MAXIM Engineering journal

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News Briefs

MAXIM REPORTS EARNINGS AND RECORD NEW PRODUCT INTRODUCTIONS FOR Q297

Maxim Integrated Products, Inc., reported net revenues of $104.7 million for the second quarter of fiscal 1997 ending December 31, 1996, compared to $106.2 million for the same period a year ago. Net income was $33.3 million for the current quarter, compared to net income of $31.9 million for the second quarter of fiscal 1996. Income per share was $0.46 per share for Q297 compared to $0.45 per share in Q296. Operating income was 46.5% of net revenues, compared to 45.1% for Q296. Sequentially, the results for Q297 showed a modest increase over the net revenues of $101 million, net income of $31.4 million, and income per share of $0.45 reported in Q197.

Maxim introduced a record 63 new products in Q297, an increase over the previous record of 59 announced in Q197.

Backlog shippable in the next twelve months remained flat at Q197 levels of $103 million. Orders requested for delivery in the next three months increased to 77% of the backlog at December 31, 1996, compared to 72% at the end of Q197 and 59% at the end of Q496.

Turns orders received in Q297 were nearly twice those received in Q197, which were 3.4 times the turns orders received in Q496. (Turns orders are customer orders that are for delivery within the same quarter and may result in revenue within the quarter if the Company has inventory available that matches those orders.) The Company believes that this higher level of turns orders experienced in Q1 and Q2 of fiscal 1997 reflects the relatively short lead times (8–10 weeks) for integrated circuits and customers' belief that shortages will not reappear in the near future. The Company now believes that Q496 represented an inflection point in the inventory correction that began in the second half of FY96.

While the Company is encouraged by the higher business levels experienced in Q297, continued revenue growth in Q3 and Q4 of fiscal 1997 is dependent upon booking rates increasing over the Q297 levels and continued high levels of turns orders that match available supply.

Jack Gifford, Chairman, President, and CEO, commented on the quarter: "Maxim performed well in Q2. Product introductions continued at a record pace, and our gross margins remain among the industry's best. The Company anticipated and was able to respond to a significant level of turns orders. The inventory correction we predicted in 1995 appears to be behind us. We believe that we managed better than most through this period of correction because of the breadth of our product market coverage and our knowledge of these markets and customers. We managed our resources well and were committed to protecting our future. Maxim has emerged from this period stronger than ever."

Mr. Gifford continued, "We are pleased to note that during the past quarter, analyst coverage of Maxim has increased from five investment banking firms to nine. We anticipate that this increased coverage will make information about Maxim and its performance even more comprehensive and widely available.

"I was happy to see that, after six consecutive years on the *Forbes* list of the Best 200 Small Companies in America, Maxim was omitted from the list this year only because we graduated; or, as Forbes put it, we were 'so strong that they shot right off the list, growing beyond our definition of a small company—less than $350 million in sales.'"

Safe harbor statement under the Private Securities Litigation Reform Act of 1995: Forward-looking statements in this news release involve risk and uncertainty. Important factors, including overall economic conditions, demand for electronic products and semiconductors generally, demand for the Company's products in particular, availability of raw material, equipment, supplies and services, unanticipated manufacturing problems, technological and product development risks, competitor's actions and other risk factors described in the Company's filings with the Securities and Exchange Commission could cause actual results to differ materially.

Design trade-offs for single-supply op amps

The trend toward low-voltage, single-supply systems is fueled by designers' attempts to balance the often contradictory goals of lower product size and cost vs. longer battery life and better system performance. This trend may be good for consumers, but it complicates the task of choosing an appropriate op amp for a given application.

Single-supply operation is generally synonymous with low-voltage operation, and moving from ±15V or ±5V to a single 5V or 3V supply rail reduces the available signal range. Consequently, the common-mode input range, output-voltage swing, CMRR, noise, and other op-amp limitations become much more important. As in all engineering, you must often sacrifice one aspect of system performance to improve another. The following discussion of trade-offs among single-supply op amps also explains how these low-voltage amplifiers differ from their higher voltage predecessors.

Input stage concerns

Input common-mode voltage range is one of the first issues a designer should consider in specifying a single-supply op amp. The first impulse is to eliminate this concern by specifying a Rail-to-Rail® input capability. Certain penalties must be paid, however, for true rail-to-rail operation.

Most of Maxim's low-voltage op amps have input common-mode voltage ranges that include the negative supply rail (**Table 1**), but only some allow inputs that extend to the positive rail as well. Others allow input voltages only within one or two volts of the positive rail. Op amps that allow signals only to the negative rail will be referred to as ground-sensing amplifiers. Those that allow signals to either rail will be referred to as rail-to-rail input amplifiers.

V_{OS} and I_B concerns

In many applications, the amplifier provides a gain of +2V/V or more to a ground-referred signal. In these cases, a ground-sensing amplifier is generally adequate for handling the signal's common-mode range. If so, it could provide better performance than one with a rail-to-rail input. Typical rail-to-rail input stages use two differential input pairs instead of one (**Figure 1**).

As the input signal moves from one supply rail to the other, the amplifier shifts from one input pair to the other. At the crossover point, this shift can cause changes in the input bias current and offset voltage that affect both the magnitude and the polarity of these parameters. These offset-voltage changes typically worsen the distortion performance and precision specifications of rail-to-rail amplifiers (in comparison with ground-sensing types). To minimize offset-voltage shifts and smooth the transition from one input pair to another, Maxim trims the offset of its rail-to-rail amplifiers at both the high and the low ends of the common-mode range.

To reduce offset voltages caused by input bias currents, the designer should match impedances at the op amp's inverting and noninverting nodes. Because input bias currents are typically larger than input offset currents, this impedance matching is good practice for all types of op amps, not just rail-to-rail input amplifiers.

To illustrate this point, **Figure 2** shows the change in input bias current vs. common-mode range for the MAX4122–MAX4129 family of op amps (which feature rail-to-rail capability at both the input and output). As the common-mode input voltage ramps from 0V to 5V, the input bias current makes an absolute change of 85nA (from -45nA to +40nA). In contrast, the specification for input *offset* current is only ±1nA. Thus, changes at the inverting and noninverting inputs (input offset current) track each other closely, despite significant changes in the magnitude and sign of the bias currents. By matching impedances at these nodes, you can minimize the offset voltage induced by changes in input bias current.

Figure 3 shows how to match impedances in the classic inverting and noninverting op-amp configurations. The inverting configuration (**Figure 4**) offers one way to eliminate changes in the input bias current by keeping the amplifier's common-mode input voltage constant at a reference voltage (V_{REF}). The output is given by $V_{OUT} = (-V_{IN} \times R2/R1) + V_{REF}(1 + R2/R1)$. If R2 = R1, this becomes $V_{OUT} = -V_{IN} + 2V_{REF}$. For V_{REF} = 2V and V_{IN} between 0V and 3V, V_{OUT} ranges from 4V to 1V. The common-mode range is fixed, so CMR errors are eliminated as well. **Table 2** lists references suitable for use in low-voltage systems.

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

Table 1. Maxim low-voltage op amps

Part	Input Voltage Range V_{CC} - xx (V)	Input Voltage Range V_{EE} + xx (V)	Output Voltage Swing V_{CC} - xx (V)	Output Voltage Swing V_{EE} + xx (V)	Output Voltage Swing Load (Ω)	Supply-Voltage Range (V)	Max Supply Current (mA)	Max Offset Voltage (mV)	Band-width (MHz)	Slew Rate (V/µs)	Voltage Noise (nV/√Hz)	Current Noise (pA/√Hz)	Voltage Gain (dB)	Voltage Gain at Load (Ω)	Min Stable Gain (V/V)	Comments
MAX4124/5	-0.25	-0.25	0.24	0.125	250	2.7 to 6.5	0.825	0.6	26	10	22	0.4	106 84	100k 250	10	Single, rail-to-rail I/O, drives 500pF. MAX4125 has shutdown.
MAX4128	-0.25	-0.25	0.28	0.18	250	2.7 to 6.5	0.825	0.75	26	10	22	0.4	106 84	100k 250	10	Dual, rail-to-rail I/O, drives 500pF
MAX4130/1	-0.25	-0.25	0.24	0.125	250	2.7 to 6.5	1.15	0.6	10	4	22	0.4	108 82	100k 250	1	Single, rail-to-rail I/O, drives 160pF. MAX4131 has shutdown.
MAX4132/3	-0.25	-0.25	0.28	0.18	250	2.7 to 6.5	1.15	0.6	10	4	22	0.4	108 82	100k 250	1	Dual, rail-to-rail I/O, drives 160pF. MAX4133 has shutdown.
MAX4134	-0.25	-0.25	0.28	0.18	250	2.7 to 6.5	1.15	0.6	10	4	22	0.4	108 82	100k 250	1	Quad, rail-to-rail I/O, drives 160pF
MAX4122/3	-0.25	-0.25	0.24	0.125	250	2.7 to 6.5	0.825	0.6	5	2	22	0.4	106 84	100k 250	1	Single, rail-to-rail I/O, drives 500pF. MAX4123 has shutdown.
MAX4126/7	-0.25	-0.25	0.28	0.18	250	2.7 to 6.5	0.825	0.75	5	2	22	0.4	106 84	100k 250	1	Dual, rail-to-rail I/O, drives 500pF. MAX4127 has shutdown.
MAX4129	-0.25	-0.25	0.28	0.18	250	2.7 to 6.5	0.825	1.5	5	2	22	0.4	106 84	100k 250	1	Quad, rail-to-rail I/O
MAX4165–9	-0.25	-0.25	0.36	0.26	25	2.7 to 6.5	1.5	0.65	5	2	26	0.4	124 100 87	100k 1k 25	1	Guaranteed 80mA output current drive, drives 500pF loads. Outputs high impedance in shutdown.
MAX4330–4	-0.25	-0.25	0.125	0.1	2k	2.7 to 6.5	0.325	0.65	3	1	28	0.26	120 95	100k 2k	1	Single/dual/quad, 300pF capacitive drive. MAX4331/3 have shutdown.
MAX4162/3/4	-0.25	-0.25	0.02 0.02	0.02 0.2	100k 10k	2.7 to 10	0.035	5	0.2	0.08	80		110 110	100k 10k	1	Single/dual/quad, drives 500pF, internal charge pump
MAX492/4/5	0	0	0.15	0.15	1k	2.7 to 6	0.15	0.5	0.5	0.2	25	0.1	108	1k	1	Dual/quad/single, precision, rail-to-rail I/O
MAX480	1	0	0.8mV	0.1mV	10k	1.6 to 36	0.015	70µV	0.02	0.012	55	0.6	112 105	100k 10k	1	Low V_{OS} and drift, micropower, I/O to negative rail
MAX478/9	1.1	-0.3	1.2	0.2	2k	2.2 to 36	0.017	70µV	0.06	0.025	49	0.01	104	50k	1	Micropower, precision
MXL1178/9	1.1	-0.3	1.2mV	0.2mV	2k	2.2 to 36	17	70µV	0.06				106	50k	1	Dual/quad, precision
MAX409/17/19	1.1	0	0.01	0.01	1M	2.5 to 10	0.0012	10	0.15	0.08	150		120	1M	10	Single/dual/quad, lowest power
MAX406/7/18	1.1	0	0.01	0.01	1M	2.5 to 10	0.0012	10	0.008 to 0.04	0.02	150		120	1M		Single/dual/quad, lowest power
MAX4180–MAX4187*	1.1	1.1	1.8	1.8	1.50	4.5 to 11	1.2	5	400	1200	2	4	66 61	1k 150	1	Single/dual/quad, low power, high bandwidth, high slew rate, low distortion. SOT23-6 package.
MXL1013/14	1.2	-0.3	6mV	1.2V	600	4 to 36	0.5	150µV	0.6	0.4	22	0.07	138	2k	1	Dual/quad, precision
MAX410/12/14	1.3	1.2	1.3	1.2	2k	±2.4 to ±5.25	2.7	1 typ	28	4.5	1.8	1.2	120 119	2k 600	1	Single/dual/quad, high speed, low noise (<2.4nV/√Hz) guaranteed)
MAX473/4/5	1.7	-0.1	0.05	0.05	Un-loaded	2.7 to 6	3	1	10	17	40		110 105 90	No load 10k 600	1	Single/dual/quad, wide output swing, 15V/µs min slew rate
MAX4212/13/16/18	2.25	-0.2	0.7	0.6	50	3.15 to 11	7	9	300	600	10	6	61 59 57	2k 150 50	1	Single/dual/triple/quad. MAX4213/18 have shutdown (outputs high impedance in shutdown). SOT23-5 package.
MAX430/2	2.5	-0.1	0.5	0.5	10k	±2.5 to ±16.5	0.5 to 2	5µV	0.125 to 0.5	0.125	0.4µ Vp-p	0.01	150	10k	1	Chopper stabilized, internal capacitors

**Future products—available after April 1997.*

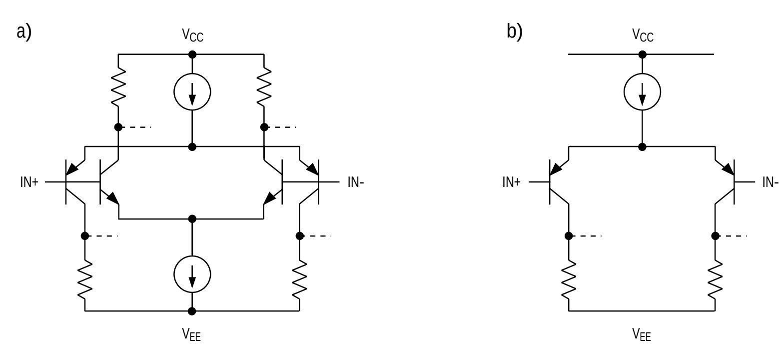


Figure 1. A rail-to-rail input stage (a) has two differential pairs, while a standard ground-sensing input stage (b) has only one.

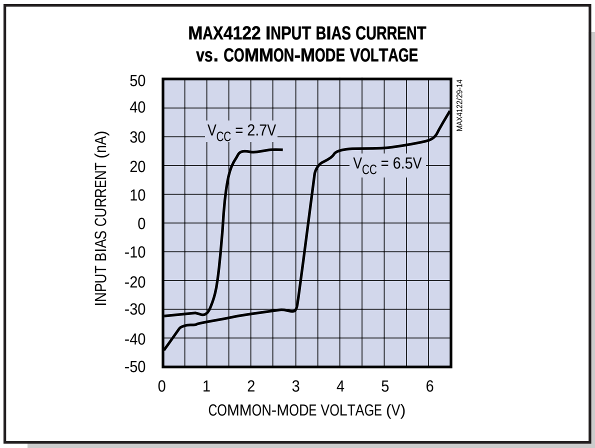


Figure 2. As the common-mode input voltage of a rail-to-rail input amplifier sweeps from one supply rail to the other, the input bias current can change, both in sign and in magnitude.

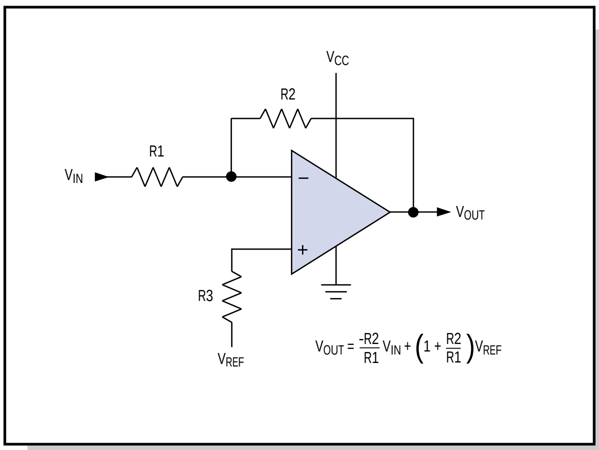


Figure 4. By holding the common-mode input voltage constant, the inverting-amplifier configuration eliminates common-mode-rejection errors.

Slew rate

Slew rate can also suffer when a rail-to-rail input amplifier is used in place of a ground-sensing amplifier. The ground-sensing amplifier's simpler input stage can take advantage of many slew-rate-enhancing circuit techniques that are simply not available to amplifiers with the two-pair, rail-to-rail input. For example, MAX4212 family op amps (Table 1) have ground-sensing inputs that help them achieve 600V/µs slew rates and 300MHz bandwidths with supply currents of only 7mA maximum. If they had rail-to-rail input stages and all other specs remained unchanged, the slew rates would be several times lower.

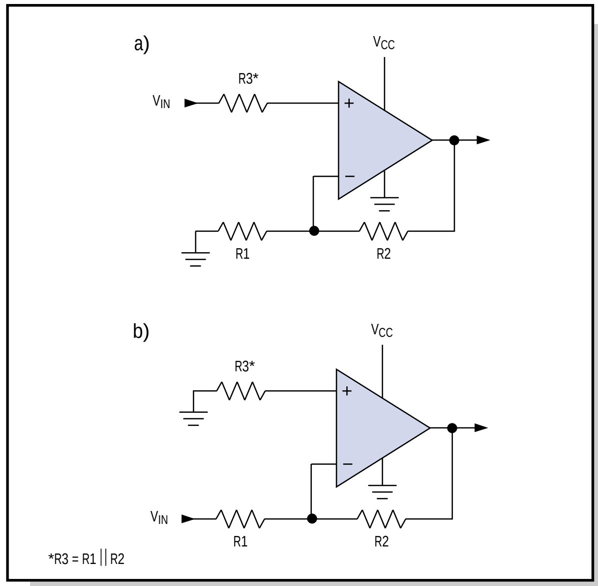


Figure 3. Matching the resistance at the inverting and noninverting nodes minimizes offset errors caused by input bias currents for both the noninverting (a) and inverting (b) configurations.

Output stage concerns

While low-voltage designs may not require op amps with rail-to-rail input stages, they typically require rail-to-rail output stages to maximize dynamic range. Because op amps provide gain in most applications, the output voltage is usually larger than the input voltage. Thus, a rail-to-rail input stage is not always required, but a rail-to-rail output stage usually is. These output stages differ from those in dual-supply op amps and cause different circuit behavior in the rail-to-rail output amplifiers.

Rail-to-rail output stages usually incorporate a common-emitter configuration, and standard output stages usually have an emitter-follower configuration (**Figure 5**). For common-emitter output stages, the voltage drop from input to output is relatively low (a single collector-to-emitter saturation voltage, or $V_{CE(SAT)}$), but the classic emitter-follower output stage cannot get closer to the rail than $V_{CE(SAT)}$ (due to the current source) plus V_{BE} (due to the output transistor).

Because a bipolar transistor's $V_{CE(SAT)}$ depends on the current through the transistor, the output swing of a bipolar op amp depends on its load current. Thus, despite claims of rail-to-rail performance, an amplifier's output stage never truly reaches the supply rail. A MAX4122 with 100kΩ load, for instance, swings to within 12mV of the positive rail and 20mV of the negative rail. With a 250Ω load, however, it swings only to within 240mV of the positive rail and 125mV of the negative rail.

Table 2. Maxim low-voltage references

Part	Output Voltage (V)	Input Voltage Range (V)	Temp. Drift (ppm/°C max)	Max Initial Accuracy, T_A = +25°C (% F.S.)	Max Quiescent Current (µA)	Max Noise, 0.1Hz to 10Hz (µVp-p, typ)	Package Options[1]	Temp. Ranges[2]	Features
MAX6120	1.2	2.4 to 11	100 (30 typ)	1	58	10	SOT23, SO	E	Low-cost, micropower, three-terminal reference
MAX6520	1.2	2.4 to 11	50	1	70	10	SOT23, SO	E	Low-cost, micropower, three-terminal reference; low drift
ICL8069	1.2	>V_{OUT}	10 to 100	2	50	5 (10Hz to 10kHz)	TO-52, TO-92, SO	C, E, M	Micropower, two-terminal reference
MAX6125	2.5	2.7 to 12.0	50	1	130	15	SOT23, SO	E	Low-cost, low-dropout, three-terminal reference
MAX872	2.5	2.7 to 20	40	0.2	10	60	DIP, SO	C, E	Lowest-power, lowest-dropout precision reference. V_{CC} = V_{OUT} + 200mV.
MAX873	2.5	4.5 to 18	7 to 20	0.06 to 0.1	280	16	DIP, SO	C, E, M	Low-power/drift, REF43 upgrade
MX580	2.5	4.5 to 30	10 to 85	0.4 to 3	1.5mA	60	TO-52, SO	C, M	Low-drift bandgap reference
MX584	2.5	4.5 to 30	5 to 30	0.05 to 0.3	1mA	50	TO-99, DIP, SO, CERDIP	C, M	Low-drift programmable reference
MAX6141	4.096	4.7 to 12.6	50	1	130	25	SOT23, SO	E	Low-cost, low-dropout, three-terminal reference
MAX676	4.096	4.5 to 18	1 to 3	0.02	10mA	1.2	DIP/SO/CERDIP	C, E, M	Lowest temperature drift in SO package, lowest long-term drift, low dropout
MAX874	4.096	4.3 to 20	40	0.2	10	60	DIP, SO	C, E	Lowest-power, lowest-dropout precision reference. V_{CC} = V_{OUT} + 200mV.
MAX6145	4.5	4.7 to 12.6	50	1	130	30	SOT23, SO	E	Low-cost, low-dropout, three-terminal reference
MAX6160	Adjustable 1.23 to 12.40	V_{OUT} + 0.2	50	1	130	15	SOT23, SO	E	Adjustable, low-cost, low-dropout, three-terminal reference

1 Package options: DIP = dual-in-line package; PLCC = plastic leadless chip carrier (quad pack); FP = flat pack
2 Temperature ranges: C = 0°C to +70°C, E = -40°C to +85°C; M = -55°C to + 125°C

For CMOS output stages, the analogy to the bipolar transistor's collector-emitter voltage is the MOSFET's drain-source voltage, which is caused by the product of on-resistance and channel current in the MOSFET. Thus, the output voltage swing for a MOSFET output stage is also a function of the load.

Gain vs. load

Besides offering a low input-to-output voltage drop, the common-emitter stage of a rail-to-rail amplifier differs from the emitter-follower stage in other important ways. Common-emitter stages provide voltage gain and have relatively high-impedance outputs; emitter-follower stages provide unity voltage gain and have low-impedance outputs. For that reason, rail-to-rail op amps usually include the output node as part of the compensation network, while standard op amps typically take their compensation at a preceding stage. For rail-to-rail op amps, the resulting dependency of gain on load current can make them unstable when driving capacitive loads.

These properties of rail-to-rail outputs can be suppressed with careful op-amp design, but the trade-off tends to be a higher supply current than required by op amps with emitter-follower output stages. The MAX4122–MAX4129 family of op amps offers good capability for driving capacitive loads (Table 1). Featuring rail-to-rail inputs and outputs that remain stable while driving 500pF, these op amps are useful for driving both improperly terminated cables and the capacitive inputs of analog-to-digital converters. The features that allow them to drive heavy capacitive loads also allow them to maintain good large-signal voltage gain, even with heavy resistive loads.

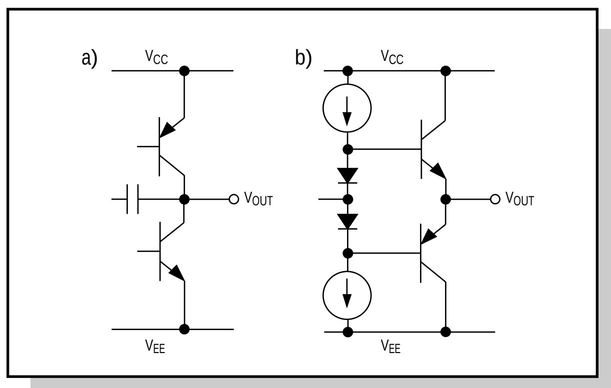


Figure 5. A rail-to-rail output stage (a) has a common-emitter configuration, while a standard output stage (b) has an emitter-follower configuration.

Open-loop gain vs. output swing

As is true for all op amps, the open-loop gain for a rail-to-rail output amplifier is a function of the output voltage swing. Thus, to evaluate a rail-to-rail output amplifier, you must specify the gain both at a given output voltage and with a given load. Maxim specifies gain this way, but not all vendors include such data in their data sheets. For example, an op amp may have 106dB of open-loop gain and the capability to drive a 250Ω load to within 125mV of the rails, but it may not be able to exhibit those capabilities at the same time. The MAX4122–MAX4129 data sheet, for instance, properly specifies large-signal voltage gain and output voltage swing in its *Electrical Characteristics* table (**Figure 6**). Large-signal voltage gain vs. output voltage and load graphs for these devices are shown in **Figure 7**.

Charge-pump op amps

The MAX4162 op-amp family illustrates a novel approach to the problems of the standard rail-to-rail output stage. These op amps have a classic emitter-follower output stage, but achieve rail-to-rail outputs with an internal charge-pump converter that provides internal supply voltages to bias the output stage. The charge-pump converter also provides power to the amplifier's other stages. Thus, the input stage has a standard ground-sensing configuration, but allows inputs to swing from ground to V_{CC}. Specifications for this family are listed in Table 1. Each device draws only 35µA (including the charge-pump converter) while providing a 200kHz bandwidth. Supply currents are low, but these amplifiers can drive relatively heavy loads of 20kΩ and 500pF.

Because a charge pump enables the construction of op amps with standard input and output structures, such amplifiers can offer performance superior to that of rail-to-rail op amps. Charge-pump op amps have very good common-mode rejection, and their single input-transistor pair is not prone to the offset-voltage changes caused by switchover between input pairs. In addition, the classic emitter-follower output stage provides high open-loop gain, even with a relatively heavy resistive load. It also allows the amplifier to remain stable while driving large capacitive loads.

General issues

Single-supply operation also aggravates the problems of noise, biasing, and distortion.

Noise

Single-supply applications are generally low voltage, and lower supply rails force the designer to make a corresponding reduction in noise just to maintain the system's signal-to-noise ratio. Unfortunately, low-voltage operation usually goes hand-in-hand with low-power operation, and as supply current decreases, amplifier noise tends to increase. All else being equal, a lower noise amplifier requires higher power dissipation.

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = +2.7V to +6.5V, V_{EE} = 0V, V_{CM} = 0V, V_{OUT} = V_{CC} / 2, R_L tied to V_{CC} / 2, $\overline{SHDN}$ ≥ 2V (or open), T_A = +25°C, unless otherwise noted.)

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
Large-Signal Voltage Gain	V_{CC} = 2.7V	V_{OUT} = 0.25V to 2.45V, R_L = 100kΩ		92	104		dB
		V_{OUT} = 0.4V to 2.3V, R_L = 250Ω		72	80		
	V_{CC} = 5V	V_{OUT} = 0.25V to 4.75V, R_L = 100kΩ		94	106		
		V_{OUT} = 0.4V to 4.6V, R_L = 250Ω		75	84		
Output Voltage Swing	MAX4122/ MAX4123/ MAX4124/ MAX4125	R_L = 100kΩ	V_{CC} - V_{OH}		12	20	mV
			V_{OL} - V_{EE}		20	25	
		R_L = 250Ω	V_{CC} - V_{OH}		240	290	
			V_{OL} - V_{EE}		125	170	
	MAX4126/ MAX4127/ MAX4128/ MAX4129	R_L = 100kΩ	V_{CC} - V_{OH}		15	30	
			V_{OL} - V_{EE}		25	40	
		R_L = 250Ω	V_{CC} - V_{OH}		280	330	
			V_{OL} - V_{EE}		180	230	

Figure 6. A proper specification for large-signal voltage gain includes both the load and the output voltage swing. Output voltage swing is a function of the load being driven.

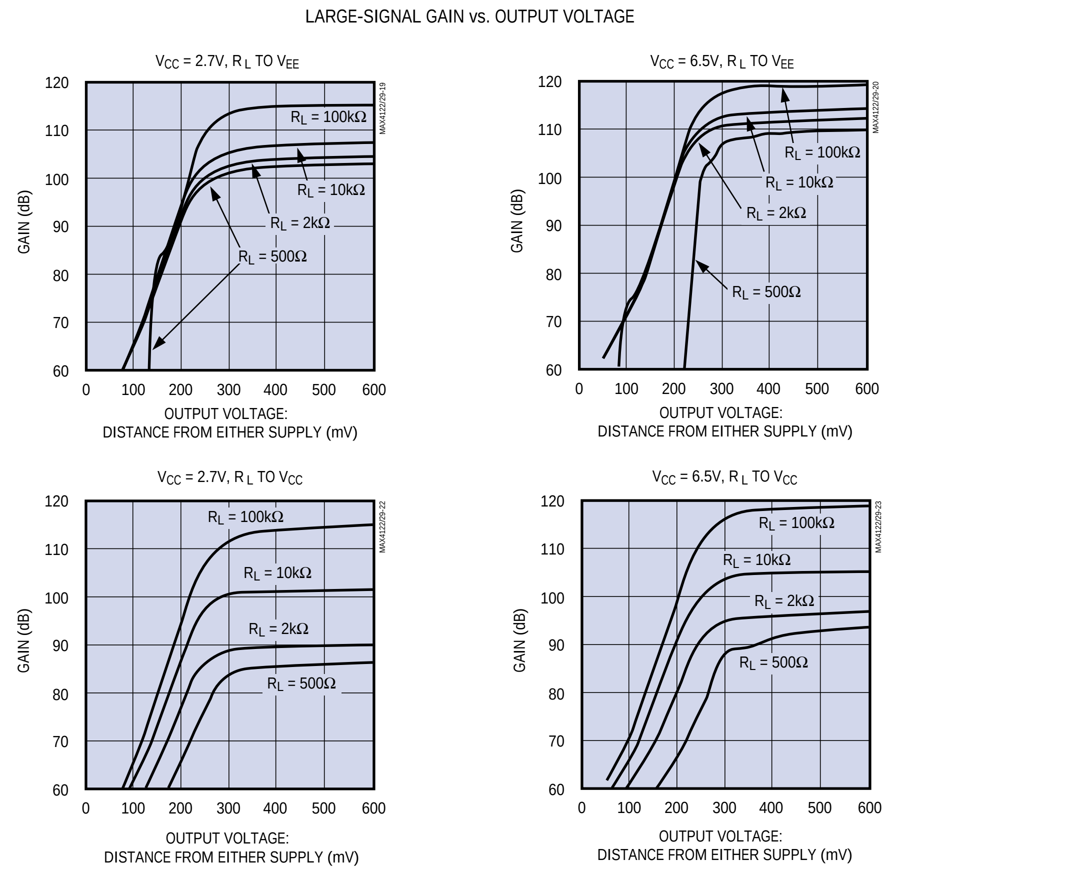


Figure 7. These graphs show a dependence of gain on the load and the output voltage swing for rail-to-rail output amplifiers.

To evaluate op-amp noise, consider all noise sources: input voltage noise, input current noise, and thermal noise caused by the gain-setting resistors. **Figure 8** illustrates these noise sources with a voltage-feedback op amp. C1 is stray capacitance at the op amp's inverting input, C2 limits noise gain and signal bandwidth at the higher frequencies, and R1/R2 are the standard gain-setting resistors. R3 balances the resistances seen by the inverting and noninverting inputs.

At low frequencies, the noise gain is given by 1 + R2/R1 (**Figure 9**). The noise gain sees its first zero at a frequency given by 1/2πR1C1, then increases at 6dB per octave until it hits the pole caused by C2. At this pole (1/2πR2C2), the noise gain is flat and equal to 1 + C1/C2. Noise gain then intercepts the open-loop gain of the amplifier and rolls off at 6dB per octave (the standard single-pole rolloff of the amplifier's open-loop gain).

Because the input voltage noise, noninverting current noise, and noise due to R3 are integrated over the entire closed-loop bandwidth and multiplied by the circuit's noise gain, you can see (from the plots of noise gain and open-loop gain) that circuit noise can be minimized by choosing an op amp with a lower unity-gain-crossover frequency. For the inverting input, current noise and the thermal noise due to R1 and R2 are integrated only over the signal bandwidth (1/2πR2C2). Since capacitor C2 is not present for current-feedback op amps, noise for those types is integrated over the entire closed-loop signal bandwidth.

Distortion

An amplifier's loop gain minimizes the distortion that would otherwise result from nonlinearities in its input-to-output transfer function. Because amplifier gain falls off at higher frequencies, the amplifier's harmonic distortion increases.

Thus, for a given frequency, an op amp can achieve superior harmonic performance if it operates in its more linear region, with maximum loop gain. This usually means biasing the output away from the supply rails, as in Figure 4 (which introduces signal inversion and offset) or **Figure 10** (which introduces offset but no signal inversion).

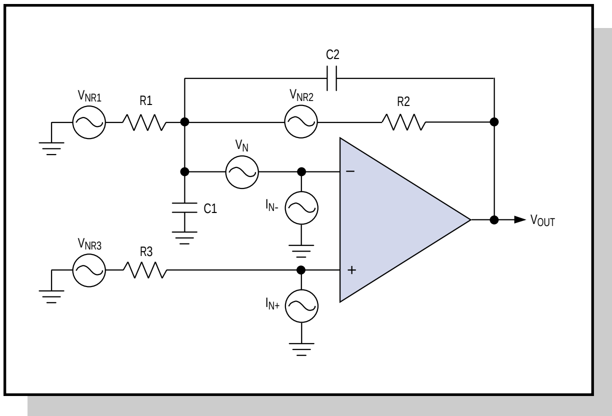


Figure 8. Major noise sources in a voltage-feedback op amp are as shown.

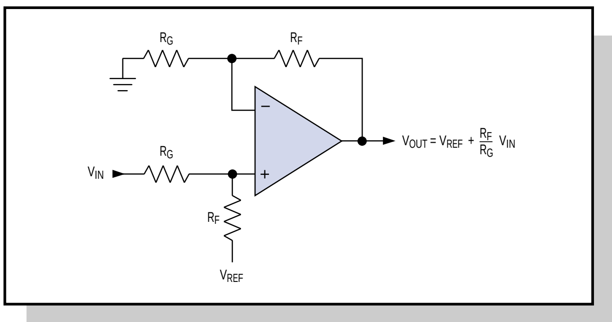


Figure 10. Providing both gain and offset to the input signal, this circuit biases the output voltage away from the supply rails.

The inverting method shown in Figure 4 eliminates common-mode nonlinearities by keeping the common-mode input voltage constant. This feature is particularly useful for rail-to-rail input amplifiers, whose nonlinearities are produced by changes in the common-mode input (as the input stage shifts from one input pair to the other).

Focus again on the output stage. A light load will improve the harmonic performance of rail-to-rail amplifiers, because gain is a function of load current. An amplifier's voltage excursion also affects distortion. All op amps tend to benefit from loads that require a minimal voltage excursion (internal nodes don't have to travel too far, so they tend to remain in their linear regions). An amplifier's slew rate, which is related to full-power bandwidth, also affects harmonic distortion. In running the amplifier above its full-power bandwidth, the associated slew-rate limitations cause severe nonlinearities.

Generating a second supply

High-performance, single-supply op amps are becoming more common, but to maximize performance you must sometimes choose a dual-supply amplifier. The selection of dual-supply types is greater because dual-supply

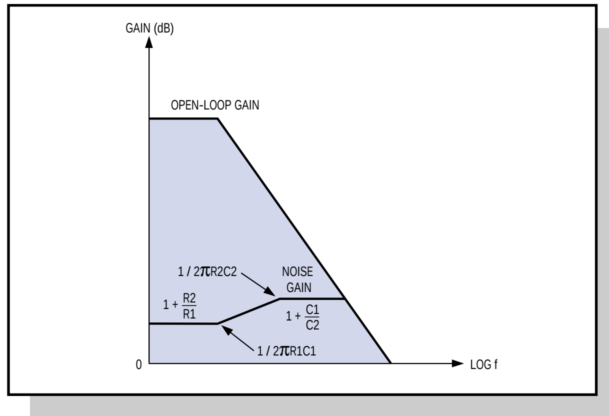


Figure 9. This graph shows noise gain and open-loop gain for the amplifier in Figure 8.

systems have been available longer, and dual-supply op amps are not designed with the same restrictions as their single-supply cousins.

Countless methods are available for generating a negative supply from an existing positive one. Switching regulators are the most flexible, but charge-pump voltage converters offer the simplest, smallest, and cheapest alternative. Because charge-pump converters provide voltage conversion with external capacitors rather than inductors, they excel at providing integer multiples of the input voltage ($-V_{IN}$, $+2V_{IN}$, etc.). Their output voltages are typically unregulated, but if load currents are relatively light, the output voltages remain fairly close to an integer multiple of the input.

Because charge-pump converters can have very low quiescent supply currents, they can be highly efficient under light loads. In **Figure 11**, a charge-pump converter is configured to generate a negative voltage that is equal to the input in magnitude but opposite in polarity. Pin-strap options set the internal oscillator frequency at 13kHz, 100kHz, or 250kHz, allowing the designer to trade off quiescent current consumption, charge-pump capacitor size, or output voltage ripple.

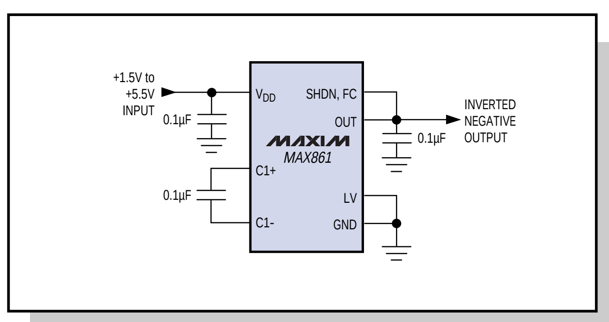


Figure 11. Simple, small, and inexpensive charge-pump converters can readily generate a negative supply rail from a positive one.

DESIGN SHOWCASE

Step-up/step-down current source charges batteries

For battery charging, the highly efficient step-down (buck) configuration is usually the topology of choice. But a different approach is required if special conditions prevail: if the supply voltage is less than the battery voltage, or (worse) if the supply voltage ranges above and below the battery voltage. The charger might need to accommodate one of several voltage sources, depending on to which is active, and it might need to charge batteries with different cell counts. All of these requirements can be met with the **Figure 1** circuit, which charges 1 to 15 cells from an input of 4V to 15V.

The topology shown is the single-ended, primary-inductance converter (SEPIC), which is notable for its step-up/step-down capability. The controller (IC1) usually regulates an output voltage, but in this case the resistive dividers at pin 3 keep the feedback unsatisfied, causing the system to produce current pulses at a level determined by its current-limit circuitry. To regulate charging current, the op amp adjusts Q1's current limit by comparing the R2 voltage (proportional to charging current) with a voltage derived from the reference in IC1. S1 and S2 let you set the charging-current level.

The maximum Q1 current set by R1 (4A) is within the capability of L1, but it allows some saturation and heating. If this peak inductor current is insufficient, I_{OUT} will fall gracefully short of the desired maximum value (1A). If V_{IN} is high and V_{OUT} is low, you can obtain more charging current by changing resistor values at the op amp's inverting input. Otherwise, higher current requires that you set a higher peak current by lowering R1. In that case, L1, L2, C1, and C2 must be larger to withstand the higher currents.

To limit the voltage stresses on Q1, C1, C2, and D1, the resistor values connected at pin 3 of IC1 set a maximum output voltage of 28V across the battery. You can extend this voltage by adjusting the resistors, but note that Q1 and D1 must withstand slightly more than V_{IN} + V_{OUT}, and the coupling capacitor (C1) must withstand V_{IN}. The full charging current flows through C1, so be sure that any substitutes can handle the required voltage and the ripple current. C1 and C2 are nonpolarized ceramic capacitors, but maintain the polarities shown if you substitute polarized capacitors.

As shown, the maximum V_{IN} is about 15V. This value can be higher if you limit the supply voltage applied to IC1 (pin 2). Either add a linear regulator for this purpose, or replace the MAX770 with a MAX773, which takes its power from a built-in shunt regulator. Note that any coupling between L1 and L2 will assume the polarities shown by the dots, but circuit operation does not depend on such coupling.

DESIGN SHOWCASE

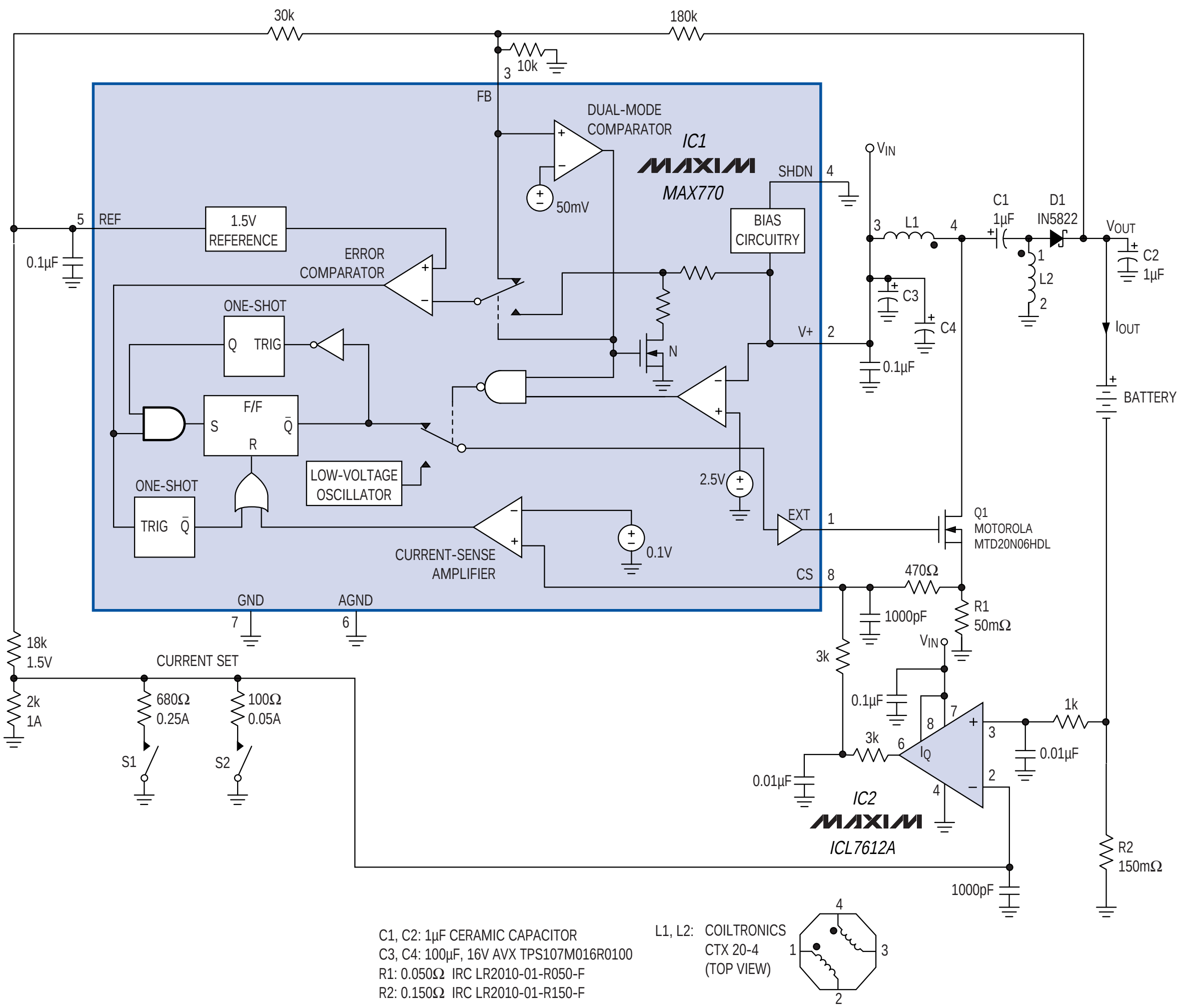


Figure 1. This versatile battery charger is built around the controller IC, which is forced to produce an average current at an amplitude regulated by the op amp.

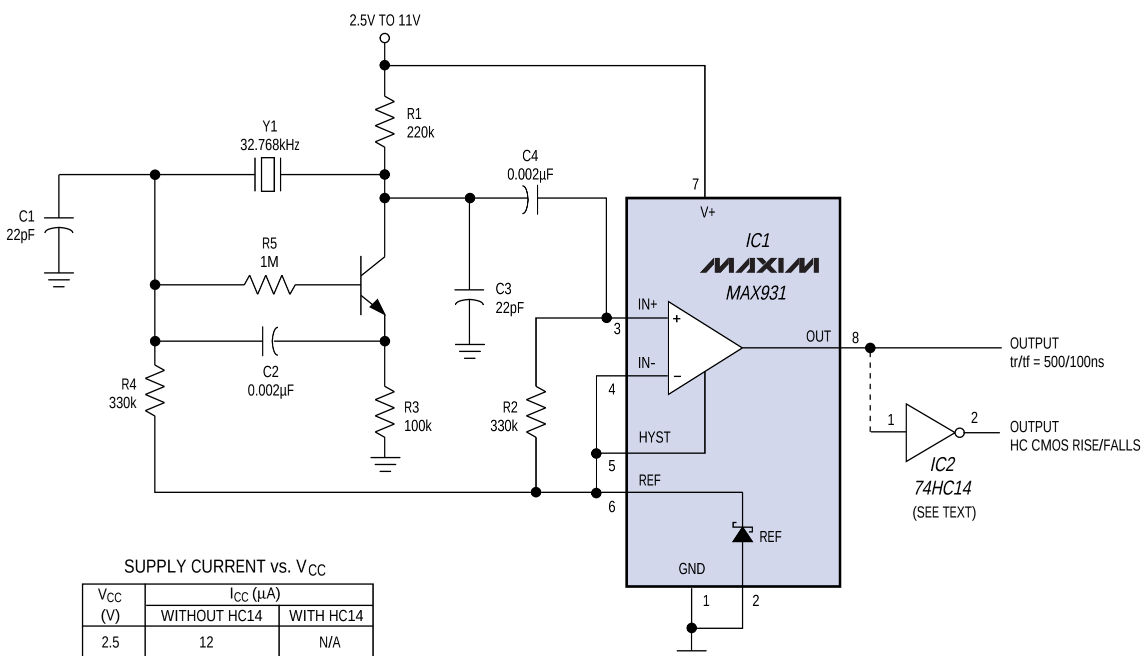
DESIGN SHOWCASE

Low-power, 32kHz oscillator operates over wide supply range

A 32kHz oscillator is often used to generate a system clock or auxiliary sleep clock in low-power instruments and microcontrollers (µCs). The usual implementation is a CMOS inverter (74HC04 or CD4049UB type) biased as a linear amplifier by connecting a large-valued resistor from the input to the output.

Inverter circuits present problems, however. Supply currents fluctuate widely over a 3V to 6V supply range, and currents below 250µA are difficult to attain. Operation can be unreliable for wide variations in supply voltage. Further, the inverter's input characteristics can vary widely (especially among different manufacturers), and they are not guaranteed.

A very low-power crystal oscillator solves these problems (**Figure 1**). Drawing only 13µA from a 3V supply, it consists of a single-transistor amplifier/oscillator (Q1) and a low-power comparator/reference device (IC1). Q1's base is biased at 1.25V via R5, R4, and the reference in IC1. V_{BE} is about 0.7V, placing the emitter at approximately 0.5V.



SUPPLY CURRENT vs. V_{CC}

V_{CC} (V)	I_{CC} (µA) WITHOUT HC14	WITH HC14
2.5	12	N/A
3.0	13	21
4.0	15	29
5.0	18	42
6.0	23	59
7.0	24	N/A
8.0	28	N/A
9.0	31	N/A
10.0	35	N/A

Figure 1. This 32kHz, low-power clock oscillator offers numerous advantages over conventional oscillator circuits based on a CMOS inverter (see text).

This constant voltage across R3 sets the transistor's quiescent current at 5µA, which fixes the collector voltage at about 1V below V_{CC}. The amplifier's nominal gain (R1/R2) is approximately 2V/V.

The crystal combined with the load capacitors C1 and C3 forms a feedback path around Q1, whose 180° of phase shift causes the oscillation. C4 couples this signal to the comparator input, whose quiescent voltage (1.25V) is set by the reference via R2. The comparator's input swing is thus centered around the reference voltage. Operating at 3V and 32kHz, IC1 draws about 7µA.

The comparator output can source 40mA and sink 5mA—more than enough for most low-power loads. The moderate-speed rise/fall times, however (500ns and 100ns, respectively), can cause standard, high-speed CMOS logic to draw higher-than-normal switching currents. In that case, the optional Schmitt trigger shown (IC2) can handle the comparator's rise/fall times with only a small penalty in supply current (see table in Figure 1). You can omit the Schmitt trigger if the oscillator drives a µC's crystal-input terminal.

Unlike inverter-based oscillators (which exhibit start-up difficulties, finicky operation, and a decade of change in supply current over the 3V to 6V range), this circuit starts quickly and reliably at any supply voltage. Component values are generally not critical, and for Q1, you can substitute any small-signal transistor with a decent beta of 100 or so at 5µA. Supply currents are nearly flat over the 2.5V to 11V supply range (the maximum allowed for IC1).

DESIGN SHOWCASE

5V step-down converter has transformer-isolated feedback

The circuit of **Figure 1** shows an alternative to opto-isolated feedback signals (the system shown is a 5V switching regulator). The zero (non-existent) line regulation of a push/pull, surface-mount transformer and driver (T2 and IC2) produces an isolated feedback signal (to pin 3 of IC1) proportional to the regulator's nominal 5V output. The result is a fully isolated dc-dc converter without the usual opto-isolator bandwidth constraints and aging characteristics.

By alternately grounding each end of T2's center-tapped primary, the transformer driver (IC2) generates an ac signal proportional to the desired 5V feedback voltage. A diode bridge (CR2–CR5) and capacitor (C4) convert this transformer's output to dc, and a diode-resistor network (CR1, R3, R4) compensates for the diode bridge's temperature coefficient. (You can substitute silicon signal diodes, such as 1N4148s, for the Schottky diodes.) The result is a zero-TC voltage slightly less than $1/2V_{OUT}$. Transformer T1 isolates V_{OUT}.

In response to a 5V output, the feedback network produces an isolated 2.404V (at IC1, pin 3) and introduces about 250ns of delay at 100kHz—the equivalent of 9° of phase shift. This bandwidth is sufficient for the control loop in most switching converters. Supply current for IC2 and the temperature-compensation network together is about 6mA.

Starting with a 5V, nonisolated transformer flyback converter in which V_{OUT} connects directly to the top of C1 and R1, you can insert the isolated-feedback circuit (bottom of Figure 1) between V_{OUT} and C1/R1. To accommodate this extra isolated-feedback circuit, simply reduce the value of R1 to ensure that the R1/R2 divider voltage is comparable to IC1's internal feedback reference (1.5V).

The isolated converter's performance is virtually identical to that of the nonisolated converter, except for isolated-feedback-circuit power consumption. T2 provides $500V_{RMS}$ isolation. (You can also get transformers with $1500V_{RMS}$ isolation.)

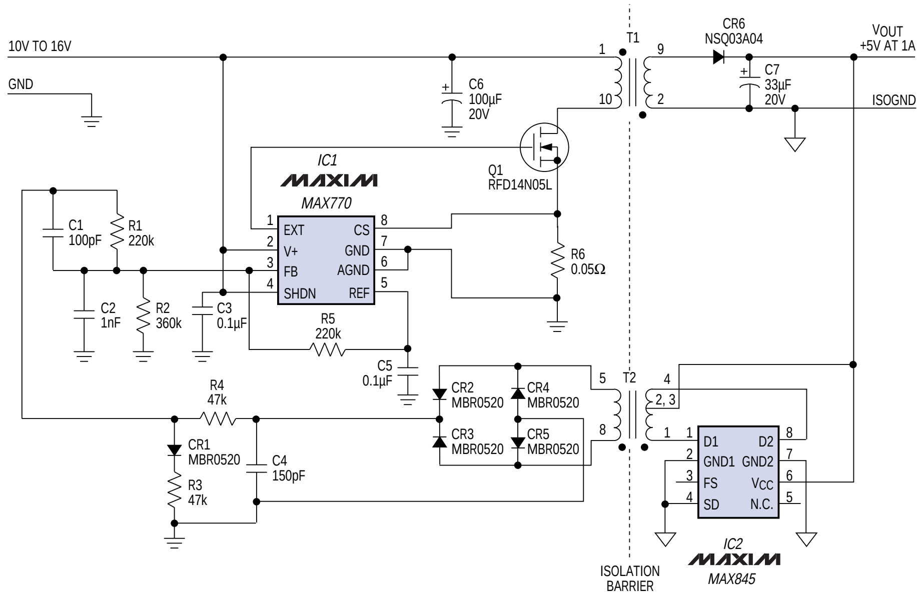


Figure 1. This fully isolated 5V switching regulator offers long-term reliability and ease of design.

DESIGN SHOWCASE

Simple circuit measures battery impedance

The circuit of **Figure 1** lets you calculate battery impedance as the ratio of an ac voltage applied across the battery to the resulting ac current through the battery. Batteries are seldom specified for parameters other than voltage and amp-hour capacity, but this internal impedance is important. A photo flash, for example, recycles twice as fast with nickel-cadmium (NiCd) batteries as with higher impedance alkaline types.

By applying an ac voltage superimposed on a ten-times-larger negative-dc voltage (at V_{FG}), the function generator determines the battery current drawn by Q1. Generator voltage causes the op-amp output to go high and turn Q1 on, which allows battery current to flow through the high-side current-sensing amplifier IC1. IC1's output current (pin 8) equals 1/2000 of this battery current.

IC1, IC2, and Q1 thus form a loop in which the op amp forces a virtual ground at the left end of R3. The op amp's extremely low offset voltage (10µV maximum) ensures accuracy. This virtual-ground condition enables the voltage divider (R5 and R3||R4) and function generator to determine the voltage across R3. The following equation represents the resulting current in R3:

Equation 1:

$$i_{R3} = \frac{R3 \| R4}{R3 \| R4 + R5} \times \frac{V_{FG}}{R3}$$

Substituting resistor values and noting that battery current is 2000 times i_{R3},

Equation 2:

$$i_{BATTERY} = -\frac{V_{FG}}{5}$$

To operate, set the generator's ac voltage to approximately 10% of its dc component. Equation 2 then gives the resulting ac current in the battery (i_B). Using an ac voltmeter, you can measure ac voltage across the battery (v_B) and calculate the average cell impedance as $v_B / (N i_B)$, where N is the number of cells. The circuit easily accommodates battery voltages of 3V or more.

You can replace the R3/R4/R5 network with its Thevenin equivalent, but the result is a smaller V_{FG}. You can regain the V_{FG} magnitude by substituting a

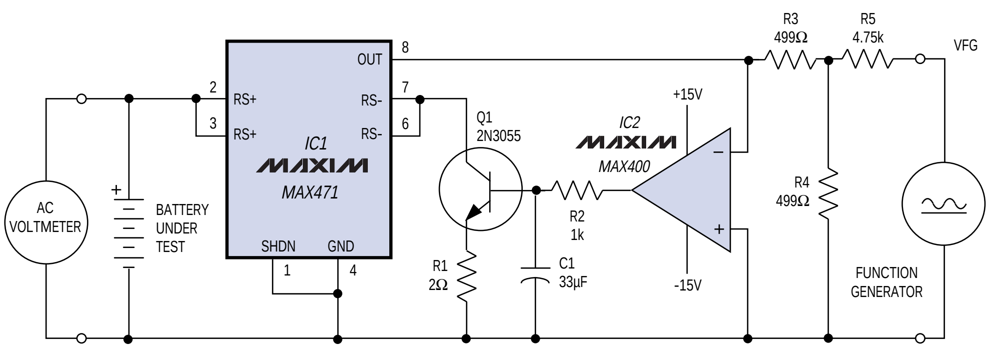


Figure 1. With a bench power supply, function generator, and ac voltmeter, this circuit measures battery impedance under a varying load.

larger value for R3, but the resulting increase in loop gain can cause instability. R2/C1 is a frequency-compensation network for the configuration shown.

The crude voltage-to-current converter (Q1/R1) should not allow Q1 to saturate under the conditions of peak battery current and minimum battery voltage. The V-to-I transconductance (set by R1) combines with IC1's scaling factor (1/2000) and the impedance seen by IC1's signal output (pin 8) to affect the loop gain. For the resistor values shown, the suggested test frequency—about 100Hz—is one for which most ac voltmeters are quite accurate.

Table 1 shows measurements made by this circuit on freshly charged NiCd and alkaline batteries.

NiCd impedance is about one-third that of alkaline, but alkaline capacity is generally double that of NiCd. This circuit applies a known and fixed ac current regardless of the battery's terminal voltage, so a simple data logger enables it to monitor battery impedance over the battery's lifetime. Because the battery current is servo-controlled, the impedance measurement (though quite small) is relatively unaffected by the circuit wiring and connections. The ac battery voltage, however, is a measure of the quality of connections between the cells and from the cells to the battery holder.

Table 1. Measurements Made by MAX471 on Freshly Charged NiCd and Alkaline Batteries

BATTERY TYPE	NUMBER OF CELLS	BATTERY CURRENT		ac BATTERY VOLTAGE (mVp-p)	PER-CELL IMPEDANCE (Ω)
		dc (A)	ac (mAp-p)		
NiCd AA	4	0.4	40	19.8 (7mV_{RMS})	0.124
Alkaline AA	4	0.4	40	50.9 (18mV_{RMS})	0.318

NEW PRODUCTS

12-bit, TTL-output ADCs sample to 10Msps, 20Msps, or 30Msps

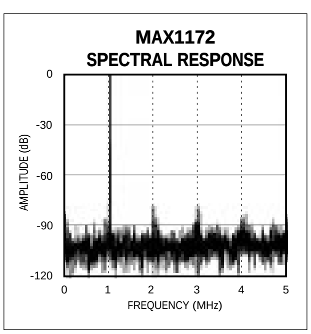
The MAX1170*/MAX1171*/MAX1172* high-speed, 12-bit analog-to-digital converters (ADCs) offer sample-rate levels of 10Msps (MAX1170), 20Msps (MAX1171), and 30Msps (MAX1172). Each has a ±2V bipolar input range, operates from +5V and -5.2V power-supply rails, and dissipates only 1.1W. For input frequencies below 1/10 the sample rate, the devices achieve a 10-bit effective resolution (ENOB).

The MAX1170/MAX1171/MAX1172 include an input buffer and track/hold to minimize the need for external components. To ease the analog-source requirement and make the devices easier to drive, their input impedances consist of 300kΩ shunted by a low, 5pF capacitance. The parallel, straight-binary digital outputs are TTL compatible.

These devices offer excellent low-noise capability (66dB SNR at 1MHz) and 120MHz input bandwidths. Wide bandwidth and low aperture jitter help deliver a spurious-free dynamic range greater than 74dB at 1MHz. Applications include medium-speed instrumentation and data acquisition, radar, professional video, and direct IF downconversion in wireless base-station receivers.

The MAX1170/MAX1171/MAX1172 come in 44-pin CERQUAD and 32-pin ceramic sidebraze packages, in versions specified for the commercial temperature range (0°C to +70°C). Prices start at $89.00 (1,000 up, FOB USA).

**Not available in Japan.*



2.7V, 12-bit/10-bit ADCs in SO-8 draw 10µA

The 12-bit MAX1241 and 10-bit MAX1243 ADCs include a 1.5µs track/hold, 7.5µs successive-approximation ADC, on-chip clock, and 3-wire serial interface, all in a small 8-pin package.

These low-power devices operate from a 2.7V to 5.25V single supply. At 300sps, a 1µA shutdown mode reduces supply current to only 10µA. At the 73ksps (max) sampling speed, the supply current is less than 1mA. Both devices accept input signals between 0V and V_{REF}, and their external reference range includes the positive supply rail.

An external clock accesses data from the 3-wire serial interface, which connects directly to standard microprocessor I/O ports. The interface is compatible with SPI™/QSPI™ and Microwire™ standards. Excellent ac characteristics, very low power consumption, ease of use, and small package size make the MAX1241/MAX1243 ADCs ideal for remote-sensor and data-acquisition applications. Pin and software compatibility between the devices simplifies the upgrade to 12 bits.

The MAX1241/MAX1243 are available in 8-pin DIP and SO packages, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $4.95 for the MAX1241 and $3.45 for the MAX1243 (1,000 up, FOB USA).

SPI and QSPI are trademarks of Motorola, Inc.

Microwire is a trademark of National Semiconductor Corp.

3.3V, 12-bit, quad V_{OUT} DAC has FORCE and SENSE pins

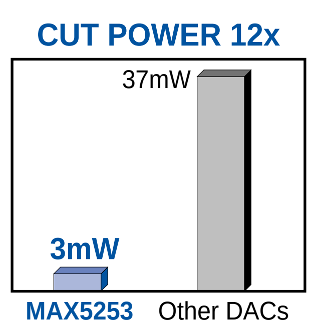
The MAX5253 is a monolithic, quad, 12-bit digital-to-analog converter (DAC) that operates from a single 3.15V to 3.6V supply. It contains double-buffered input registers, four 12-bit DACs, and four precision output amplifiers, plus control logic and a serial interface.

The MAX5253 operates on 3mW, and its space-saving SSOP occupies only 0.09 in.^{2} of board area. Accessible feedback connections for the output amplifier (FORCE and SENSE pins) enable remote sensing, specific gain configurations, and high output driver capability. Each amplifier provides Rail-to-Rail® output swings.

Other features include a low-power shutdown mode that lowers the 0.9mA quiescent current to 20µA (max), and an internal power-on reset that guarantees that all outputs will be zero when power is applied. Also included is a general-purpose logic output that is user programmable for the serial control of other external devices.

The 3-wire interface is compatible with SPI/QSPI and Microwire synchronous-serial standards. The DAC registers can be updated independently or simultaneously.

The MAX5253 is available in a 20-pin DIP or SSOP, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $11.35 (1,000 up, FOB USA).



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

NEW PRODUCTS

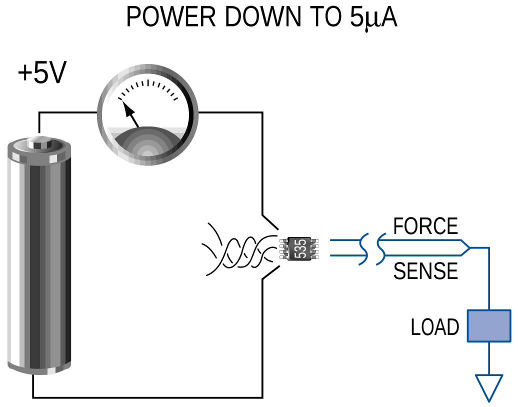
Micropower, 13-bit V_{OUT} DAC features smallest package

The MAX535 is a 13-bit digital-to-analog converter (DAC) with precision output amplifier in a small, 8-pin µMAX package. It is designed for industrial and instrumentation applications that require more than 12 bits of resolution but cannot justify the price of a 14- or 16-bit DAC. The MAX535 draws 280µA in normal operation with a single +5V supply and only 10µA in shutdown mode.

Access to the amplifier's inverting input allows the user to configure the device for specific gains and high output current capability. The DAC output swings rail-to-rail and settles in 16µs. At power-up, the power-on reset circuitry clears the DAC output to zero.

The MAX535 serial interface is compatible with SPI/QSPI and Microwire synchronous-serial standards, and the input is double buffered (an input register followed by a DAC register). All logic inputs are TTL/CMOS compatible, and all are buffered with Schmitt triggers that allow a direct interface to opto-couplers.

The MAX535 comes in 8-pin µMAX packages (50% smaller than an 8-pin SO) and 8-pin DIPs, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $4.95 (1,000 up, FOB USA).



16-bit, single 5V DAC in 8-pin SO

The MAX541 is the first 16-bit DAC for industrial and instrumentation applications in an 8-pin SO package. Ideal for process-control and precise-measurement applications, this device features a maximum DNL and INL of ±1LSB over the entire operating temperature range, providing high accuracy in a small footprint. It operates from a single 5V supply and consumes only 1.5mW of power. With a 2.5V external reference, the device provides 38µV resolution. The DAC output range is 0V to V_{REF}.

The 6.25MHz, 3-wire serial interface is compatible with SPI/QSPI and Microwire synchronous-serial standards. For applications that require isolation, all digital inputs include Schmitt triggers that allow a direct interface with slow-transitioning opto-coupler signals. An internal power-on reset clears the DAC output to zero when power is initially applied.

For 14-bit applications, the pin- and software-compatible MAX544 is available. The MAX541/MAX544 come in 8-pin DIP and SO packages. The MAX541 has three performance grades (INL = 1, 2, or 4), and the MAX544 has two (INL = 0.5 or 1). Each is available in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $9.95 for the MAX541 and $7.90 for the MAX544 (1,000 up, FOB USA).

3.3V, 13-bit DAC in tiny µMAX package consumes <1mW

The MAX5351 is a 13-bit, 3.3V, voltage-output DAC with precision output amplifier in an 8-pin µMAX package (50% smaller than an 8-pin SO). Its 13-bit resolution and low power (less than 1mW for normal operation, 33µW in shutdown) are well suited for 3V portable industrial and instrumentation applications that require a cost-effective DAC.

The MAX5351 offers a unique feature: access to the amplifier's inverting input allows configurations for remote sensing, specific gains, or high output current capability. The DAC output swings rail-to-rail and settles in 20µs. At power-up, internal power-on-reset circuitry clears the DAC output to zero.

The internal DAC has a double-buffered register, and the 3-wire serial interface is compatible with SPI/QSPI and Microwire synchronous-serial interface standards.

The MAX5351 is available in 8-pin DIP and µMAX packages, in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $5.50 (1,000 up, FOB USA).

NEW PRODUCTS

PWM step-down switching converter has internal power switches

The MAX887 is an adjustable-output, step-down, dc-dc switching converter. It accepts input voltages from 3V to 11V and delivers output currents as high as 600mA. Its 100%-duty-cycle capability minimizes dropout voltage (typically 300mV at 500mA).

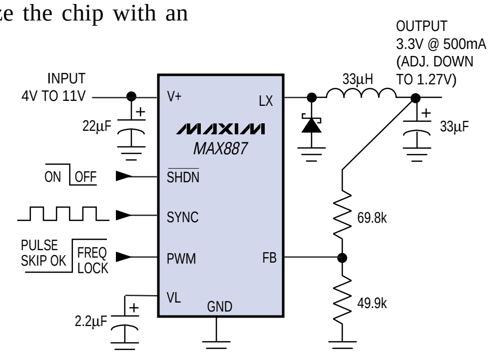
To save board area, the chip includes internal power MOSFETs for the power-switch and synchronous-rectifier functions. The synchronous rectifier enables efficiencies as high as 93%. An internal high-frequency oscillator eliminates audio-frequency interference and enables the use of tiny surface-mount components that further reduce board area. To avoid interference with sensitive RF and data-acquisition circuits, a SYNC input allows the user to synchronize the chip with an external clock.

The MAX887's fixed-frequency pulse-width modulation (PWM) minimizes noise in sensitive communications applications. Holding the SYNC input low activates the chip's Idle Mode™ control scheme, which allows the MAX887 to shift automatically between PWM for heavy loads and high-efficiency pulse-frequency modulation (PFM) for light loads (below 100mA).

Current-mode operation provides superior response to line and load transients, and cycle-by-cycle current limiting protects the internal MOSFET and driver. In addition, the MAX887's shutdown mode extends battery life by lowering the quiescent supply current to 2.5µA (typical).

The MAX887 comes in an 8-pin SO package, in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $2.44 (1,000 up, FOB USA).

Idle Mode is a trademark of Maxim Integrated Products.



3V/5V comparators offer dual speed and auto-standby

The MAX975/MAX977 single/dual comparators operate with a 3V or 5V single supply, and each has three modes of operation: high speed, high speed with auto-standby, and low power. Propagation delays are 28ns in high-speed mode (5mV overdrive) and 820ns in low-speed mode (10mV overdrive). The outputs swing rail-to-rail without pull-up circuitry for an easy interface to TTL/CMOS logic.

The auto-standby feature automatically places in low-power mode any comparator that exceeds a programmed interval without an output transition. The maximum supply current for this condition is 5µA. This timeout period equals $10C_{STO}$ microseconds, where C_{STO} is an external capacitor's value in picofarads. Internal hysteresis for high-speed mode ensures clean output switching, even for slow-moving input signals. All inputs and outputs can tolerate a continuous short circuit to either rail.

The MAX975 comes in an 8-pin SO or µMAX package, and the MAX977 comes in a 14-pin SO or 16-pin QSOP. Both are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $1.95 (1,000 up, FOB USA).

Quad, SPST analog switches operate on 2V

The MAX4536/MAX4537/MAX4538 are quad, single-pole/single-throw (SPST) analog switches. Each device has a common enable input, and each is pin compatible with the industry-standard 74HC4316. MAX4536 switches are normally open (NO), and MAX4537 switches are normally closed (NC). The MAX4538 has two NO and two NC switches.

Each device operates from a single 2V to 12V supply or from dual ±2V to ±6V supplies. On-resistances measure 100Ω (max) with dual ±5V supplies and 200Ω (max) with a single 5V supply. On-resistances match to within 4Ω (max) and are constant to within 10Ω (max) over the specified signal range. Applications include portable and battery-operated equipment, low-voltage data-acquisition systems, and audio-signal routing.

MAX4536/MAX4537/MAX4538 switches handle rail-to-rail analog signals with only 1nA of off-leakage current at +25°C and only 10nA at +85°C. Timing for t_{ON} and t_{OFF} is only 100ns and 80ns, respectively. To ensure TTL/CMOS-logic compatibility, the digital-input thresholds remain at 0.8V and 2.4V whether operating with 5V or ±5V supplies. The switch outputs and digital inputs have >2kV of ESD protection per MIL-STD-883 Method 3015.7.

MAX4536/MAX4537/MAX4538 switches are available in 16-pin DIP, QSOP, and narrow-SO packages, in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $0.98 (1,000 up, FOB USA).

NEW PRODUCTS

Low-noise, dual-output bias for GaAsFET and VCO tuner diodes

The MAX768 is a small, low-noise, dual-output charge pump with power-ready indicator. Powered by a 3.6V lithium-ion (Li-Ion) battery, this single IC has three important jobs: it biases a GaAsFET power amplifier (PA); it drives an LCD or voltage-controlled oscillator (VCO); and it protects the GaAsFET by controlling the drain switch until the negative bias is within regulation.

The MAX768 provides positive and negative regulated outputs using only low-cost capacitors. It includes a voltage-doubler charge pump followed by an inverting charge pump to produce unregulated outputs that are ±2 times the input voltage. Internal linear regulators then provide the low-noise positive/negative regulated outputs. A logic power-ready output controls the drain switch to the GaAsFET, protecting the device by indicating when the negative voltage has risen to within 10% of its regulation setpoint.

The MAX768 is intended for use in low-voltage systems for which a simple charge-pump inverter is inadequate to bias the GaAsFET, or in which the VCO needs more range to improve its signal-to-noise ratio. A typical application provides low-noise, regulated ±5V outputs from inputs as low as 3V. The IC's 2.5V to 5.5V input range enables it to work directly from a single Li-Ion cell or a three-cell NiMH/NiCd battery.

Output ripple is less than 2mVp-p, and available output current is at least 5mA per output. The internal linear regulators are composed of CMOS devices, so quiescent current remains independent of output loading even in dropout, and dropout voltage with no load current approaches zero. The MAX768 operates at one of two preset switching frequencies (25kHz or 100kHz), or it can be synchronized to an external clock in the 20kHz to 240kHz range. This flexibility enables users to optimize designs for noise, capacitor size, and quiescent supply current.

The MAX768 is available in a space-saving 16-pin QSOP (the same size as an 8-pin SO), in versions specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $2.40 (1,000 up, FOB USA).

Quad/triple, SPDT RGB switches include 250MHz video buffers

The MAX498 (quad) and MAX499 (triple) video switch/buffer ICs include single-pole/double-throw switches plus closed-loop buffer amplifiers. The amplifiers feature closed-loop +2V/V gains, 250MHz -3dB bandwidths, 0.1dB gain flatness to 70MHz, and 1250V/µs slew rates.

Fast switching (3ns) and fast settling (12ns to 0.1% for a 4V step) make the MAX498/MAX499 suitable for a wide range of video applications. Low differential gain/phase errors (0.03%/0.06°) and wide bandwidth make them ideal for RGB and composite-video applications. The on-board buffer amplifiers can deliver ±2.5V into back-terminated 50Ω or 75Ω cables or ±2V to a 75Ω load.

For implementing large switch arrays, each IC includes a low-power disable mode that places the outputs in a high-impedance state. Four TTL/CMOS-compatible logic inputs control channel selection and output enable/disable functions. Each video input is isolated by an ac ground pin that limits channel-to-channel capacitance, reducing crosstalk to 90dB at 10MHz.

Typical power dissipation for the 4-channel MAX498 (operating on ±5V supplies) is 390mW with all buffers enabled and 130mW with all buffers disabled. For the 3-channel MAX499, the corresponding dissipations are 300mW enabled and 100mW disabled.

The MAX498 comes in a 28-pin wide SO, and the MAX499 comes in a 24-pin wide SO. Both are specified for the commercial temperature range (0°C to +70°C). Prices start at $3.50 (1,000 up, FOB USA).

1.6V synchronous step-down controller powers Pentium Pro µPs

The MAX798 step-down controller produces 1.6V to 6V regulated output voltages, as required by Intel's Pentium Pro® microprocessor. Pin-for-pin compatible with Maxim's 2.5V (min) MAX797, it offers improved output voltage accuracy (± 1.5%), load regulation (± 0.4%), and maximum line regulation (± 0.05%).

The MAX798 powers the latest-generation CPUs in notebook and subnotebook computers, mobile communicators, PDAs, cellular phones, and other battery-powered systems. It combines synchronous rectification (an active MOSFET in place of a passive Schottky diode) with Maxim's proprietary Idle Mode control scheme to produce efficiencies as high as 95%. The outputs deliver as much as 10A.

The output voltage is adjustable in the 1.6V to 6V range by two external resistors. The 4.5V to 30V input voltage range enables use of wall-adapter chargers and NiCd battery packs of up to 15 cells. The MAX798's excellent dynamic response corrects output transients within five clock cycles. In addition, its internal bootstrap circuits provide gate drive for inexpensive n-channel external MOSFETs.

A fixed-frequency pulse-width modulation (PWM) operating mode reduces noise and RF interference in sensitive applications, such as mobile communications and pen-entry systems. An override input ($\overline{\text{SKIP}}$) allows automatic switchover to Idle Mode operation at light loads (for high-efficiency pulse skipping). As an alternative, $\overline{\text{SKIP}}$ can force the converter to low-noise, fixed-frequency mode for all load conditions.

The MAX798 is available in 16-pin narrow-SO packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $3.65 (1,000 up, FOB USA).

Pentium Pro is a registered trademark of Intel Corp.

NEW PRODUCTS

Current-limited power switches protect against shorts and overloads

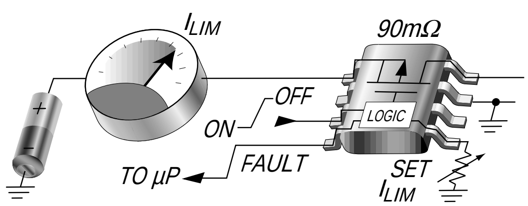
MAX890L/MAX891L*/MAX892L*/MAX894L/MAX895L power switches limit current through the switch to a safe level set by the user. They protect your system from short circuits and overload faults at a card slot or a plug-in port—problems that can pull down the main supply voltage or drain a battery very quickly. Conventional protection circuits turn off a switch in the presence of high current using a current-sense resistor, differential amplifier/comparator, and logic. ICs in the MAX890L family allow the user to set a maximum current limit with a single external resistor.

These high-side, p-channel MOSFET power switches are available in single or dual packages with a variety of current limits. The single MAX890L has a current limit that's adjustable to 1A, and comes in an 8-pin SO. The single MAX891L/MAX892L have current limits that are adjustable to 500mA and 250mA, respectively, and are available in tiny 8-pin µMAX packages. The dual MAX894L/MAX895L have independent maximum current limits of 500mA and 250mA, respectively, and come in a single 8-pin SO package.

A low-power external resistor sets the current limit between the maximum value (1A, 500mA, 250mA) and 20% of the maximum limit. The MAX891L, for example, can limit currents from 500mA down to 100mA. These switches' fast, 2µs response also prevents glitches and resets during plug-ins, when heavy capacitive loads can cause momentary short circuits. All devices include thermal-overload protection. A logic FAULT output alerts a microprocessor in the event of a fault. These parts' 2.7V to 5.5V input voltage range is ideal for 3V and 5V systems. At 3V, the MAX890L has a typical on-resistance of only 0.09Ω.

Applications include notebook and hand-held computers with slots and ports that accommodate the Universal System Bus (USB), as well as PCMCIA, CardBus, and power ports for peripheral devices. MAX890L family ICs feature very low quiescent currents (10µA for single switches and 16µA for dual switches). In the off state, these currents drop to just 0.1µA for all devices. All are specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $1.25 (1,000 up, FOB USA).

**Future product—available after April 1997.*

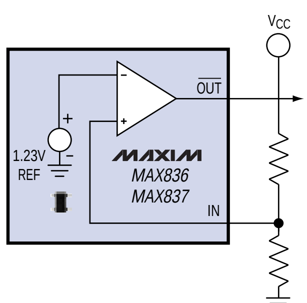


3.5µA voltage monitors come in 4-pin SOT

The MAX836/MAX837 are low-cost, 4-pin voltage monitors that contain a comparator and a 1.204V precision bandgap reference, enabling the user to set any trip threshold using two external resistors. The two ICs differ only in the output driver: an open-drain, n-channel output driver for the MAX836; a push-pull output driver for the MAX837.

Applications include load switching, precision battery monitoring, and threshold detectors. Typical supply current is 3.5µA.

The MAX836/MAX837 come in SOT143-4 packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.90 (1,000 up, FOB USA).



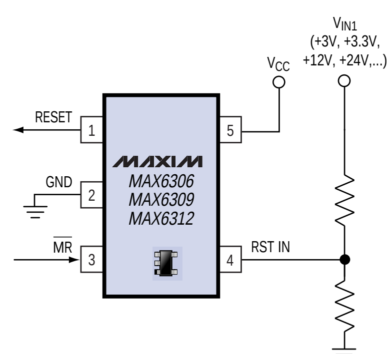
Only dual-voltage µP-reset ICs in 5-pin SOTs

The MAX6305–MAX6313 are dual-voltage µP-reset ICs. While monitoring 5V and 3.3V (for example), each device asserts a reset when either of the monitored voltages falls below a programmed threshold. Each ignores fast transients on the monitored rails. A small SOT23-5 package and low, 16µA (max) supply current make the devices ideal for portable equipment.

The nine products in this family offer various combinations of features. These features include a pretrimmed reset threshold for V_{CC}, up to two adjustable undervoltage reset inputs, an adjustable overvoltage input, and a manual reset input. Outputs can be open-drain $\overline{\text{RESET}}$, active $\overline{\text{RESET}}$, or active RESET.

For each product, the desired threshold voltage and reset-timeout interval are specified by suffix numbers, as explained in the data sheet. Available factory-trimmed thresholds range from 2.5V to 5.0V in 100mV increments, and available timeouts (minimum values) are 1ms, 20ms, 140ms, and 1120ms. An external resistor-divider enables each device to monitor any reasonable level, including 12V and 24V.

The MAX6305–MAX6313 come in SOT23-5 packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $1.20 (1,000 up, FOB USA).



NEW PRODUCTS

4-pin voltage monitors have pin-selectable timeout delay

The MAX821/MAX822 voltage monitors are suitable for use in microprocessor and other digital systems. Available in tiny, 4-pin SOT143 packages, they assert a reset signal whenever V_{CC} falls below a programmed threshold, and they maintain the reset for a pin-selectable timeout interval after V_{CC} returns above the threshold. The devices differ only in output: the MAX821 has an active-low $\overline{RESET}$ (guaranteed valid for V_{CC} down to 1V), and the MAX822 has an active-high RESET.

Seven reset thresholds are available for 3V, 3.3V, and 5V systems, ranging from 2.63V to 4.63V, as designated by suffix letters according to the data sheet. The desired timeout interval is set by connections to the SRT input: 100ms min (high), 20ms min (floating), or 1ms max (ground). Each device ignores fast transients on V_{CC}. Low supply currents (2.5µA typical with V_{CC} = 5V and 1.8µA typical with V_{CC} = 3.3V) make the MAX821/MAX822 ideal for use in portable equipment.

The MAX821/MAX822 come in SOT143-4 packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.90 (1,000 up, FOB USA).

2.5µA, SOT IC voltage monitors have latched outputs

The MAX834/MAX835 micropower voltage monitors draw just 2.5µA of supply current, yet each combines a 1.204V precision bandgap reference, comparator, and latched output in a small SOT23-5 package. The MAX834 output is an open-drain, n-channel driver, and the MAX835 output is a push-pull driver capable of both sourcing and sinking current. Two external resistors set the voltage trip threshold.

The internal threshold's ±1.25% trip accuracy enables the MAX834/MAX835 to be used in such applications as precision battery monitoring, load switching, and threshold detection. Low power consumption makes them especially well suited to battery-powered systems. Once tripped, these devices maintain low outputs until cleared by a 14µs (min) positive pulse at CLEAR. This feature enables a battery-load disconnect switch that protects the battery from a damaging deep discharge.

The MAX834/MAX835 are available in 5-pin SOT23-5 packages specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $1.00 (10,000 up, FOB USA).

RS-485/RS-422 transceivers guarantee logic 1 output during open circuit

Each device in the MAX3080–MAX3089 family of high-speed RS-485/RS-422 communications transceivers includes one driver and one receiver. All operate on 5V and typically draw 375µA supply currents when unloaded or when fully loaded with drivers disabled. Most include a low-power shutdown mode that lowers the supply current to 1nA (typical).

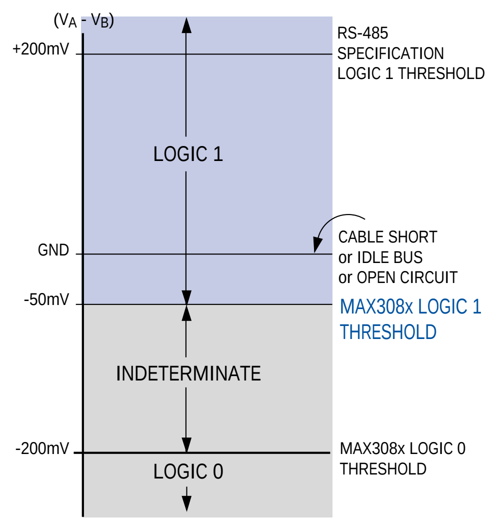
Internal fail-safe circuitry ensures that any receiver with an open or shorted input has a logic-high output. This feature guarantees, for example, a logic-high output for any receiver driven by a transmitter output in a high-impedance state. MAX3080–MAX3089 driver outputs are short-circuit current limited, and they are also protected by thermal-shutdown circuitry that places them in a high-impedance state to avoid excessive power dissipation.

Three transceivers feature slew-rate-limited drivers that minimize EMI and reduce reflections caused by improperly terminated cables, allowing error-free data transmissions to 115kbps. Another three have higher slew-rate limits that enable data rates to 500kbps, and three others omit slew-rate constraints, enabling data rates as high as 10Mbps. A three-state input on the MAX3089 allows you to select the maximum data rate as 115kbps, 500kbps, or 10Mbps. (See the data-sheet selection table.)

All receivers have an input impedance of 1/8-unit load, allowing as many as 256 transceivers on one bus. Three devices are intended for half-duplex communications, six for full-duplex communications, and one (the MAX3089) allows you to choose between half- and full-duplex operation. The MAX3089 also provides separate pins for independently programming the phase from driver input to output and receiver input to output.

The MAX3080–MAX3089 come in 8-pin and 14-pin plastic DIP and SO packages, in versions specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $1.33 (1,000 up, FOB USA).

MAX3080 FAMILY
DIFFERENTIAL INPUT VOLTAGE



NEW PRODUCTS

250kbps, 5-Tx/3-Rx, 3V RS-232 transceiver reduces supply current to 1µA

The MAX3238 RS-232 transceiver contains five drivers and three receivers, and comprises a complete serial port for EIA/TIA-232 and V.28/V.24 communications. The MAX3238 operates on 3V to 5.5V and handles data rates to 250kbps. While in AutoShutdown Plus™ mode, the MAX3238 shuts down automatically when no signals have been transmitted or received for 30 seconds. Therefore, in most applications, the average supply current is only 1µA. Typical applications include high-speed modems and ISDN systems.

AutoShutdown Plus is activated for normal operation when $\overline{\text{FORCEOFF}}$ = V_{CC} and FORCEON = ground. While in this mode, the device enters shutdown whenever the receiver and transmitter inputs are inactive for 30 seconds. (Shutdown lowers I_{CC} to 1µA and places the transmitter outputs in high-impedance state.) A valid transition on any receiver or transmitter input then restores the chip to normal operation, typically within 100µs. Thus, the AutoShutdown Plus feature allows you to save power without changing the existing BIOS or operating system.

A proprietary, high-efficiency dual charge pump and low-dropout transmitter combine to deliver true RS-232 signal amplitudes at the transmitter outputs with V_{CC} as low as 3V. In 3.3V systems, the MAX3238 operates with small, 0.1µF external capacitors; for 5V and mixed 3V/5V systems, the required capacitors are somewhat larger.

The receivers remain active during AutoShutdown Plus mode, but they can be turned off by driving $\overline{\text{FORCEOFF}}$ low. The receivers should be so disabled if, for example, they connect to an IC that can draw current through an internal ESD-protection diode when V_{CC} is turned off. Receiver R1 has an auxiliary output (R1OUTB) that is always active. In shutdown, when all the primary outputs are disabled, R1OUTB can be used to monitor an external modem, UART, or other device.

The MAX3238 comes in a 28-pin SSOP, specified for the commercial (0°C to +70°C) or extended-industrial (-40°C to +85°C) temperature range. Prices start at $3.29 (1,000 up, FOB USA).

AutoShutdown Plus is a trademark of Maxim Integrated Products.

50ppm/°C, three-terminal reference offered in a SOT23 package

The MAX6520 is a 1.2V, micropower, three-terminal voltage reference in a tiny SOT23 package. Ideal for 3V battery-powered equipment in which power conservation is critical, the MAX6520 offers a low-power alternative to existing two-terminal shunt references. Unlike those types, which waste battery current and require an external series resistor, the MAX6520 has a low, 50µA supply current (70µA max) that is independent of input voltage. MAX6520 efficiency is therefore maximized at all battery voltages.

Temperature drift for the MAX6520 is guaranteed to be less than 50ppm/°C in the SOT23 package. The device operates from supply voltages as low as 2.4V and has an initial accuracy of ±1%.

The MAX6520 is available in an 8-pin SO or 3-pin SOT23-3 package specified for the extended-industrial temperature range (-40°C to +85°C). Prices start at $0.95 (1,000 up, FOB USA).

Low-noise, precision voltage references guarantee 2ppm/°C tempcos

MAX6225A/MAX6241A/MAX6250A precision voltage references feature low noise and extremely low temperature coefficients. Excellent line/load regulation and low output impedance at high frequency make them ideal for use in systems with digital resolution to 16 bits. They feature a buried-zener technology that provides a very low, 1.5µVp-p (typical) output noise (0.1Hz to 10Hz).

Each reference exhibits the ultra-low temperature coefficient (1ppm/°C typical) normally associated with more costly and power-hungry heated references while consuming relatively small amounts of power (20mW typical). The devices achieve exceptional temperature stability with a new proprietary circuit.

Output voltages are fixed at 2.500V (MAX6225A), 4.096V (MAX6241A), and 5.000V (MAX6250A), with initial accuracies of ±0.02%. Each reference guarantees its load-regulation specification for source/sink currents to ±15mA. All three devices include options for external voltage trimming and noise reduction.

MAX6225A/MAX6241A/MAX6250A devices come in 8-pin DIPs and SOs, in versions specified for the commercial (0°C to +70°C), extended-industrial (-40°C to +85°C), or military (-55°C to +125°C) temperature range. Prices start at $4.65 (1,000 up, FOB USA).

ULTRA-LOW NOISE