MAXIM
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News Briefs

FORBES RATES MAXIM AMONG AMERICA'S BEST SMALL COMPANIES

For the fourth consecutive year, Maxim Integrated Products is among America's most prosperous small companies—an incredible accomplishment considering only 16 companies out of 500 have been on the list all four years. Most firms last only two years on the Forbes list, but, after 30 consecutive quarters of increasing profits, Maxim's winning wave continues.

Maxim consistently creates analog solutions that add value to customers' microprocessor-based technology. A record 33 products were announced in the first quarter of fiscal year 1994. And in the last 10 years, Maxim has introduced over 600 products—more than any other analog company.

The challenge for Maxim is to continue choosing the right products to develop. CEO Jack Gifford explains: "Analog technology is one of the world's largest arenas for invention. Neither market size nor inventive opportunity can limit Maxim's growth." Maxim looks forward to being among the champions again next year.

ISO 9001 AND QUALITY CERTIFICATIONS

In June of 1993, Maxim received ISO 9001 certification—the most stringent and comprehensive ISO 9000-level audit. The audit covered most phases of manufacturing, including design, process, test, and shipping.

More than 75 major OEMs and manufacturing companies have surveyed and audited Maxim's manufacturing operations. Audit results confirm Maxim's compliance with the following recognized quality standards:

- MIL-Q 9858
- MIL-I 45208
- MIL-STD 45662
- MIL-STD 1686
- MIL HANDBOOK 263

Accredited by the Dutch Council for Certification

ABS Quality Evaluations, Inc. Quality Assurance Certification

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ISO 9001

Certificate Number: 30337

Maxim welcomes and encourages customer audits.

Selecting voltage references

Voltage references are simple devices, but making the right choice for a given application can be a chore if you don't take an orderly approach. This article simplifies the task with a review of the available reference types and a discussion of the specifications manufacturers use to describe them.

Unlike most electronic circuits, the voltage reference resists any change in output. While most circuits try to produce an ideal waveform or a faithful replica of input variations, the ideal reference maintains constant V_{OUT} despite all variations in time, temperature, input voltage, and load current. References differ in their approximation of this ideal, so to choose well you must be familiar with the available types and their performance parameters. These two topics are covered in the following sections.

Voltage-stable devices

Before the advent of solid-state voltage references, engineers in search of a stable voltage had to use standard cells or batteries. Both are self-powered and produce stable, well-defined voltages when not loaded. But, since their output voltages are so temperature sensitive, they must be specified at a single temperature.

The standard cell consists of liquid mercury and liquid electrolyte in an H-shaped glass container. Though accurate to a few parts per million, it can take weeks or months to recover if overloaded or tipped on its side!

Mercury cells (batteries) are more robust. Good for several years without replacement, they provide about 2-½ digit accuracy when new. They furnish only a few milliamps of current. Though still used in some portable applications, most have been replaced by modern low-current (10fA) references.

The first modern voltage reference is the zener diode. Used mostly in clamp circuits and power supplies, it comes in a variety of voltages, packages, and power ratings. Not quite accurate enough or stable enough to qualify as a voltage reference by itself, the zener produces a reasonably constant voltage when connected in series with a resistor and a source of unregulated voltage.

The zener's temperature coefficient (tempco) is a function of its breakdown voltage, and is remarkably low at approximately 6.3V. By placing a conventional pin junction in series with the zener, you get a combination whose forward voltage drop (at a specific operating current) can be tailored for extremely low tempcos. Known as a reference diode, this combination has seen lots of development. For tempcos below 25ppm/°C, however, the cost becomes prohibitive for testing, matching, and selecting the diodes.

Zeners have a well-understood aging effect, and the best reference diodes receive years of burn-in conditioning to minimize the output changes caused by aging. Such devices are produced not by the zener manufacturers, but by specialty houses and manufacturers of high-end voltmeters and laboratory voltage standards.

The combination of a reference diode and op amp in a hybrid IC produces the amplified diode—a voltage reference with many advantages. Rather than testing and matching diodes (a procedure involving thousands of logged measurements on hundreds of parts at dozens of temperatures) you simply combine randomly selected op amps and reference diodes, and set the tempco with standard op-amp trimming techniques.

Each amplified diode requires a complete temperature sweep followed by several trims, and a second temperature sweep to confirm performance, but the resulting tempco is better than 1ppm/°C. Maxim's hybrid references, the MAX670 and MAX671, are built and tested in this way.

The MAX670/MAX671 amplified-diode references use internal resistor networks to amplify the output to 10.000V ±1mV, independently of the precise zener current and voltage required for minimum tempco.

In addition, the MAX670/MAX671's op amp is configured as a 4-wire power supply with separate force and sense leads to eliminate the effect of voltage drops along the connecting wires. As a result, the reference voltage appears exactly where it is needed—not just at the amplified diode's output terminals (see the sidebar, *Kelvin-sensed outputs*). This feature is vital to low-ppm applications because it eliminates ground-loop errors, thermal voltages, and IR drops in the connections—including a socket (if used) for the voltage reference itself. (At 1mA, a 10mΩ trace resistance produces a 10fV (1ppm) error. What trace resistance do you specify?)

Kelvin connections also allow the delivery of considerable load current. If necessary, you can boost the load current to several amperes (without degrading accuracy) by adding an external pass transistor within the feedback loop. Thus, the amplified diode not only eliminates board trimming during manufacture, it insures repeatability—both on the production line and following field repair.

The zener diode's successor is the bandgap reference. Almost impossible to make with discrete components, the bandgap reference is made practical by integrated-circuit technology. Bandgaps are based on a simple and elegant principle—take a known problem and turn it into a solution.

The problem is that forward-conducting silicon diodes have a well-defined temperature coefficient (2mV/°C), but a hard-to-control offset voltage. The solution is to fabricate (for example) 11 identical diodes on a silicon substrate, arrayed in a tight group for close thermal matching. Connect all but one central diode in parallel. Then, drive that diode and the remaining group with two identical currents, so the central diode operates with an approximate 10-times higher current density across its junction. The central-diode voltage has a negative tempco, but the voltage difference (for the single diode vs. the group) has a positive tempco.

If you then arrange for the voltage difference (times a gain factor) plus the central-diode voltage to equal the bandgap voltage of silicon (1.205V), the sum will (ideally) have a tempco of zero (**Figure 1**). That is what the bandgap circuit does.

The simplest and least expensive bandgap reference is a two-terminal device such as Maxim's ICL8069, which operates like a zener diode. Unlike zeners, however, the bandgap has a low voltage (1.23V) and a very sharp knee at low operating currents: the voltage change from 50fA to 5mA is less than 15mV (**Figure 2**). Low voltage and low current make bandgap references suitable for operation in feedback networks, biasing networks for op amps, and other circuits for which the zener reference is inappropriate.

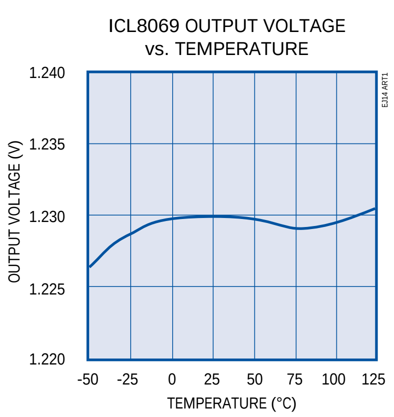


Figure 1. The familiar "S" curve of this bandgap reference shows a minimum variation with temperature.

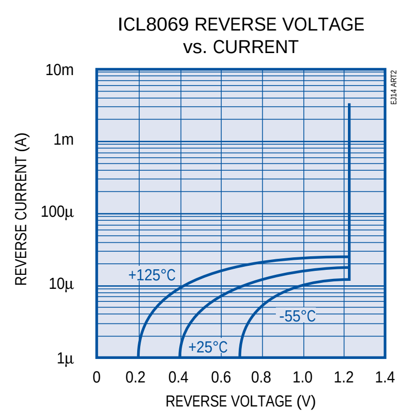


Figure 2. Bandgap diodes have a much sharper "knee" than that of actual diodes.

Kelvin-sensed outputs

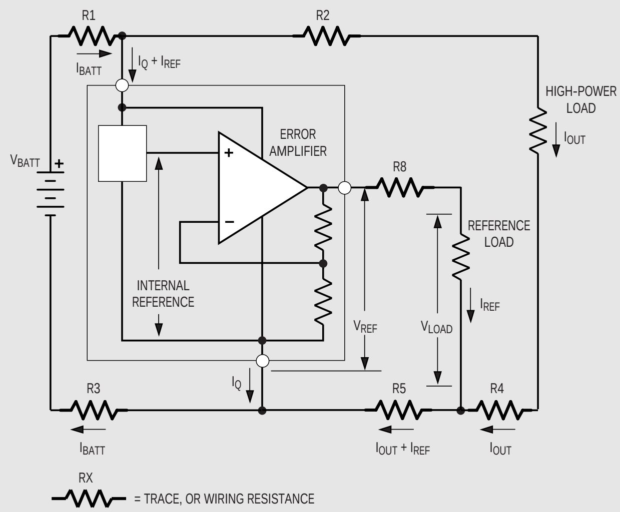
Separate force and sense paths can greatly improve the performance of a voltage reference. That arrangement (called a Kelvin connection) is common in high-accuracy designs, but it also removes most of the noise and drift in a reference circuit of modest accuracy.

Such a circuit is the 3-wire, 2.5V reference of **Figure A**. Though suitable for use with 12-bit A/D and D/A converters, it is prone to errors that are often overlooked or dismissed as insignificant. These errors are due almost entirely to the effects of printed-circuit resistance and poor layout.

Note, for example, that I_{REF} (10mA) and I_{OUT} (100mA) share a ground-return trace whose resistance is represented by R5. Assuming this trace measures only 10mΩ (have you measured yours lately?), the resulting dc voltage error is 1.02mV—nearly two LSBs in a 12-bit system with a 2.5V reference.

R5 (and R8) also produce variations in reference voltage as the reference load varies. These resistances may measure only 10mΩ as printed-circuit traces, but the values (and the resulting errors) can escalate if the reference is placed in a socket, or if the reference load current passes through an edge connector. Connectors are particularly troublesome because their resistances change each time they are reconnected.

3-TERMINAL REFERENCE



$V_{LOAD} = V_{REF} - I_{REF}R8 - (I_{OUT} + I_{REF})R5$
FOR 10 m TRACE RESISTANCES, A 10mA REFERENCE LOAD, AND A HIGH POWER LOAD,
V_{LOAD} IS 1.02mV LESS THAN V_{REF} FOR V_{REF} = 2.5V, THE RESULTING ERROR IS 408ppm

Figure A.

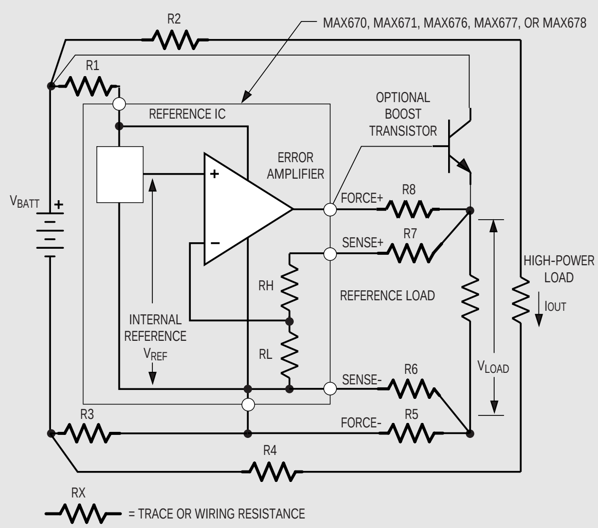
R1 and R3 cause less-obvious problems. They don't contribute dc errors, but fast transients in the high-power load must pass through them. The resulting voltage modulation at the reference-supply pins can cause instability in the reference.

The circuit of **Figure B** is similar but offers two major improvements. First, it isolates the reference and high-power loads by providing separate paths from the high-power load all the way back to the battery terminals. High-power load transients no longer modulate the reference, because the connecting traces (R2 and R4) are separate from those of the reference (R1 and R3).

Second, the reference load is Kelvin-connected to its drive circuit. The high resistance of RH and RL assures accurate feedback to the error amplifier, regardless of trace resistance in the sense lines (R7 and R6). And, the errors due to trace resistance in the force lines (R8 and R5) are excluded by the amplifier's feedback (sense) connections.

Separate force and sense lines allow the reference load and its error amplifier to be separated (if necessary) by lengthy wires and numerous connectors. Calculations show that the errors in Figure B can be made astonishingly small—so small that little penalty accrues if you reconnect the high-power load as in Figure A. In that case, note that a change in the voltage across R5 (in Figure B) shifts all voltages in the reference circuit, but V_{LOAD} remains constant.

KELVIN-SENSED REFERENCE



$V_{LOAD} = V_{REF} \times (RH + RL) / RL \times K$

$K = (RH + RL + R7 + R6) / (RH + RL) = \frac{300,000 + 100,000 + 0.01 + 0.01}{300,000 + 100,000} = 1.000\ 000\ 05$

Figure B.

Kelvin connections not only compensate for errors that arise in passive components; they also accomodate active components such as the optional boost transistor shown in Figure B. With that transistor in place (replacing the R8 force line), you can increase current-source capability in the reference without degrading accuracy. Similarly, you can increase the current-sink capability by adding a pnp transistor with its collector connected to ground.

Finally—the accuracy achieved with Kelvin connections eliminates the need for board trimming during manufacture. The result is repeatable perfomance, both for the units of a production lot and for a single unit before and after field repair.

Specifications

To select the best reference for a given application, you must be aware not only of the different reference types, but also of special definitions manufacturers use for the specifications that describe voltage-reference performance. The following entries define and discuss each parameter.

Accuracy: This is an ambiguous term. It is literally the sum of all deviations from the ideal output value, expressed as a fraction of the ideal, subtracted from one, and multiplied by 100. A perfect reference, therefore, is 100% accurate. But in common usage, accuracy and total error are used interchangeably. A "1%-accurate" reference is generally understood to have a total error of 1%, not 99%.

Error: a particular category of deviation from the ideal. Voltage-reference errors are expressed either as absolute values (millivolts, for example,) or as fractions, and in percent (%) or parts per million (ppm).

Initial accuracy: the output-voltage tolerance exhibited by a voltage reference following the initial turn-on of power. It is usually measured at no load or for a range of load currents. In many applications, initial accuracy is the most important specification. For low-cost references, it may be the only accuracy specification.

Turn-on drift: a change in output voltage over a specified time interval following turn-on. (Initial accuracy is rarely specified over a time interval, but a few milliseconds can be assumed for most modern devices. One exception is the reference with substrate oven, which takes many seconds to stabilize.) With or without an oven, all references exhibit some change over the first seconds or minutes following turn-on. Usually asymptotic, turn-on drift is an important specification for portable systems that conserve battery energy by powering the reference only for short periods.

Short-term drift: similar to turn-on drift, but specified for a short period (milliseconds to minutes) at any time after turn-on. It often appears in data sheets as a chart recording or scope photo. Short-term drift differs from noise only in the units of measure; both are small, unpredictable, and random.

Long-term drift: slow changes in voltage-reference output that occur over minutes, days, or months of continuous operation. Long-term drift, usually expressed in ppm/1000 hours, is a form of noise and is therefore random and unpredictable.

Because long-term-drift measurements are time-consuming and expensive, this parameter is characterized by sample tests only. (Who can wait for 10-year drift curves?) Note that the sample tests provide no guarantee of future performance, but statistical data analysis offers a high level of confidence in the test results.

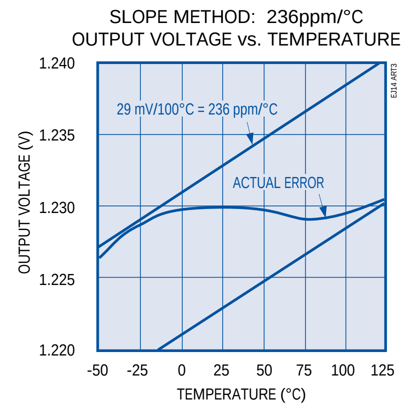


Figure 3. The slope method of depicting V_{OUT} vs. temperature simply illustrates the maximum dv/dt with a straight line on the graph.

Aging: a gradual change in output voltage caused by long-term changes in the characteristics of the reference. Aging differs from long-term drift, however: aging results in a slow unidirectional change in the reference voltage; while long-term drift causes random fluctuations.

Noise: electrical noise at the output terminals of a voltage reference. It can include wideband thermal noise, low-frequency spikes of wideband (popcorn) noise, and narrowband 1/f noise. Thermal noise is small and easily filtered with a simple RC network, unless the application prohibits that approach. For applications that power the reference only for short intervals, most forms of noise translate to a component of the initial accuracy.

Temperature drift: a change in output voltage due to temperature, expressed in ppm/°C or %/°C. Usually the second most important specification after initial accuracy, it becomes dominant for applications in which the initial accuracy can be compensated by a

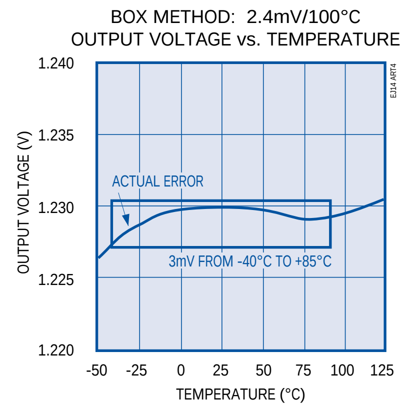


Figure 4. The box method, which encloses the extremes of V_{OUT} variation within a box, gives a closer approximation to the actual error.

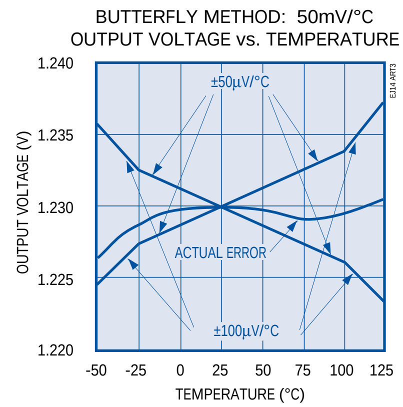


Figure 5. The butterfly method gives one actual data point at +25°C, plus a limiting envelope that specifies the error more tightly than does the slope method.

calibration of adjustable gain. Three methods of specification are common:

Slope method (**Figure 3**): a line representing the worst-case (highest) dv/dt over the temperature range of interest. Used mostly on older military products with an assumption that the drift is linear (often wrong), this method enables worst-case calculations. One problem: the actual point of maximum slope is not specified.

Box method (**Figure 4**): a box formed by min/max limits for output voltage over the temperature range of interest. This construction corresponds to the method of test, and provides a closer estimate of actual error than does the slope method. The box guarantees limits for the temperature error, but (like the slope) says nothing about the exact shape and slope of the output response.

Butterfly method (**Figure 5**): a more detailed set of limits that actually shows one datum point (at +25°C), with minimum and maximum slope lines passing through it, and two or more breakpoints along each line. The name comes from the shape of these lines as they appear on the graph of output voltage vs. temperature.

Figures 3-5 represent the same fictitious voltage reference. Note that the numerical error estimates listed on each figure are not easily compared, but you can “convert the box” by drawing a diagonal across it. That slope then allows a closer comparison with the other two methods of specification.

Self-heating: a change in temperature and consequent change in output voltage caused by the flow of load current internal to the reference. This effect is sneaky because it has several time constants ranging from microseconds to seconds. Self-heating is rarely specified because it doesn't appear in high-speed measurements of line and load regulation.

You can choose a reference that is specified at the extremes of load current, or eliminate self-heating by adding an external transistor or buffer amplifier to handle the load current. The monolithic, 1ppm MAX676–MAX678 references offer another option: they include active circuitry that maintains a constant internal power dissipation as the load current changes.

Load regulation: an error produced by a change in load current. Like line regulation, this dc specification does not include the effects of load transients.

Line regulation: an error produced by a change in the input voltage. This dc specification does not include the effects of ripple voltage or line transients. For battery-powered applications, the modern voltage reference is far superior to its predecessors, both for line regulation and for the closely related specification of dropout voltage (associated with the minimum-allowed input voltage).

Dropout voltage: The minimum input-to-output voltage difference (also called minimum input-to-output differential), that will guarantee proper operation. Dropout voltage sometimes appears as a line in the specification table, but it often appears only as the lower voltage level in the conditions for the line-regulation specificaton. The dropout specification is particularly important for 4.096V references powered from 5V supplies.

Transient response: the response of a voltage-reference output to a transient of input voltage or output current. Voltage references are not power supplies, and they rarely excel in the rejection of transients. Data sheets may publish scope photos or typical curves for transient and ac performance, but guaranteed specifications are rare. In general, you must add other circuitry to shield the reference from line and load transients.

This review of reference types and specifications provides most of the information you'll need to select a reference for your application. (See the table in the sidebar *Temperature-correction ROM delivers 0.6ppm/°C temperature coefficient*, for a summary of representative references from Maxim.) Also helpful are the following discussions on countering the effects of temperature, a collection of pitfalls to avoid, and another collection of hints on how to enhance the performance of your voltage reference.

Temperature compensation

One way to prevent the unwanted temperature response exhibited by all voltage references is to eliminate temperature changes. But, barring the surgical implant of electronic devices, few applications can guarantee a stable ambient temperature. Even laboratory conditions are deceptive; if the reference is confined, covered, or located near a ventilation duct or power-supply component, its temperature can change dramatically. Several techniques can minimize these changes:

Constant-temperature oven: You can certainly stabilize the temperature of a reference by operating it in an oven whose temperature is regulated well above ambient (typically +50°C to +85°C). The scheme has drawbacks, however. Elevated temperature accelerates the aging process in zener diodes, increasing their long-term drift and decreasing their life expectancy.

The oven poses problems. Its heat must be vented or otherwise disposed, the required power may demand a larger supply, and cycling thermostats may generate EMI. You can eliminate the EMI with

Two-terminal and three-terminal micropower references

Two-terminal and three-terminal reference types can differ considerably in actual power consumption. Consider two circuits, each generating 2.5V from a 6V battery that is allowed to discharge to 3V (see **Figure C**).

Quiescent current for the three-terminal device is the sum of the I_Q shown in the data sheet plus the load current; this sum is fairly constant over the entire range of battery voltage. But for the two-terminal design, current is limited mainly by R_{IN}, whose value is established by the minimum values for battery voltage ($V_{BATT(MIN)}$) and quiescent current ($I_{Q(MIN)}$):

$R_{IN} = (V_{BATT(MIN)} - V_{REF}) / (I_{Q(MIN)} + I_{LOAD})$.

For $V_{BATT(MIN)}$ = 3V and $I_{Q(MIN)}$ = 10fA,
R_{IN} = (3V – 2.5V) / (10fA + 100fA) = 4545Ω

Over the battery's 3V-to-6V range,
$I_Q + I_{BATT} = (V_{BATT} - V_{REF})/R_{IN}$ = 110fA for V_{BATT} = 3V,
and = 770fA for V_{BATT} = 6V.

Thus, the quiescent current can increase six-fold when you install a fresh battery. R_{IN} values less than 4545Ω draw much more current. If, for example, you let the battery discharge to 2.7V instead of 3V, R_{IN} becomes 1818Ω and the battery current (at 6V) becomes 1.925mA. Power consumption for that condition is 11.55mW, which is no longer micropower!

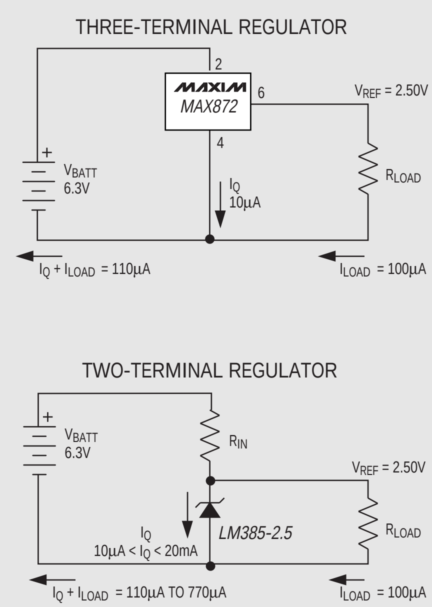


Figure C. The three-terminal voltage-reference circuit draws constant current as the battery discharges. In the two-terminal circuit, R_{IN} makes the quiescent current proportional to battery voltage.

linear or proportional regulators, but they cost more and take longer to warm up.

Further, the voltage reference cannot stabilize until some time after the oven has stabilized. Thermal shock at turn-on causes temperature gradients in the reference and associated wiring that can produce errors for twenty minutes or so. These errors are sometimes far worse than the temperature coefficient being minimized by the oven! Note that specifications for 6- and 8-digit DVMs (which include oven-stabilized references) are not valid for 30 minutes to an hour after start-up.

Some manufacturers incorporate the oven and control circuitry on the voltage-reference IC, and enclose it in a thermally isolated cover. This approach greatly reduces warm-up time (at the expense of power consumption), but some devices tend to stall or lock up if the supply voltage dips, or if supply voltages are not sequenced correctly at turn-on.

Thermistors (positive-tempco resistors): A thermistor, padded with appropriate series and parallel resistors and placed in the input or feedback path of a reference buffer amplifier, can temperature-compensate the reference by modifying the amplifier's response over temperature. You should place the thermistor close to the reference. This technique can "promote" the performance of an inexpensive reference over a limited range (say, +5°C to +35°C).

Thermistor compensation requires not only that you characterize the reference in question, but that all production units have a similar temperature profile. Maxim's ICL8069, for example, has an S-shaped profile that allows improvement over a limited range. Note that outside this range the circuit over-compensates, producing an error much greater than the original!

Diode: As mentioned earlier, a conventional diode in series with a zener can modify the zener's tempco, but you must allocate lots of time for characterizing and matching the components. In other words, don't do it. Go buy what you need; it's much cheaper.

Memory: If your system includes a processor, then stored data offers an elegant way to temperature-compensate a reference. First, mount a thermistor, diode, or other temperature-sensing device near the reference. (It can be linear or non-linear, but it must be repeatable.) Measure reference voltage vs. temperature over the whole temperature range using a 7- or 8-digit DVM, and save the data to ROM as a look-up table. During operation, you can correct the reference output at will by monitoring temperature, looking up the correction factor in ROM, and applying it through dedicated circuitry.

This consumes very little current, compensates any shape of error profile, and works over any temperature range you choose. The net error is limited only by the repeatability and hysteresis of the reference. A small plug-in module containing the reference, temperature device, and ROM can be characterized in a temperature chamber and programmed without recourse to the system processor.

Even simpler is to use a monolithic reference IC that includes the ROM and temperature measurement system—such as the MAX676, MAX677, and MAX678 precision voltage references, with outputs of 4.0960V, 5.0000V, and 10.0000V. See the sidebar *Temperature-correction ROM delivers 0.6ppm/°C temperature coefficient.* These ICs provide 0.01% initial accuracy, with low tempcos of 0.6ppm/°C over the entire temperature range. Supply current, 6mA at +25°C, is less than 14mA over the full range. The internal temperature-correction circuitry results in superior performance.

The MAX676, for example, (4.0960V output) operates on 4.75V to 18V with less than 1ppm of noise. Separate force and sense terminals (like those of the MAX670 and MAX671 mentioned in the previous discussion of amplified diodes) allow the MAX676–MAX678 devices to reside in a socket and deliver their reference voltage to the exact spot needed; not just at the package terminals. In addition to the <0.6ppm/°C output, each has an auxiliary output whose voltage is proportional to temperature.

Circuit pitfalls

No matter how good a reference is, poor circuit engineering can make it look bad. The following is a summary of the problems most often encountered.

Ground: Noise or offset voltage in the ground node makes all other troubleshooting measurements suspect. All measurements should be referenced to

Temperature-correction ROM delivers 0.6ppm/°C temperature coefficient

The MAX676–MAX678 voltage references use a combination of a coarse laser trim at wafer sort and a 14-temperature post-package trim to achieve a guaranteed maximum temperature drift of less than 1ppm/°C (0.6ppm/°C typical). The post-package trim allows Maxim to offer full-specification, 1ppm/°C-grade devices in the SOIC package. Mil-temp devices with 1.5ppm/°C tempcos are available in CERDIP packages.

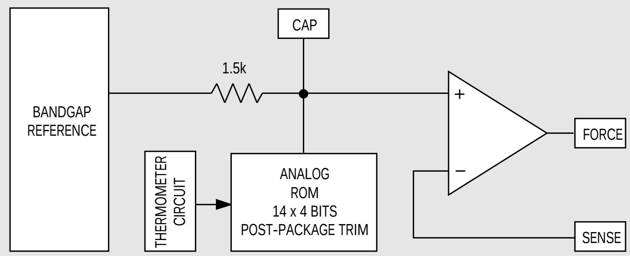


Figure D.

Figures D and E shows the benefit of post-package trim on the 5.000V MAX677CPP. Before final trimming, the total error from -40°C to +85°C is about 4mV, or an average of 6.4ppm/°C—about the performance level on the industry-standard REF02. The initial voltage accuracy at +25°C is about 0.08%—also better than the REF02 specification. But, through the use of the internal temperature sensor and analog ROM, the total initial error is reduced to virtually zero (0.5mV maximum guaranteed), and the output voltage variation with temperature is reduced to less than 0.5mV.

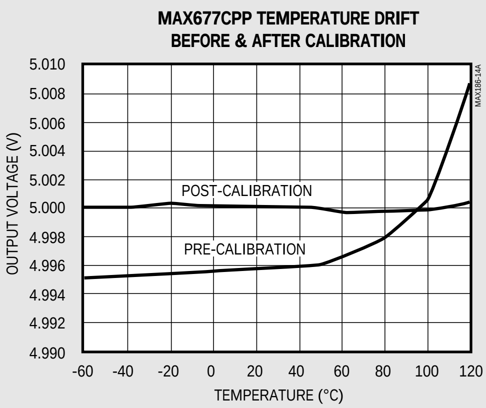


Figure E.

IC design improves output noise. The MAX677's 0.1Hz to 10Hz noise is much smaller than most other references (see Table), and the CAP pin provides access to an internal node (with 1.5kΩ impedance) that enables the reduction of wideband noise. A 0.47µF capacitor connected to the CAP pin reduces wideband noise by a factor of two.

Voltage References

Part Number	Voltage (V)	Temp. Drift (ppm/°C max)	Initial Accuracy T_A = +25°C (%F.S. max)	Quiescent Current (mA max)	Noise 0.1Hz-10Hz (µVp-p), max(typ)	Package Options[1]	Temp. Ranges[2]	Features	Price† 1000-up ($)
ICL8069	1.2	10 to 100	2	0.05	5 (10Hz to 10kHz)	TO-52,TO-92,SO*	C,E,M	Micropower two-terminal reference	0.65
MAX872	2.5	40	0.2	10µA	(60)	DIP,SO	C,E	Lowest power, lowest dropout precision reference. $V_{CC} = V_{OUT}$ + 200mV	2.12
MAX873	2.5	7 to 20	0.06 to 0.1	0.28	(16)	DIP,SO	C,E,M	Low-power/drift, REF43 upgrade	2.95
MX580	2.5	10 to 85	0.4 to 3	1.5	(60)	TO-52,SO**	C,M	Low-drift bandgap reference	2.33
MX584	2.5	5 to 30	0.05 to 0.3	1	(50)	TO-99,DIP,SO,CERDIP	C,M	Low-drift, programmable reference	3.09
MAX874	4.096	40	0.2	10µA	(60)	DIP,SO	C,E	Lowest power, lowest dropout precision reference.$V_{CC} = V_{OUT}$ + 200mV	2.12
MAX676	4.096	<1	0.01	10	(1.5)	DIP/SO	C,E,M	Lowest temp drift in SO pkg, lowest long-term Drift, low dropout	5.23
MAX675	5.0	12 to 20	0.15	1.4	15	TO-99,DIP,SO,CERDIP	C,E,M	Low-drift, low-noise bandgap reference	3.08
MAX677	5.0	<1	0.01	10	(2)	DIP/SO	C,E,M	Lowest temp drift in SO pkg, lowest long-term drift	5.23
MAX875	5.0	7 to 20	0.06 to 0.1	0.28	(32)	DIP,SO	C,E,M	Low-power/drift, REF02 upgrade	2.95
MX584	5.0	5 to 30	0.05 to 0.3	1	(50)	TO-99,DIP,SO ,CERDIP	C,M	Low-drift, programmable reference	3.09
REF02	5.0	8.5 to 250	0.3 to 2	1.4	15	TO-99,DIP,SO,CERDIP	C,M	Low-drift bandgap reference	1.80
MX584	7.5	5 to 30	0.05 to 0.3	1	(50)	TO-99,DIP,SO,CERDIP	C,M	Low-drift, programmable reference	3.09
MAX670	10.0	3 to 10	0.025	14	50	SB Ceramic	E,M	Kelvin connected, ultra low-drift reference	38.51
MAX671	10.0	1 to 10	0.01	14	50	SB Ceramic	C,E,M	Kelvin connected, ultra low-drift reference	37.41
MAX674	10.0	12 to 20	0.15	1.4	30	TO-99,DIP,SO,CERDIP	C,E,M	Low-drift, low-noise bandgap reference	3.08
MAX678	10.0	<1	0.01	10	(3)	DIP/SO	C,E,M	Lowest temp drift in SO pkg, lowest long-term drift	5.23
MAX876	10.0	7 to 20	0.06 to 0.1	0.28	(64)	DIP,SO	C,E,M	Low-power/drift, REF01 upgrade	2.95
MX581	10.0	5 to 30	0.05 to 0.3	1	(50)	TO-39,SO***	C,M	Low-drift bandgap reference	2.90
MX584	10.0	5 to 30	0.05 to 0.3	1	(50)	TO-99,DIP,SO,CERDIP	C,M	Low-drift, programmable reference	3.09
MX2700	10.0	3 to 10	0.025 to 0.05	14	(50)	SB Ceramic	I,M	Ultra low-drift voltage reference	19.61
MX2710	10.0	1 to 5	0.01	14	(30)	SB Ceramic	C	Ultra low-drift voltage reference	24.74
REF01	10.0	8.5 to 65	0.3 to 1	1.4	30	TO-99,DIP,SO,CERDIP	C,M	Low-drift bandgap reference	2.05
MX2701	-10.0	3 to 10	0.025 to 0.05	14	(50)	SB Ceramic	I,M	Ultra low-drift voltage reference	24.02

* The ICL8069 is available in a 2-pin TO-52 and TO-92 package, or an 8-pin SO package.
** The MX580 is available in a 3-pin TO-52 and 8-pin SO package.
*** The MX581 is available in a 3-pin TO-39 and 8-pin SO package.
1 Package Options: DIP = Dual-In-Line Package, PLCC = Plastic Leadless Chip Carrier (quad pack), FP = Flat Pack
2 Temp Ranges: C = 0°C to +70°C, I = -25°C to +85°C, E = -40°C to +85°C, M = -55°C to +125°C
† Prices provided are for design guidance and are FOB USA. International prices will differ due to local duties, taxes, and exchange rates.

the same point, which is connected to the Kelvin ground sense pin of the reference.

Noise and glitches: Use an oscilloscope to ensure that the reference output is stable. As with op amps, very high capacitive loads may cause oscillations. When monitored with a digital voltmeter, a reference output with high-frequency oscillations appears to have very poor initial accuracy and poor stability. Also use the oscilloscope to look for transients on the reference output caused by rapidly varying load currents, such as those drawn by the reference inputs of some A/D converters.

A/D converters: These devices, particularly successive-approximation types, have high-speed switches that may introduce extremely narrow, energetic current pulses at the source and reference inputs. You may have to buffer the reference with an amplifier or a resistor of 20Ω to 100Ω. Contrary to intuition, adding capacitance to ground can make things worse.

Buffering: The initial offset voltage, offset-voltage temperature drift, and gain errors of most buffers will significantly degrade the reference accuracy if you simply connect a buffer to the reference output. The preferred method is to include the buffer *inside* the reference's feedback loop (via its sense inputs). A simple (but high-performance) single-transistor buffer is shown in the data sheets for the MAX670/MAX671 and MAX676–MAX678 references.

Improving the specifications

Some specifications can’t be improved by circuit changes. Others, however, can be improved by modifying the external circuitry. This approach (vs. purchasing a premium reference) can save you time and money.

Temperature: In the unlikely event that the 0.6ppm/°C tempco of the MAX676–MAX678 is inadequate, you can control temperature. Adding an oven, for example, may solve some of your other design problems (see *Temperature compensation*).

Many references include a PTAT (Proportional To Absolute Temperature) output for convenience, so you need only add (for instance) an op amp driving a power transistor in close thermal contact with the reference. As an alternative in battery-powered applications with a human operator, the PTAT voltage might drive a comparator that activates a front-panel display, warning that the results may be out of range.

Line regulation and power-supply rejection ratio: By filtering and pre-regulating the input voltage, a zener or three-terminal regulator can greatly improve line regulation, line-transient rejection, and ripple rejection. On the other hand, most references provide only a few milliamps, so a simple, low-cost RC output filter may be appropriate.

Noise: Adding a simple RC lowpass filter can reduce output noise, but the capacitor should have very low ESR to be effective at the audio frequencies. Check the reference data sheet before adding capacitance to the output—too much capacitance can cause oscillation.

Source and sink capability, and load regulation: An external buffer amplifier can deliver more load current, but be sure to use a reference with separate force and sense terminals, which is designed to drive an external pass transistor within the reference’s feedback loop.

(Circle 1)

DESIGN SHOWCASE

Boost converter yields orderly shutdown

Some microprocessor (µP) systems require more time for shutdown than is provided by conventional circuits for power-fail detection. Between first warning and the actual loss of power, such systems have extensive "housekeeping" tasks to perform in addition to the memory-write operations that save critical data.

A backup battery and dc-dc regulator can buy extra time for the µP by maintaining V_{CC} at 5V following the initial warning of impending power loss (**Figure 1**). When V_{CC} falls below 4.65V, µP supervisor IC1 issues a logic-low signal at pin 7. This signal applies a non-maskable interrupt (NMI) to the µP, and (via Q2) turns off Q1 and pulls IC2 out of shutdown.

As the µP shutdown routine begins, IC2 quickly restores the V_{CC} line to 5V, which supplies as much as 200mA from a 2.5V lithium cell. When the routine ends, the µP shuts down IC2 via an I/O line, allowing a second decline in V_{CC}. At 4.4V, the µP supervisor IC3 enters its normal battery-backup mode. If desired, you can connect separate batteries for the boost converter and for RAM backup.

(Circle 2)

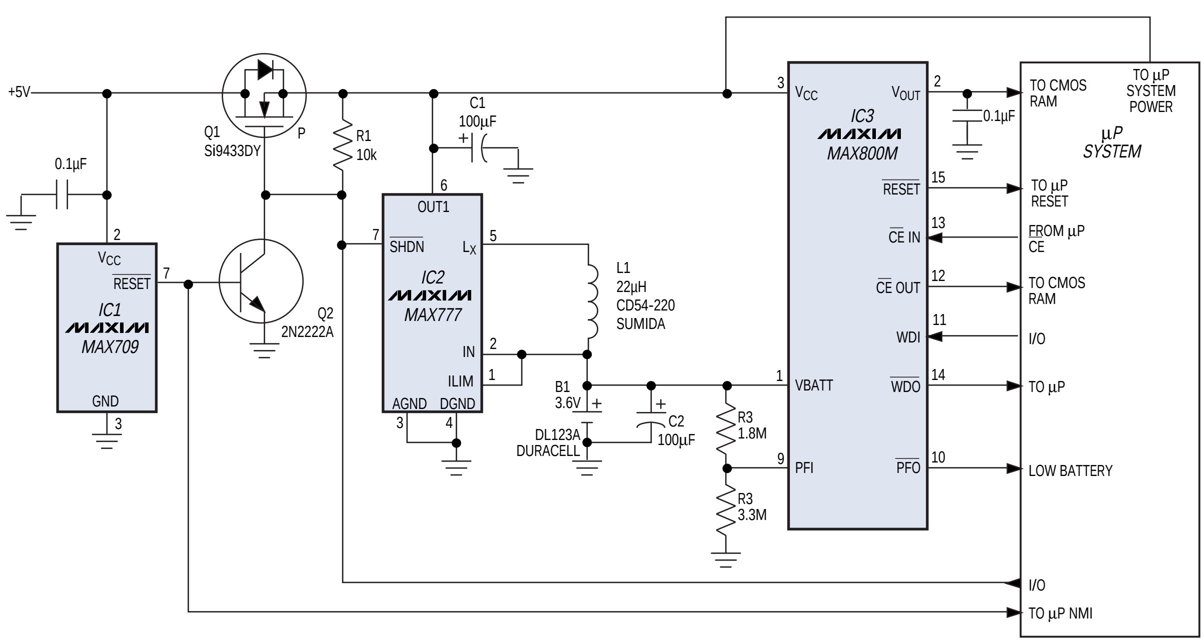


Figure 1. During the brief interval between a low-V_{CC} warning and power fail, this system's boost converter (IC2) derives 5V from the backup battery, giving the µP time to complete its shutdown routine.

DESIGN SHOWCASE

High-frequency switching IC powers portable telephone

Switched-capacitor voltage converters provide convenient sources of negative voltage for battery-operated systems, but the switching frequency poses a problem for portable telephones and radios. Appearing as sidebands about the carrier frequency, the switching energy is difficult to filter unless its frequency is relatively high.

IC1 in **Figure 1**, for example, is a switched-capacitor voltage converter that normally operates at 4kHz. By connecting its BOOST pin to V+, you can raise this frequency to 32kHz or so, moving the interference above the frequency band of interest for most audio applications. For radio applications, the switching frequencies must be even higher.

IC1's OSC pin lets you override the internal oscillator with external frequencies as high as 500kHz. The arrangement shown drives the IC with a 375kHz square wave of 50% duty cycle. HC logic gates provide the required rail-to-rail amplitude, and an internal divide-by-two stage lowers the frequency of this drive signal before applying it to the internal switches. The resulting sidebands, about 190kHz from the carrier, are easily removed by filtering.

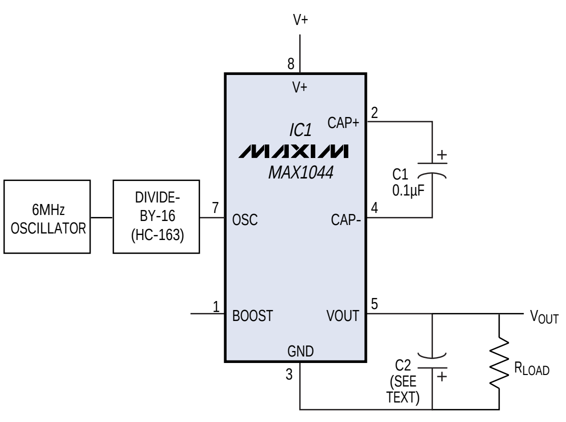


Figure 1. Driving this switching converter at an unusually high rate (375kHz) produces high-frequency switching noise that is easy to filter.

The following data illustrates the effects of load resistance and output capacitance (C2) on output voltage, ripple amplitude, and supply current (for IC1):

OUTPUT CAPACITANCE	LOAD RESISTANCE	1 mΩ	100 kΩ	10 kΩ	1 kΩ
C2 = 0.1µF	$-V_{OUT}$ (V)	4.95	4.92	4.88	4.56
	I+ (mA)	2.29	2.34	2.78	6.60
	M_{RIPPLE} (mV_{p-p})	60	60	70	200
C2 = 1µF	$-V_{OUT}$ (V)	4.93	4.92	4.88	4.61
	I+ (mA)	2.43	2.46	2.90	6.77
	M_{RIPPLE} (mV_{p-p})*	20	20	20	60
C2 = 10µF	$-V_{OUT}$ (V)	4.94	4.93	4.90	4.62
	I+ (mA)	2.37	2.41	2.85	6.63
	M_{RIPPLE} (mV_{p-p})**	10	10	10	30

* Plus 100mV, 0.1µs spikes
** Plus 60mV, 0.1µs spikes

Larger output capacitors obviously improve the load regulation and ripple voltage. Adding a 0.1µF ceramic capacitor in parallel with C2 can lower the fast spike amplitudes (for C2 values of 1µF and 10µF) to about 20mV. If practical, adding a linear regulator at the output can further reduce the variation of output voltage with load current.

When IC1 generates the negative supply for a data converter, you can minimize the effect of switching noise by synchronizing IC1 to the system clock or the data converter's clock. As an alternative, you can turn off the chip during each data conversion (using the BOOST pin), provided that C2 can support the negative output voltage during those intervals.

(Circle 3)

P-FET linear regulator has low dropout voltage

P-channel MOSFETs (P-FETs), though more expensive than pnp transistors, are free of the dissipation loss associated with base drive in a pnp circuit. P-FETs also have a lower saturation voltage at light loads (**Figure 1**). In fact, the low $r_{DS(ON)}$, logic-level, p-channel power MOSFETs currently available can regulate 5V from a 5.1V battery!

This capability lets the **Figure 2** circuit derive 5V ±10% from four battery cells, even when they've discharged as low as 4.6V. Low dropout voltage lets the circuit "ride down" on the declining battery voltage, finally falling out of regulation at approximately 4.6V. The low input-to-output differential at that time (0.1V) allows nearly 100% efficiency. Note that the output accuracy of IC1 (±0.6% over temperature) makes it suitable as a 2.5V system reference.

IC2's pin-programmable bias current makes possible a low-power mode in which the entire circuit draws less than 50µA. Five milliamps is available in this mode for circuitry such as backup RAM and a real-time clock. In high-power mode, the regulator can deliver 1A.

The 100µF output capacitor (C1) is chosen to accomodate the maximum load currents of 1A; for lighter loads you can scale the capacitor to a smaller value. Beware, though—the circuit's loop stability depends on lag compensation in which $1/2\pi R_{ESR}C1 > 14kHz$, where R_{ESR} is C1's equivalent series resistance. (Figure 1 recommends acceptable capacitor types for C1.)

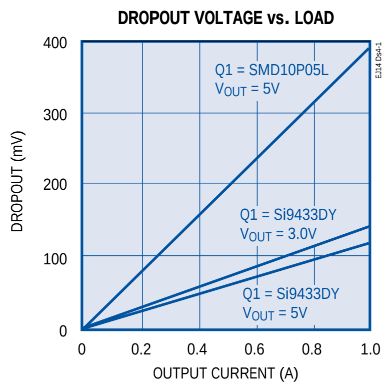


Figure 1. A p-channel MOSFET (Q1) allows this linear regulator to operate with V_{IN} to-V_{OUT} differentials lower than 100mV.

Configured for a 5V output (R1 = 100kΩ), the circuit can deliver 500mA from five cells producing 7.5V, or 1A from four cells producing 6V. Configured for 3V (R1 = 20kΩ), it delivers 500mA from four cells producing 6V, or 1A from three cells producing 4.5V. The input voltage can range from 3V to 15V, subject to a limitation; with no heatsink on Q1, the MOSFET's package-dissipation rating limits the input voltage and output current as follows: $I_{OUT} \times (V_{IN} - V_{OUT}) < 1.25W$.

(Circle 4)

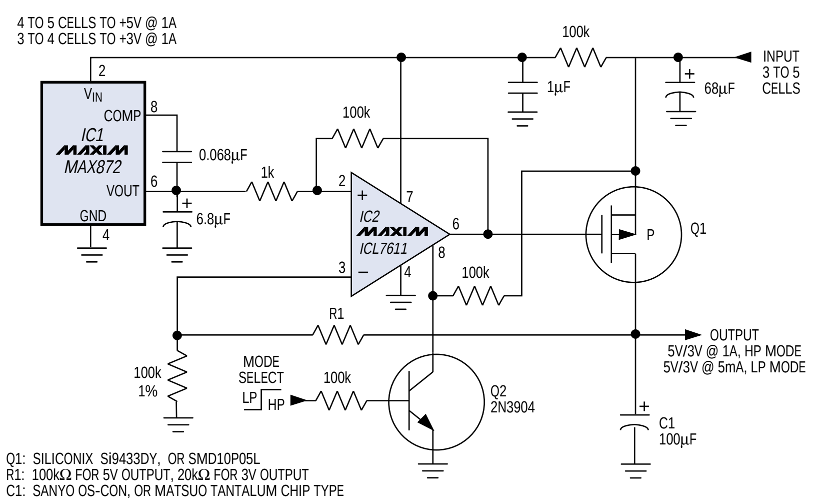


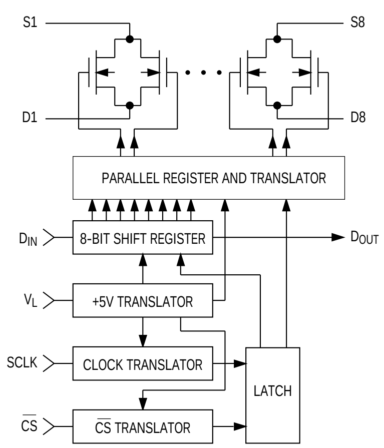
Figure 2. At low output current, these p-channel MOSFETs exhibit low source-to-drain voltage (i.e., dropout voltage in the Figure 1 circuit).

NEW PRODUCTS

8-channel analog switch has serial digital control

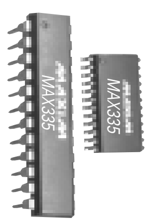
The MAX335 is an 8-channel, single-pole/single-throw analog switch capable of handling signal swings from ±5V to ±20V. Its serial digital interface, ideal for daisy-chaining applications, is compatible with Motorola's SPI™ interface standard.

Simplified Block Diagram



To update the switch settings (on or off), you take $\overline{CS}$ low and apply data to the DIN pin while clocking the SCLK pin. Each rising clock edge latches one bit of control data into an internal shift register. (The output data for daisy-chaining is guaranteed stable at the next rising edge.) After shifting in eight bits, you pull $\overline{CS}$ high, which transfers the data to a parallel register and updates the switches.

As a safety measure, all switches go to the off state when V_L is less than 2.4V. To guarantee off switches during power-up, this condition also resets the internal serial and parallel shift registers to zero. Hysteresis (approximately 100mV) aids in noise rejection.



The MAX335 comes in 24-pin narrow-DIP and wide-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 $2.84 (1000 up, FOB USA).

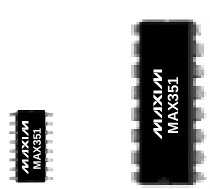
(Circle 6)

Precision quad analog switches provide on-resistance matching (<2Ω) and flatness (<3Ω)

MAX351/MAX352/MAX353 analog switches have these configurations: four normally closed (NC) (MAX351), four normally open (NO) (MAX352), and two NC plus two NO (MAX353). All three devices have on resistance less than 35Ω, with flatness (<3Ω) and matching between channels (<2Ω) guaranteed over the analog-signal range.

These ICs are fabricated with Maxim's new 44V silicon-gate process. Design improvements guarantee extremely low charge injection (10pC). Each device offers low leakage (less than 250pA at +25°C, and less than 6nA at +85°C). The 44V maximum breakdown voltage allows each device to handle rail-to-rail analog signals.

Each device retains CMOS-logic compatibility while operating on a single positive supply (+10V to +30V) or a bipolar supply (±4.5V to ±20V). The MAX351/MAX352/MAX353 switches 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 $1.76 (1000 up, FOB USA).



16-PIN NARROW SO   16-PIN DIP

(Circle 7)

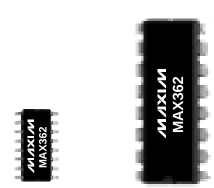
Precision analog switches offer <2Ω matching and <3Ω flatness

The MAX361-MAX365 family of precision, quad, single-pole/single-throw (SPST) analog switches have typical on-resistances of 50Ω. They offer low leakage (<500pA) and fast switching (turn-on time is <250ns; turn-off time is <170ns). Other improvements include 2Ω channel matching, 4Ω flatness over the analog signal range, low power consumption (<180µW), and extremely low charge injection (5pC). All are guaranteed (per Method 3015.7 of MIL-STD-883) to withstand electrostatic discharge (ESD) exceeding 2kV.

The MAX361/MAX364 have TTL/CMOS-compatible inputs and four normally closed SPST switches. The MAX362/MAX365, also TTL/CMOS compatible, have four normally open SPST switches. A V_L supply allows the setting of arbitrary switching thresholds for logic levels other than TTL. All devices are fabricated with a 44V silicon-gate process that allows rail-to-rail analog-voltage switching. They operate on single supplies of +10V to +30V, or dual supplies of ±4.5V to ±20V.

MAX361-MAX365 devices 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 (MAX361/MAX362 only) military (-55°C to +125°C) temperature ranges. Prices (1000 up, FOB USA) start at $1.29 for the MAX361/MAX362, and $1.14 for the MAX364/MAX365.

(Circle 8)



16-PIN NARROW SO   16-PIN DIP

NEW PRODUCTS

Industry's first RGB video switches include 75Ω output buffers

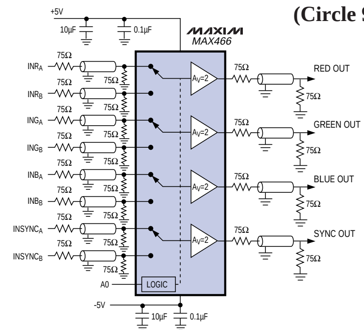
- *100MHz bandwidth, Av = 1V/V (MAX463/MAX464)*
- *90MHz bandwidth, Av = 2V/V (MAX465/MAX466)*

MAX463–MAX466 ICs, each combining two high-performance video switches with a high-accuracy video amplifier, compose the first available family of two-channel, buffered, RGB video switches. Fast switching times (20ns) and low differential gain/phase errors (0.02%/0.06°) enable the parts to serve most video applications.

Each device operates on ±5V and accepts inputs and outputs as high as ±2.5V. Four logic inputs provide digital control of all video inputs and outputs. Output amplifiers are fully characterized and guaranteed for output swings of ±2V into 75Ω or ±2.5V into 150Ω. MAX463/MAX464 devices have buffer-amplifier gains of 1V/V. MAX465/MAX466 devices have gains of 2V/V to accomodate back-terminated coaxial lines. Slew rates are 200V/µs for the MAX463/MAX464 and 300V/µs for the MAX465/MAX466. For MAX463/MAX464 devices, the -3dB bandwidth is 100MHz.

MAX463–MAX466 devices come in 24-pin and 28-pin DIP and wide-SO packages, in versions tested for the commercial (0°C to +70°C) and extended-industrial (-40°C to +85°C) temperature ranges. Prices (1000 up, FOB USA) start at \$6.97 for the MAX463/MAX465, and \$7.97 for the MAX464/MAX466.

(Circle 9)



Regulated charge-pump boosts 2-cell battery to 5V

The MAX619 charge-pump converter generates a regulated 5V from input voltages between 2V and 3.6V. Its input range and low quiescent current are ideal for 3V-only and battery-backup applications.

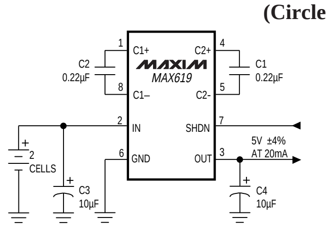
Most charge pumps produce only an integer-multiple of the input voltage. The MAX619, however, operates in one of three modes: for V_{IN} between 3.0V and 3.6V, it acts as a doubler; for V_{IN} between 2.0V and 2.5V, it acts as a tripler; and for V_{IN} between 2.5V and 3.0V, it alternates between doubler and tripler modes to produce an effective multiple of 2.5 times.

The MAX619 transfers energy from its charge-pump capacitors to the output capacitor and load during each oscillator cycle. It regulates by skipping one or more cycles in response to changes in load current or input voltage (with a limiting frequency of 500kHz, continuous). Low operating current (150µA maximum) gives the device an efficiency of almost 80% for the conditions V_{IN} = 3V, V_{OUT} = 5V, and I_{OUT} = 20mA.

Space-saving MAX619 applications feature a small 8-pin package, no inductor, and a high switching frequency that allows use of physically small external components (four capacitors). A logic-controlled shutdown mode draws only 10µA maximum supply current. While in shutdown, the output disconnects from the input and drops to 0V.

MAX619s 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 \$2.35 (1000 up, FOB USA).

(Circle 10)



9V-to-3.3V step-down converters extract maximum battery energy

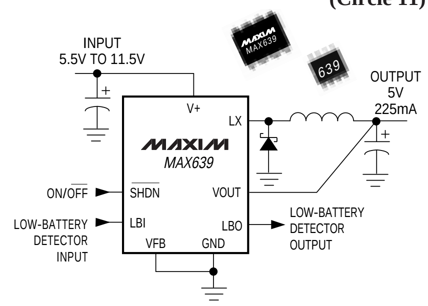
Step-down converters should squeeze the last drop of energy from their battery sources while delivering the widest possible range of load currents. The MAX639/MAX640/MAX653 family of dc-dc converters achieves this goal with efficiencies exceeding 94%, for output currents ranging from 2mA to 225mA. Contributing to this performance is the ultra-low, 20µA maximum quiescent current (10µA typical), and very large, internal MOSFET switching transistors.

The converters have preset output voltages of 5V (MAX639), 3.3V (MAX640), and 3.0V (MAX653), plus a Dual-Mode™ operation that allows adjustment of each output via an external resistor network. Low dropout voltage (0.5V) allows regulation over a wide range of input voltages. Typical applications include 5V regulation from 9V batteries and 3.3V or 3.0V regulation from lower-voltage batteries.

The devices save space because the required external components (an inductor, a diode, and two capacitors) are small and inexpensive. In particular, a "constant-peak-current" design allows the use of physically small surface-mount inductors.

MAX639/MAX640/MAX653 devices come in 8-pin plastic 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 \$2.95 (1000 up, FOB USA).

(Circle 11)



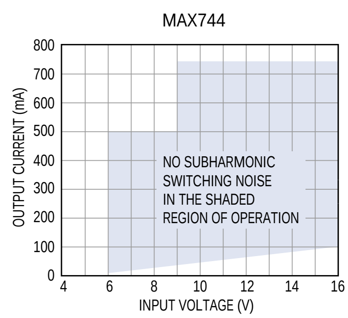
NEW PRODUCTS

94%-efficient step-down regulators produce no sub-fundamental switching noise

The MAX730A, one of seven new step-down dc-dc converters suitable for applications in portable and wireless communications, provides compact size, long battery life, and low switching noise. As drop-in replacements for the popular MAX730 series (pulse-width-modulated (PWM) step-down dc-dc converters), the MAX730A series offers 50% more output current, 94% efficiency, and freedom from sub-fundamental switching noise.

This absence of noise below the fundamental switching frequency combines with the MAX730A family's fixed-frequency PWM operation and guaranteed limits of oscillator frequency (typically centered around 180kHz), to assure an easily filtered output ripple voltage—important for noise-sensitive applications in wireless communications, audio, and instrumentation. The MAX744A, for example, is designed for cellular applications. To avoid harmonic interference with the sensitive IF frequency at 455kHz, it guarantees switching-frequency limits of 159kHz and 212kHz.

Output current is guaranteed to 500mA for the MAX730A/MAX748A/MAX750A/MAX763A, and to 750mA for the MAX738A/MAX744A/MAX758A. Each device includes a space-saving internal power switch, and each extends battery life with a 6µA shutdown mode. Design work is simplified because the selection and optimization of external components has already been performed by Maxim.



MAX730A/MAX738A/MAX744A devices have fixed 5V outputs, and MAX748A/MAX763A devices have fixed 3.3V outputs. The MAX750A and MAX758A outputs are adjustable from 1.25V to V_{IN}. The MAX730A/MAX750A/MAX763A accept input voltages to 11V, and the MAX738A/MAX744A/MAX748A/MAX758A accept inputs to 16V. Features common to all include cycle-by-cycle current limiting, short-circuit protection, and soft-start capability.

All seven devices come in 8-pin DIPs. Additional packages include 8-pin SO for the MAX730A/MAX750A/MAX763A, and 16-pin SO for the MAX738A/MAX744A/MAX748A/MAX758A. The MAX730A/MAX750A/ MAX763A are priced from $2.15, the MAX738A/MAX748A/MAX758A cost $2.60, and the MAX744A costs $2.90. (All prices are 1000 up, FOB USA.) All versions are 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. Evaluation kits are available to speed your designs.

(Circle 12)

Low-cost 5V-to-3.3V converters are 92% efficient

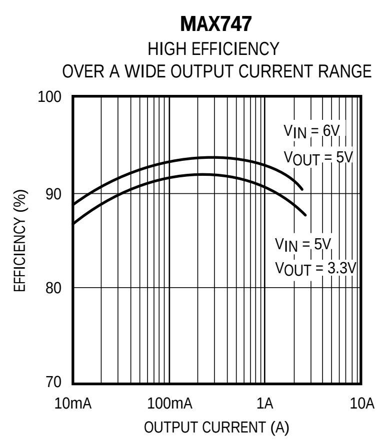
The MAX746 and MAX747 step-down regulators are the lowest-cost ICs available for high-current, high-efficiency regulation at low input and output voltages. They excel in step-down applications such as the "Green PC" (5V input to 3.3V output). Typical efficiencies for 5V-to-3.3V conversion at 10mA-to-2.5A loads is 88% to 92%. To accommodate recent and future digital products, the MAX746/MAX747 outputs can be adjusted from 2V to 14.5V.

A proprietary, pulse-width-modulated (PWM) control scheme (Idle-Mode™) minimizes switching losses by reducing the switching frequency for light loads. The resulting high efficiency holds for a wide range of load currents (250:1), assuring maximum battery life whether the system is running at full power or in standby. Also extending battery life is the low (800µA) quiescent supply current and the ultra-low (0.6µA) shutdown current.

Other features include adjustable current limiting, soft-start capability, and a built-in low-battery detector. The input range is 4V to 15V, and the output is either fixed at 5V or adjustable from 2V to V_{IN}. The MAX746 drives an external, high-side n-channel MOSFET. The MAX747 drives an external p-channel MOSFET.

The MAX746 comes in 16-pin narrow SOs and DIPs, and the MAX747 comes in 14-pin narrow SOs and DIPs. Both 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. Prices for both start at $2.25 (1000 up, FOB USA).

(Circle 13)



NEW PRODUCTS

5V-to-3.3V step-down controller delivers up to 10A

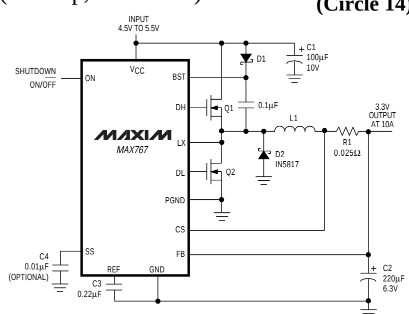
- *Very small board area*
- *>90% efficient*
- *Low-cost, external, n-channel MOSFET switches*
- *Comes in SSOP (Shrink Small-Outline Package)*
- *1A to 10A output current, depending on external components*

The MAX767 is a high-efficiency, synchronous step-down controller suitable for portable and desktop computer power supplies. It converts 5V to 3.3V at 10A, without a heatsink. The MAX767 is distinguished from comparable low-voltage switching regulators by its small size (a consequence of high switching frequency) and its low-cost external components (all MOSFETs are n-channel).

The MAX767's 300kHz operating frequency enables use of small, low-cost, external surface-mount components. The 2.5µH inductor, for instance, is much smaller than that specified for competing ICs. Further, the external n-channel MOSFETs (which cost less than p-channel devices) result in >90% efficiency over a wide range of load currents. High efficiency eliminates the need for heatsinks.

The input range is 4.5V to 5.5V, and the 750µA quiescent operating current drops to only 125µA in standby mode. A monolithic BiCMOS device, the MAX767 comes in a 20-pin SSOP, tested for either the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $3.40 (1000 up, FOB USA).

(Circle 14)



Step-up dc-dc converters deliver 150mA at 12V or 15V

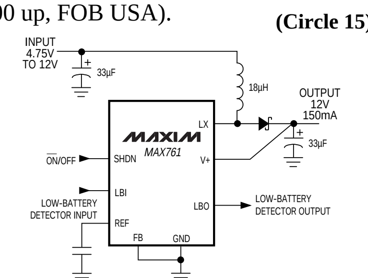
The MAX761/MAX762 step-up switching regulators generate 12V or 15V from 5V with 86% efficiency. Each has a preset output (12V for the MAX761, 15V for the MAX762). In addition, the internal Dual Mode™ circuitry allows adjustment of each output with an external resistor divider. For flash-memory programming, the MAX761 delivers 150mA at 12V for inputs from 4.75V to 12V.

High efficiency in these devices is the result of low quiescent current (110µA maximum) and a current-limited, pulse-frequency-modulated (PFM) control scheme. This design retains the benefit of pulse-width-modulation (PWM) converters (high efficiency with heavy loads), while avoiding the high supply current (2mA to 10mA) of earlier PWM converters. Other features include a logic-controlled shutdown mode with 5µA maximum supply current, an input range of 2V to 16.5V, and a 1.50V reference.

High switching frequency (to 300kHz) allows the use of a physically small surface-mount inductor. Other small external components include a diode and two capacitors. The space-saving 8-pin MAX761/MAX762 are suitable for medium- and high-power applications.

The MAX761 and MAX762 come in 8-pin DIP and SO packages, in versions tested for the 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 $2.23 (1000 up, FOB USA).

(Circle 15)



Inverting 5W dc-dc controllers provide -5V, -12V, or -15V at 85% efficiency

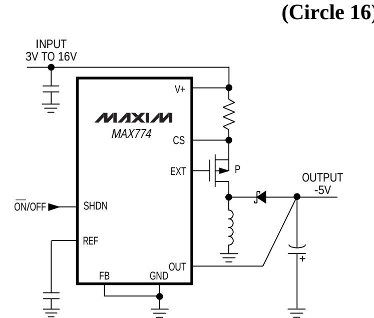
The MAX774/MAX775/MAX776 inverting switching regulators convert positive supply voltages to negative output voltages with high efficiency. The MAX774 delivers 1A at -5V, the MAX775 delivers 0.5A at -12V, and the MAX776 delivers 0.4A at -15V.

High efficiency in these devices results from low quiescent current (100µA maximum) and a current-limited, pulse-frequency-modulated (PFM) control scheme. This design retains the benefit of pulse-width-modulation (PWM) converters (high efficiency with heavy loads), while avoiding the high supply current (2mA to 10mA) of earlier PWM converters. Other features include a logic-controlled shutdown mode with 5µA maximum supply current, an input range of 3V to 16.5V, and a 1.50V reference.

High switching frequency (to 300kHz) allows the use of a physically small surface-mount inductor. Other external components include a current-sense resistor, a diode, two capacitors, and an external p-channel power MOSFET. The space-saving 8-pin MAX774/MAX775/MAX776 are suitable for medium- and high-power applications.

MAX774/MAX775/MAX776 regulators come in 8-pin DIP and SO packages, in versions tested for the 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 $2.23 (1000 up, FOB USA).

(Circle 16)



NEW PRODUCTS

Negative charge pump provides GaAsFET bias in cellular phones

The MAX850–MAX853 ICs produce -4.1V outputs useful as low-noise bias voltages for GaAsFET devices, such as the power-amplifier modules in cellular telephones and other wireless communications products. Each member of the MAX850 family has a charge-pump inverter that accepts input voltages from 4.5V to 10V, and each includes a low-noise linear regulator for rejecting ripple voltage generated by the charge pumps. The resulting output noise is only 2mVp-p.

Maxim's Dual-Mode™ circuitry can override the preset -4.1V output voltage when necessary, enabling an external resistive divider to set the output to any value between -1.3V and -9.5V. Output current capability is 5mA. Other features include a 100kHz switching frequency (which allows use of small capacitors), and a shutdown mode that draws less than 1µA. The MAX850/MAX853 have active-low shutdown controls, and the MAX851 has an active-high control. The MAX852 clock can be synchronized by an external signal.

MAX850–MAX853 ICs come in 8-pin SO packages, in versions tested for the commercial (0°C to +70°C) and extended-industrial (-40°C to +85°C) temperature ranges.

(Circle 17)

DC-DC converters accept inputs above and below the output voltage

MAX877/MAX878/MAX879 dc-dc converters provide fixed outputs from battery voltages that range from above V_{OUT} (at full charge) to below V_{OUT} (near end of discharge). Most dc-dc converters either boost or buck the input voltage, but members of the MAX877 family do both. Each device regulates in a switched linear mode for inputs above V_{OUT}. As the input falls below V_{OUT}, operation shifts smoothly to a pulse-skipping boost mode that maintains the regulated output for inputs down to 1V.

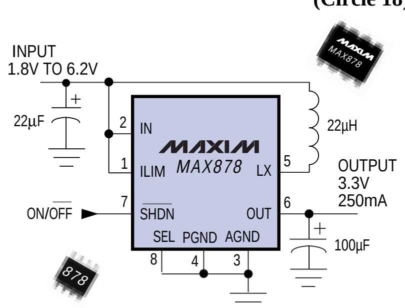
The MAX877 output is preset to 5V, and the MAX878 has pin-selectable preset outputs of 3.0V and 3.3V. MAX879 outputs, set by an external resistive divider, range from 2.5V to 6.2V. Each device includes a low-$V_{CE(sat)}$ bipolar switch that helps achieve peak efficiencies as high as 85%.

Most dc-dc converters have a diode connection between input and output that continues to drain the battery even when their outputs are out of regulation. In MAX877/MAX878/MAX879 devices, however, an internal Active Rectifier™ design disconnects the load completely during shutdown. Shutdown lowers the supply current to a battery-saving 20µA.

Each member of the MAX877 family operates with three small and inexpensive external components (an inductor and two capacitors). The inductors are physically small, because switching frequencies in the pulse-skipping step-up mode are as high as 300kHz. Some application circuits derive 5V from three or four NiCd or alkaline cells, and others derive 3.0V or 3.3V from a lithium cell or from two or three NiCd cells.

MAX877/MAX878/MAX879 devices 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 $2.95 (1000 up, FOB USA).

(Circle 18)



Step-up converters derive highest power from 1-cell (1V) inputs

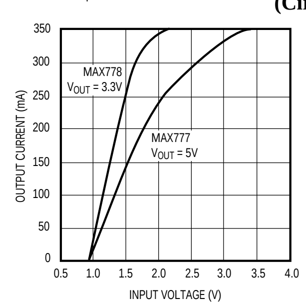
The MAX777/MAX778/MAX779 are pulse-skipping, step-up dc-dc converters that accept input voltages as low as 1V. Each derives more power from a single-cell battery than does any other IC, and each requires only three external components—an inductor (typically 22µH) and two capacitors.

Regulated outputs are 5V (MAX777), pin-selectable 3.0V or 3.3V (MAX778), and 2.5V to 6V, set with an external resistive divider (MAX779). Each device guarantees start-up at 1.0V with a 10mA load. At 1.1V, the output current capabilities are 30mA at 5V or 60mA at 3.3V. At 1.5V, the ICs typically produce 150mA at 5V, or 250mA at 3.3V.

Each device includes an internal, synchronous Active Rectifier™ that eliminates the need for an external Schottky catch diode. This circuit turns off when the IC is off or in shutdown mode, breaking the input-to-output dc path that allows battery-current drain in conventional step-up converters. The Active Rectifier™ permits regulation even when $V_{IN} > V_{OUT}$, enabling the regulation of input voltages that range above and below the output voltage. The maximum input voltage is 6.2V.

MAX777/MAX778/MAX779 ICs come in 8-pin DIP or 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 $2.65 (1000 up, FOB USA). A preassembled evaluation kit (MAX778EVKIT-SO) is also available for $40.

(Circle 19)



NEW PRODUCTS

RAM-protection IC draws only 2nA in backup

The MXD1210 is a low-power CMOS-RAM controller. Its internal voltage-monitoring and battery-switchover circuitry converts standard CMOS RAM to nonvolatile memory while drawing only 230µA of supply current. In backup mode, the device draws only 2nA.

An internal comparator circuit monitors the applied input voltage (V_{CC}). If V_{CC} goes out of tolerance (by ±5% or ±10%, according to the high/low state of the TOL terminal), the chip inhibits further write operations by gating off the RAM's chip-enable signal ($\overline{CE}$). If V_{CC} drops further, below V_{BATT} (i.e., the greater of V_{BATT1} or V_{BATT2}), the device assures uninterrupted power by switching the RAM from V_{CC} to the backup battery.

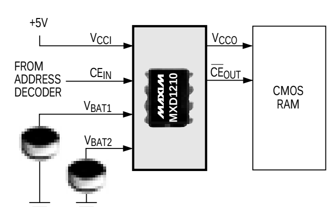
The MXD1210 also accomodates an optional second backup battery. If switchover is required with the second battery connected, monitor circuits automatically choose the one with higher terminal voltage.

The MXD1210 enters a "freshness-seal" mode when the batteries are first connected (it exits that mode when V_{CC} first comes within tolerance). Because no data is to be saved, the MXD1210 does *not* provide supply current to the RAM while in this mode. By eliminating battery drain, it assures a full realization of battery shelf life during extended storage.

The MXD1210 comes in 8-pin DIP, 8-pin SO, and 16-pin SO packages, screened 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 $2.44 (1000 up, FOB USA).

(Circle 20)

CONVERT RAM TO NONVOLATILE MEMORY



5V RS-232 transceiver serves as both DTE and DCE serial port

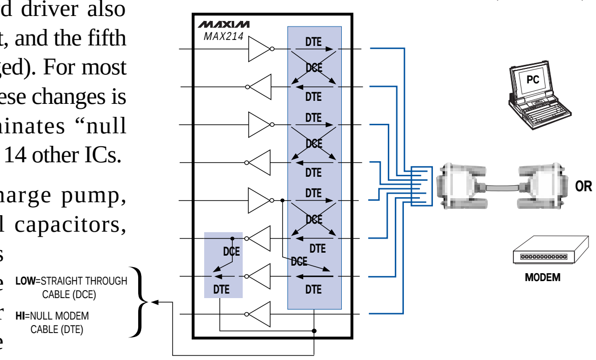
The MAX214 is a 5V RS-232 transceiver—software programmable via a single control pin as a complete, 8-line serial port for either data terminal equipment (DTE) or data circuit terminating equipment (DCE).

DTE mode configures the device as three drivers and five receivers, and DCE mode swaps the three driver outputs with three receiver inputs (the third driver also goes to the fourth receiver input, and the fifth receiver input remains unchanged). For most applications, the net result of these changes is an RS-232 device that eliminates "null modem" cables and as many as 14 other ICs.

The MAX214's dual charge pump, operating with 1µF external capacitors, generates the voltages necessary to produce the minimum ±5V transmitter output levels specified in the RS-232 standard. The device maintains full LapLink™ compatibility, with data rates guaranteed to 116kbits/sec. It also has a shutdown mode that lowers the maximum quiescent supply current from 20mA to 20µA. While in shutdown, the receivers remain active—to detect ring-indicator signals, for example.

The MAX214 comes in 28-pin DIP and wide-SO packages, 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 21)



™LapLink is a trademark of Traveling Software, Inc.

Low-power RS-485 ICs draw only 350µA max

MAX487/MAX488/MAX489 devices operate on 350µA (maximum) I_{CC}, the lowest power consumption available among RS-485 transceiver ICs. Slew-rate-limited output transitions virtually eliminate reflections caused by mismatched terminations in the data lines. As a result, MAX487/MAX488/MAX489 devices provide error-free transmission on longer cables.

Each device can transmit at least 150kbits/sec. The MAX487, a half-duplex transceiver with the industry-standard "75176" pinout, has receiver input impedances four times higher than those of other RS-485 transceivers. You can therefore connect as many as 128 MAX487s on one line, vs. the usual RS-485 limit of 32.

The MAX488 ("75179" pinout) and MAX489 ("75180" pinout), along with their 2.5Mbps equivalents, the MAX490 ("75179" pinout) and MAX491 ("75180" pinout), are full-duplex transceivers for both RS-485 and RS-422 applications. MAX488 transmitters and receivers are always enabled when the power is applied; MAX489 transmitters and receivers have separate control inputs.

The MAX487 and MAX488 come in 8-pin DIP and SO packages, and the MAX489 comes in 14-pin DIP and SO packages. All are available in versions tested for the commercial (0°C to +70°C) and extended-industrial (-40°C to +85°C) temperature ranges. Prices start at $1.25 (1000 up, FOB USA).

(Circle 22)

REDUCE RS-485 POWER CONSUMPTION