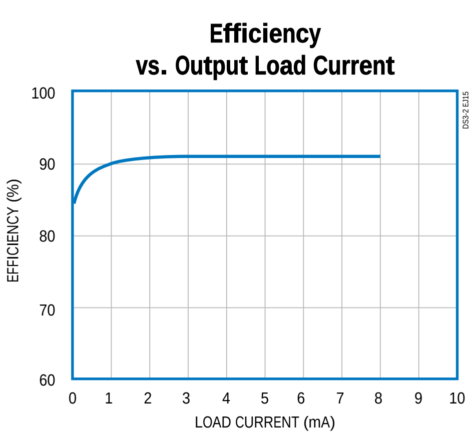


Figure 2. Efficiency in the Figure 1 circuit exceeds 90% for load currents between 1mA and 8mA.

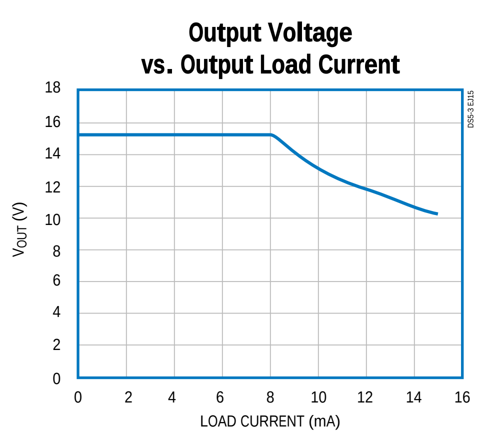


Figure 3. The oscillator frequency in Figure 1, set low to conserve power, also sets a sharp limit on load current.

NEW PRODUCTS

Triple, 8-bit DACs have serial data and control

The monolithic MAX512 and MAX513 are triple, 8-bit D/A converters (DACs) with serial inputs and voltage outputs. The MAX512 operates on 5V or ±5V, and the MAX513 operates on ±3V or any single 3V supply in the range 2.7V to 3.6V.

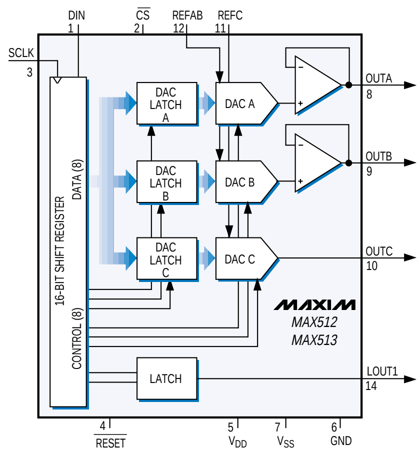
The fast, 5MHz serial interface, compatible with SPI™, QSPI™, and MicroWire™ synchronous serial-interface standards, feeds a 16-bit shift register that holds 8 bits of data and 8 bits of control information. An 8-bit latch preceding each DAC enables the rising edge of $\overline{CS}$ to strobe an update of any one DAC register or a simultaneous update of all three.

Three control bits select one DAC (or all three) for updating, and three more bits select one (or all three) for shutdown. Maximum supply currents are less than 1mA/DAC during normal operation and 1µA/DAC during shutdown. A remaining control bit programs the latched output LOUT, which is available for use as a digital control line.

The MAX512/MAX513 come in 14-pin DIP and narrow-SO packages. Their low power consumption and small size make them ideal for portable and battery-powered applications such as programmable attenuators and digitally adjustable offset, gain, and RF-bias circuits. Each IC is available in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $2.85 (1000 up, FOB USA).

(Circle 5)

BLOCK DIAGRAM



Quad, 12-bit, V_{OUT} DACs offer ½LSB accuracy in 16-pin SOs

The MAX536 and MAX537 are the smallest and most accurate quad, 12-bit D/A converters (DACs) available. Ideal for servo control and precision, fast-settling applications, these devices each replace four 12-bit DACs and four precision op amps with a single, space-saving DIP or SO package.

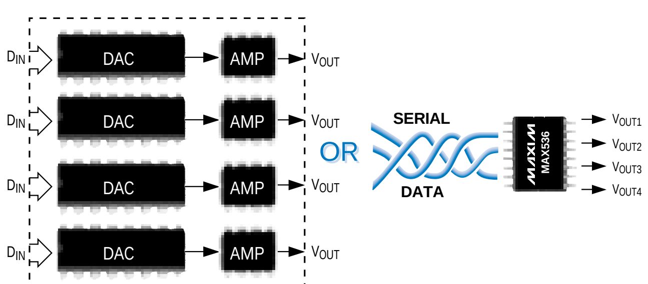
Each includes a fast, 3-wire, 10MHz serial interface compatible with the SPI™, QSPI™, and MicroWire™ synchronous serial-interface standards. The serial interface aids opto-isolation, frees I/O pins at the microcontroller, reduces package size, and saves space by reducing the number of pc traces to be routed. The double-buffered serial inputs consist of an input register followed by a DAC register. They operate on 16-bit digital words, which contain the 12-bit data and the four control bits that specify independent or simultaneous updating.

The converters guarantee 12-bit monotonicity, ±½LSB relative accuracy, and ±1LSB total unadjusted error (MAX536). The MAX536 provides a 10V output swing with supply voltages of -5V and 12V to 15V, and the MAX537 provides a 2.5V output swing with ±5V supplies.

The MAX536/MAX537 come in 16-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $16.95 (1000 up, FOB USA).

(Circle 6)

REPLACE 4 12-BIT DACs & 4 OP AMPS!



50mA DC-DC inverters are the world's smallest

At 0.1in.², the MAX860 and MAX861 are the world's smallest DC-DC voltage inverters capable of producing 50mA. Operating with small external capacitors and no inductors, these charge-pump ICs convert positive inputs (1.5V to 5.5V) to the corresponding unregulated negative outputs (-1.5V to -5.5V). Typical output impedance is 15Ω.

To optimize capacitor size, supply current, and output impedance in a given application, you select one of three fixed internal frequencies: 6kHz to 130kHz for the MAX860, and 13kHz to 250kHz for the MAX861. The MAX860 at 130kHz requires 4.7µF capacitors; the MAX861 at 250kHz requires 2.2µF capacitors. Typical quiescent supply currents range from 180µA to 3.3mA, depending on the frequency selected, and a logic-controlled shutdown pin reduces the current to less than 1µA. By comparison, the pin-compatible, industry-standard 7660 inverter switches at 5kHz, exhibits 55Ω output impedance, and requires 10µF capacitors.

These charge-pump devices can also be configured as voltage doublers. Both are pin compatible with the 7660 charge pump. Applications include medical instruments, interface power supplies, hand-held instruments, power supplies for op amps and other analog circuitry, and GaAsFET-bias supplies. An evaluation kit (MAX860EVKIT-SO) helps speed your design cycles.

The MAX860/MAX861 come in 8-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $1.75 (1000 up, FOB USA).

(Circle 7)

NEW PRODUCTS

5V CMOS analog switches guarantee 35Ω on-resistance

The MAX391, MAX392, and MAX393 each contain four single-pole/single-throw (SPST) analog switches. MAX391 switches are normally closed (NC); MAX392 switches are normally open (NO); and the MAX393 has two NC and two NO switches. Each device is guaranteed to operate at 3V and is fully specified for operation at 5V and ±5V.

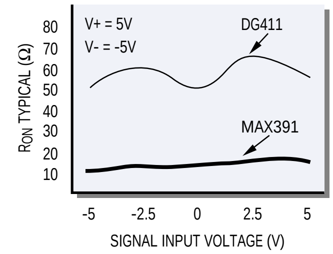
The three devices have low on-resistance (25Ω typical), with channels guaranteed to match within 2Ω. Variations per channel are no greater than 4Ω over the specified signal range. Charge injection is guaranteed no greater than 5pC, and leakage current has been improved—to 2.5nA maximum at +85°C. Digital inputs are TTL/CMOS compatible, and power consumption is an ultra-low 1μW.

Fast break-before-make switching makes the devices ideal for multiplexer applications; multiple outputs can be tied together with no concern for momentary shorting between channels. Other applications include low-voltage, high-accuracy data acquisition, 5V and ±5V DACs and ADCs, audio-signal routing, and battery-operated systems.

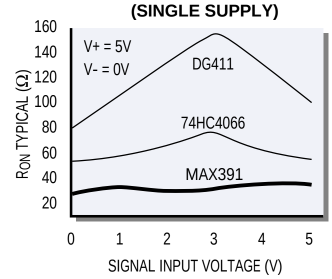
The MAX391/MAX392/MAX393 come in 16-pin DIP and narrow-SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $1.87 (1000 up, FOB USA).

(Circle 8)

R_{ON} vs. SIGNAL VOLTAGE (DUAL SUPPLIES)



R_{ON} vs. SIGNAL VOLTAGE (SINGLE SUPPLY)

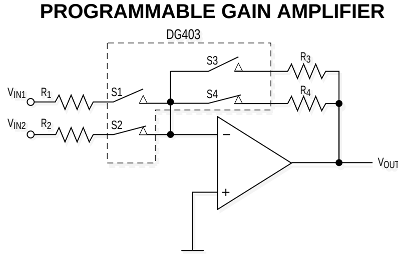


Improved switch/mux family offers more accurate signal processing

The analog switches and multiplexers of Maxim's new DG400 family are plug-in compatible upgrades for the industry-standard parts, and meet all the original DG400 specifications. In addition, they are the first to guarantee 3Ω on-resistance match between channels and 4Ω flatness over the analog signal range. The result is improved linearity and accuracy with lower distortion—for attenuators, tuned filters, sample/hold amplifiers, and programmable-gain amplifiers.

Only DG400 devices from Maxim guarantee a maximum for charge injection (10pC). They also feature ESD protection in excess of 2000V (per MIL-STD 883, Method 3015.7) and low leakage over temperature (<5nA at +85°C). Fabricated with a new silicon-gate process, the Maxim parts are TTL/CMOS compatible and handle rail-to-rail signals. They operate from single supplies of 10V to 30V or bipolar supplies of ±4.5V to ±20V.

PROGRAMMABLE GAIN AMPLIFIER



Devices in Maxim's DG400 family come in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Please contact the Customer Service Department for prices and package options.

(Circle 9)

1A step-down controllers draw only 100µA

The MAX649, MAX651, and MAX652 DC-DC step-down controllers provide efficiencies greater than 90% for output currents from 10mA to 2A—a dynamic range of 200:1! They maximize battery life in alarms, detectors, and other systems that "sleep" for long periods and then deliver relatively high power.

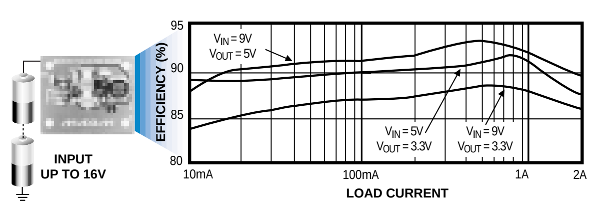
The devices accept inputs from 4V to 16.5V, and generate regulated outputs of 5V, 3.3V, and 3V, respectively. The outputs are also adjustable from 1.5V to V_{IN}, using two external resistors. Each controller delivers as much as 5W to a load. Each has a low 100μA quiescent current and a low 5μA shutdown current (maximum over temperature), which eliminates the need for a low-current backup regulator or DC-DC converter.

The MAX649/MAX651/MAX652 operate with tiny external components, forming all-surface-mount circuits only 0.7in.^{2} in area. The ICs drive p-channel MOSFETs at a high frequency (to 300kHz), which enables the use of inductors only 5mm high and less than 9mm in diameter.

The MAX649/MAX651/MAX652 come in 8-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $1.60 (1000 up, FOB USA).

(Circle 10)

90%-EFFICIENT STEP-DOWN CONVERSION OVER A 200:1 LOAD RANGE



NEW PRODUCTS

3V-to-5V step-up controllers are 80% efficient from 1mA to 1A

MAX770–MAX773 DC-DC step-up controllers are 80% to 85% efficient for load currents from 10mA to 1A—a dynamic range of 100:1. These compact devices save space and extend battery life in systems that sleep for long periods but awaken periodically to deliver high power (detectors and alarms, for example). Quiescent current is 110µA (maximum over temperature), dropping to 5µA (max over temp.) in the logic-controlled shutdown mode.

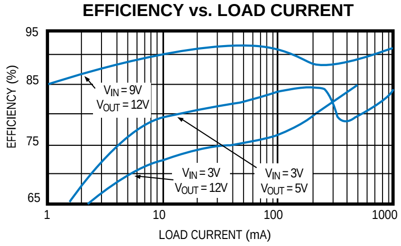
The current-limited PFM control scheme maintains high efficiency over a wide load range. These ICs drive n-channel MOSFETs at frequencies to 300kHz, in circuits that occupy less than 0.7in.^{2}. The all-surface-mount circuits use small 150µF capacitors and a small, inexpensive 33µH inductor.

The MAX770/MAX771/MAX772 controllers accept minimum inputs of 2V, and provide preset outputs of 5V, 12V, and 15V, respectively. The outputs can also be user-adjusted with two external resistors. The MAX773 has a shunt regulator that enables it to accept inputs from 3V to beyond 16V.

The MAX770/MAX771/MAX772 controllers come in 8-pin DIP and SO packages, and the MAX773 comes in 14-pin DIP and narrow-SO packages. Each comes in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $2.15 (1000 up, FOB USA).

(Circle 11)

EFFICIENCY vs. LOAD CURRENT



1A step-down regulators come in 16-pin SO

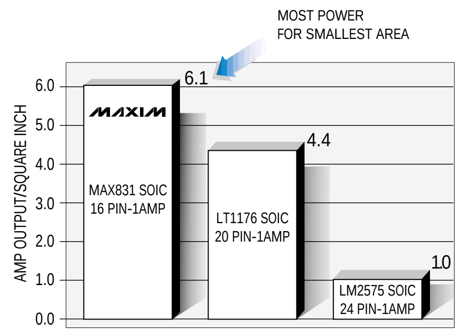
The MAX830–MAX833 are switch-mode, step-down, DC-DC regulators with pulse-width-modulation (PWM) control. Few external components are required—each monolithic-bipolar device includes control circuitry, an oscillator, and a 1A power switch.

MAX831/MAX832/MAX833 outputs are preset at 5V, 3.3V, and 3V, respectively; the MAX830 output is adjustable. All the regulators accept input voltages from 8V to 40V. All have excellent dynamic and transient response characteristics, and all have the following features: preset 100kHz oscillator frequency, 8.5mA quiescent current, and cycle-by-cycle current limiting that protects against overcurrent and short-circuit faults.

Applications for the MAX830–MAX833 include multiple-output buck converters, distribution of power from high-voltage buses, and high-current, high-voltage step-down supplies. The MAX830–MAX833 come in 16-pin SO packages, in versions tested for the commercial (0°C to +70°C) and extended-industrial (-40°C to +85°C) temperature ranges. Prices start at $3.99 (1000 up, FOB USA).

(Circle 12)

SMALLEST BOARD AREA PER AMP
IN A SURFACE-MOUNT PACKAGE!



Extend battery life while boosting two cells to 5V or 3.3V

MAX856–MAX859 step-up DC-DC converters extend battery life with the world's best combination of high efficiency, low quiescent current, and ultra-low shutdown current. High switching frequency and low current limit (0.5MHz, 125mA) permit the use of small 11¢ inductors only 2.6mm high. Low profiles suit these devices for use on type I PCMCIA cards.

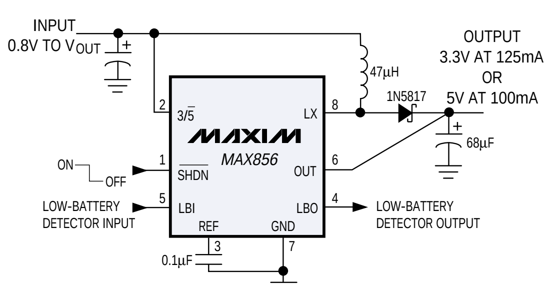
The MAX856, for instance, has a 25µA quiescent current, 85% efficiency (delivering 5V from a 2.5V input), and less than 1µA shutdown current. The MAX856 and MAX857—lower-cost, lower-current versions of the MAX756 and MAX757—deliver 100mA at 5V with a peak current limit of 500mA for the internal switching transistor. The MAX858 and MAX859 deliver 25mA with a current limit of 125mA.

MAX856/MAX858 devices offer pin-selectable 3.3V or 5V outputs; MAX857/MAX859 devices let you adjust the output from 2.5V to 6V using two external resistors. All MAX856–MAX859 devices guarantee start-up at 1.8V and operation down to 0.8V. Each converter includes a low-battery detector (LBI/LBO). An evaluation kit (MAX856EVKIT-SO) will help speed your design cycles.

The MAX856–MAX859s are intended for use in palmtop computers, PCMCIA cards, PDAs, 2- and 3-cell battery-powered systems, portable data-collection equipment, and medical instrumentation. They come in 8-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $1.70 (1000 up, FOB USA).

(Circle 13)

TYPICAL OPERATING CIRCUIT



NEW PRODUCTS

High-side current-sense amplifiers are ±2% accurate over temperature

The MAX471 and MAX472 are dedicated, bidirectional, high-side current-sense amplifiers—especially useful in portable applications because they can sense a battery's charge and discharge currents without interrupting the ground path. They reduce design time, cost, and board space in portable computers and handiterminals by eliminating precision amplifiers and resistor networks.

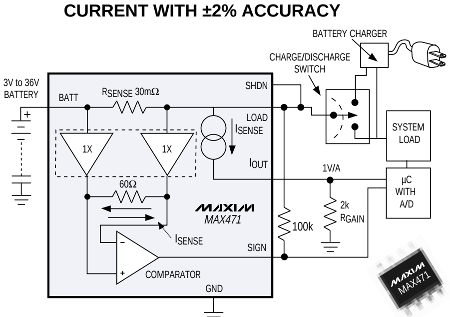
The MAX471 includes a 30mΩ sense resistor that enables measurement of battery currents from 30mA to 3A. The MAX472 operates with an external sense resistor that allows measurement of other ranges as required. Both devices operate from 3V to 36V, draw less than 100µA over temperature, and provide a power-saving shutdown mode that draws only 12µA.

Placed in series with the positive battery terminal and load, the MAX471 requires only two external resistors for operation. Each chip produces a digital output indicating direction of the sensed current. A current output (rather than voltage) allows the user to scale the output voltage as required with an external gain-setting resistor (2kΩ, for instance, produces a gain of 1V/A). Accuracy is ±2% over temperature.

The MAX471/MAX472 come in 8-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C) and extended-industrial (-40°C to +85°C) temperature ranges. Prices start at $1.70 (1000 up, FOB USA).

(Circle 14)

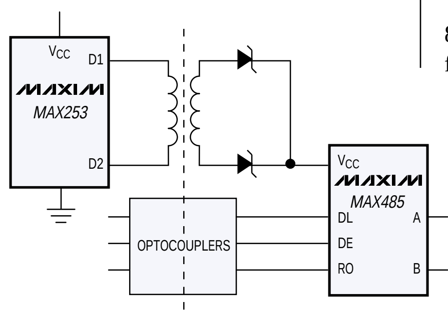
MEASURE BATTERY CHARGE/DISCHARGE CURRENT WITH ±2% ACCURACY



5V IC provides isolated power for RS-485 circuits

The MAX253 is a monolithic oscillator and power driver that provides isolated 5V power for RS-485 or RS-232 applications. By driving the primary of a center-tapped transformer and rectifier, it forms a circuit that delivers 300mA (1.5W) at the 5V output. The internal oscillator frequency is pin-selectable at 200kHz or 350kHz.

MAX253 DRIVING A MAX485



A low-power shutdown mode reduces the already low operating current (5mA maximum, 1mA typical) to only 10µA maximum. Low on-resistance in the internal power switch (1.5Ω) helps to stabilize the output voltage, regardless of load. And by combining the MAX253 with optoisolators and an RS-485 IC from the MAX483–MAX491 family, you can build a complete, optically isolated RS-485 transceiver.

The MAX253 comes in a space-saving, 8-pin µMax package that occupies one-fourth the area of a standard 8-pin SO package. It comes in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $1.25 (1000 up, FOB USA).

(Circle 15)

3V µP supervisors are first to offer backup-battery switchover

MAX690R/S/T, MAX802R/S/T, MAX804R/S/T, and MAX805R/S/T microprocessor supervisors are especially designed for 3V and 3.3V operation (as opposed to 5V devices respecified for 3V operation). The MAX690R/S/T and MAX802R/S/T issue RESETs, and the otherwise identical MAX804R/S/T and MAX805R/S/T issue $\overline{\text{RESET}}$s. Each device asserts the reset signal after a 200ms delay following power-up, power-down, or brownout conditions.

Each device provides automatic backup-battery switchover when the main power supply fails. Note that 5V supervisors, which simply choose the higher of the backup and V_{CC} voltages, cause erroneous switchovers in a 3V system because the backup-battery voltage (3V to 3.6V) is typically greater than V_{CC} (2.7V to 3.6V). To avoid this problem, devices in the MAX690R/S/T family switch to backup only when V_{CC} falls below 2.4V.

Devices in the MAX690R/S/T family include a supply-voltage monitor, a 200ms time delay, and a 1.6sec watchdog timer. Normal operating currents are 200µA for the MAX690R/S/T and MAX802R/S/T, and 50µA for the MAX804R/S/T and MAX805R/S/T. In backup-battery mode they draw only 50nA. Device suffixes R, S, and T designate the available voltage-monitor thresholds (2.55V to 2.70V, 2.85V to 3.00V, or 3.00V to 3.15V).

Devices in the MAX690R/S/T family come in 8-pin DIP and SO packages, in versions tested for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), and military (-55°C to +125°C) temperature ranges. Prices start at $3.23 (1000 up, FOB USA).

(Circle 16)

TRUE 3V µP SUPERVISOR