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News Briefs

MAXIM REPORTS RESULTS FOR THE SECOND QUARTER OF FISCAL 1999

Maxim Integrated Products, Inc., (MXIM) reported net revenues of $145 million for the second quarter of fiscal 1999 ending December 26, 1998, compared to $135 million for the same quarter in fiscal 1998. Net income was $46.5 million in Q299, compared to $42.8 million for the second quarter of fiscal 1998. Income per share was $0.31 for Q299, compared to $0.29 for the same period a year ago.

During the quarter, the Company increased cash and short-term investments by $50.4 million after paying $8.9 million for 317,500 shares of its common stock and $5.1 million for capital equipment. Inventory declined by $1.4 million during Q299. Accounts receivable also declined $12.1 million during the quarter.

Annualized return on average stockholders' equity during the quarter was 26.8%, one of the highest in the industry today.

Net bookings on the Company were $141 million in Q299, an 11% increase over the Q199 level of $127 million. During the quarter, customers continued their trend of ordering for near-term delivery. Turns orders received in the quarter were $52 million, a 24% increase over the Q199 level (turns orders are customer orders that are for delivery within the same quarter and may result in revenue within the same quarter if the Company has available inventory that matches those orders).

Order cancellations during the quarter were approximately $15 million, the lowest level in the last several quarters. Second quarter ending backlog shippable within the next 12 months was approximately $135 million, including $109 million requested for shipment by the end of Q399.

During Q299, bookings grew in Europe and the Pacific Rim. Market conditions in Japan continue to be difficult, and business in that country declined during the quarter. While some of the strength in the Pacific Rim is due to the transfer of contract manufacturing to lower cost manufacturing areas, the Company also saw an increase in its OEM business in Korea.

Bookings improved in the communications (primarily cell phones) and the computer (primarily notebook related) end markets. In addition, the Company experienced moderate bookings growth in the broad-based traditional standard analog products that serve most of the Company's end markets.

Gross margins for Q299 were 68.7%, an increase from the 67.5% reported in Q199. During the quarter, the Company expensed $2.8 million of costs that were in excess of the costs achieved by the Company's lowest cost wafer fabrication facility (Beaverton). In addition, the Company increased inventory reserves by $2.5 million, further increasing cost of sales in Q299.

Jack Gifford, Chairman, President and Chief Executive Officer, commented on the quarter: "Although bookings in Q299 did grow substantially over Q199 (which now looks like the low point), Q399's growth (or lack of it) should indicate whether we are just bouncing off the bottom, or whether a growth trend has resumed."

Mr. Gifford continued: "Since our Q299 shipments slightly exceeded our net bookings, our Q399 opening backlog declined from the previous quarter. Our ability to ship at the Q299 level or above in Q399 will depend on Q399 turns orders that are at or above Q299 levels."

Choosing the optimum buffer/ ADC combination for your application

Selecting the optimum drive amplifier (or buffer) for a specific analog-to-digital converter (ADC) requires attention to impedance matching, charge injection, noise reduction, and output accuracy. ADC manufacturers often recommend a specific amplifier for a given converter, but the combination must be compatible with the target system. Overall performance must be considered as well as the ADC's input structure and its effect on the buffer.

Progress in the development of ADCs—including ever-increasing speed and resolution, switched-capacitor input structures, and single-supply operation—is forcing system designers to evaluate the associated drive amplifier very carefully. The drive amplifier, or buffer, must provide a low source impedance and sufficient output current to drive the ADC inputs, and its high-frequency output impedance must be sufficiently low to avoid excessive conversion error. For many sampling ADCs, the buffer also must amplify extremely low-level signals.

How noise affects performance

Ideally, an op-amp signal source should contribute no error beyond that of the ADC. As a minimum condition for avoiding excess noise in the system, the signal-to-noise ratio (SNR) of the source should be better than the theoretical limit of the ADC. Fortunately, the noise performance of all new-generation op amps is much better than 12 bits, and those with good 16-bit noise performance are not difficult to find. It's important to note, however, that the noise powers of the amplifier and the ADC are cumulative.

Figure 1 is an excellent example of a low-noise, low-distortion interface between a 16-bit successive-approximation ADC (MAX195) and its input drive amplifier (MAX4256). For this example, calculate the total RMS noise contributed by the buffer using information from the MAX4256 data sheet:

Input voltage-noise density

$$e_N = 7.9\text{nV}/\sqrt{\text{Hz}}, \text{ at } f = 30\text{kHz}$$

Input current-noise density

$$i_N = 0.5f\text{A}/\sqrt{\text{Hz}}, \text{ at } f = 1\text{kHz}.$$

Because the effective noise bandwidth of a single-pole filter is 1.57 times the -3dB corner frequency, the MAX4256's noise bandwidth is GBW/1.57A_V. In addition to voltage-noise and current-noise sources in the IC, each resistor in the circuit contributes a noise voltage. Thus, the total equivalent input-referred noise is:

$$e_t = \sqrt{e_N^2 + [i_N(R1/R2)]^2 + (e_r)^2}$$

That is, total noise =

$$\sqrt{\left((\text{volt. noise})^2 + (\text{cur. noise} \cdot R_{eq})^2 + (\text{res. noise})^2\right)}$$

To simplify calculation, remember that the noise generated by a 1kΩ resistor in a 1Hz bandwidth is 4nV_{RMS}. That information reduces the formula to:

$$e_r = \left(4\text{nV}/\sqrt{\text{Hz}}\right)\sqrt{\left(\text{BW} \cdot R_{eq}/1\text{k}\Omega\right)};$$

where R_{eq}(BW) is the equivalent resistance in a specified bandwidth. Assuming a bandwidth of 20kHz for this typical audio-frequency application, and bearing in mind the MAX195 sampling rate (85ksps), the result is e_N = 8.7nV/√Hz. Note that the MAX4256's input current noise of 0.5fA/√Hz is insignificant in comparison. Total output noise referred to the op-amp circuit's bandwidth is:

$$\begin{aligned} E_T &= e_t\sqrt{[\text{BW}(1/\beta)]} \\ &= \left(8.7\text{nV}/\sqrt{\text{Hz}}\right)\sqrt{20\text{kHz}(1.57)(11)} \\ &= 17\mu V_{RMS} \end{aligned}$$

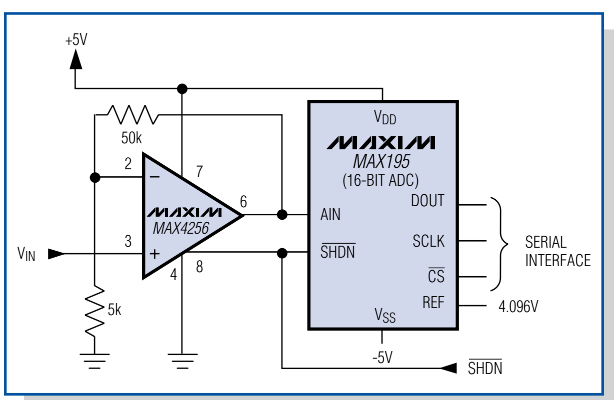

Figure 1. This interface between a drive amplifier and a 16-bit ADC offers low noise and low distortion.

To determine the total noise power for the ADC/op-amp combination, first convert the ADC signal noise and distortion (SINAD) values from decibels to voltage. Then calculate the square root of the sum of the squares and convert the value back to decibels. In this case, we use the MAX195's minimum guaranteed SINAD value of 87dB. Converting to voltage (44.7µV) and combining with E_T = 17µV results in a total noise power of 86.4dB—a degradation of only 0.6LSB in the ADC's SNR. A series of these calculations can demonstrate the effect of a given drive amplifier on the overall performance.

Distortion

Distortion also degrades dynamic performance, but this effect can be minimized by choosing an amplifier whose distortion is much less than the converter's total harmonic distortion (THD). Again, **Figure 2's** circuit is very effective: the MAX195's THD is only -97dB (0.0014%), and the MAX4256's SINAD is an outstanding -115dB.

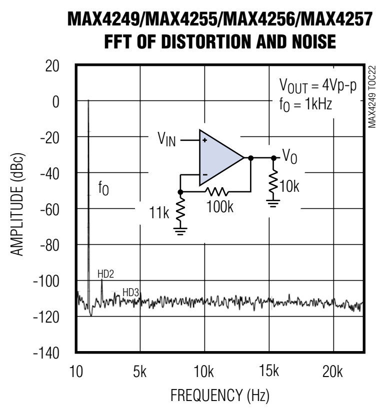

Figure 2. The MAX4256 offers an outstanding spurious-free dynamic range (SFDR) of 115dB.

This high performance allows use of the noninverting configuration and a single-supply op amp (MAX4256).

Another way to evaluate op amps as drive amplifiers is to compare their numerical specifications to the weight (step size) of the ADC's least significant bit (LSB) in volts. For example, the LSB for a 16-bit ADC with a 5.000V unipolar input range is 76µV. To approximate the amplifier's error contribution, compare that number to the amplifier's input offset voltage, drift, and noise, all multiplied by its closed-loop gain. Thus, a closed-loop gain of +11V/V and an offset of 70µV (typical for the MAX4256) produce an error of 770µV, which for a 16-bit application is 10LSBs! If DC accuracy is important, the buffer's offset must either be much less than the ADC's maximum offset (±3LSBs for the MAX195), or it should be trimmed through hardware or software.

The MAX410 family op amps also work well with the ±5V supplies used by the MAX195. The MAX410 has a ±3.5V common-mode input range and a similar output-voltage swing, which allows the converter to operate with reference voltages up to 3.5V. The MAX410's offset voltage (250µV) is approximately 2LSBs. Its drift (1µV/°C), unity-gain bandwidth (28MHz), and low voltage noise (2.4nV/$\sqrt{Hz}$) are all compatible with 16-bit performance (**Figure 3**).

Bandwidth and settling time

To determine speed requirements for the drive amplifier, match its settling time to the ADC's acquisition time. That is, the conversion results will be accurate if the ADC samples the input signal for an interval longer than the amplifier's worst-case settling time. By definition, settling time is the interval between the application of an

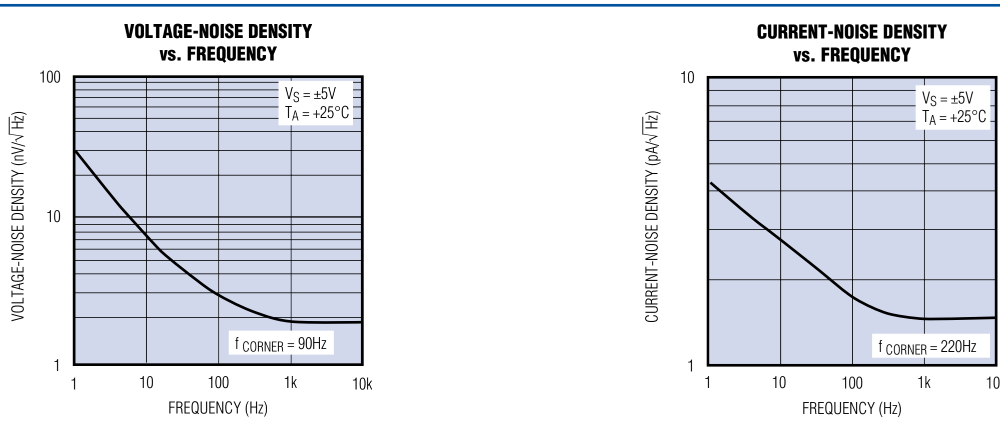

Figure 3. Voltage- and current-noise density graphs (for the MAX410) aid in calculating the accuracy obtainable with a given ADC.

input voltage step and the point at which the output signal reaches and stays within a given error band centered on the resulting steady-state output level **(Figure 4)**.

For large input steps, the amplifier's slew-rate limit restricts the speed with which its output can change. The result, for a given input amplitude and for an amplifier with a given slew rate, is a maximum at the frequency that can be faithfully reproduced:

$$f_{MAX} = SR/2\pi Vp$$

where Vp is the peak output voltage.

A first-order approximation of settling time (t_S) can be made if the following conditions apply:

- The input signal does not cause the amplifier output to enter slew-rate limiting
- The amplifier's -3dB corner frequency is known
- The output amplitude rolls off at 20dB/decade for at least one decade of frequency above f_{-3dB}.

Then,

$$t_S = -{}^1/_2\pi f_{-3dB}[\ln(V_O/V_S - 1)] \qquad [1]$$

To calculate t_S to within ${}^1/_2$LSB at N-bit resolution, replace V_O/V_S with the expression $(2^N - {}^1/_2)/2^N$, where N is the number of bits. Equation [1] now becomes:

$$t_S = 0.11(1 + N)/f_{-3dB} \qquad [2]$$

Finding an amplifier that meets the requirements of your application may be difficult. Numerous op amps can operate satisfactorily with 12-bit ADCs, but only a few are suitable for driving 14- and 16-bit ADCs above 500kHz. The choice involves trade-offs among the parameters of noise, distortion, and settling time.

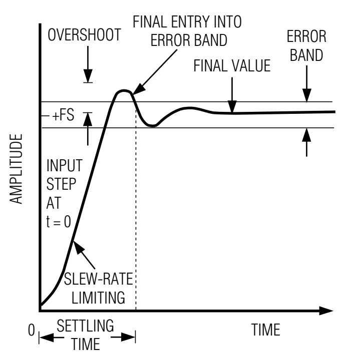

Figure 4. Output settling time is defined with respect to an error band centered on the final settled value.

Settling time poses a problem because few op-amp manufacturers test this specification at levels equivalent to 16-bit performance (0.001%).

Consider bandwidth and settling time for the drive amplifier in Figure 1. For its typical slew rate of 2.1V/µs, the maximum frequency this buffer can handle with an input amplitude of 2Vp-p is $f_{MAX} = SR/2\pi 2Vp$ = 167kHz. Similarly, for settling time, solve equation [2] for the f_{-3dB} frequency after substituting the 16-bit settling time (1.6µs at 0.001%) for t_S. Though just an approximation, the surprising result is 1.17MHz. Bandwidth requirements for high-resolution settling time can be much higher than expected, and designers often underestimate the bandwidth necessary to sustain gain accuracy. Insufficient gain over the input-signal bandwidth can easily introduce errors greater than 1LSB. Fortunately, the MAX4256 offers a -3dB corner frequency of 22MHz.

High-speed applications

For demanding video and other high-speed applications, Maxim offers a broad range of video op amps that are also suitable for use as ADC drivers. Among them, the members of a new family of low-noise, low-distortion, 880MHz video op amps make outstanding drive amplifiers (**Table 1** and **Figure 5**):

- -3dB bandwidth of 880MHz (MAX4104)
- 0.1dB gain flatness to 100MHz (MAX4104/MAX4105)
- 1400V/µs slew rate (MAX4105/MAX4305)
- Spurious-free dynamic range (SFDR) (5MHz, R_L = 100Ω) of -88dBc (MAX4104/MAX4304)
- High output-current drive: ±70mA
- Low input offset voltage: ±1mV

Also noteworthy as drive amplifiers are the MAX4106/MAX4107 op amps, which combine high speed with an ultra-low noise level of 0.75nV/√Hz. The MAX4106 is compensated for closed-loop gains of +5V/V or greater, the MAX4107 for +10V/V or greater. Low-distortion

Table 1. Op amp family for ADC driver applications

PART	MINIMUM STABLE GAIN (V/V)	BANDWIDTH (MHz)	PIN-PACKAGE
MAX4104	1	880	5-pin SOT23, 8-pin SO
MAX4304	2	730	5-pin SOT23, 8-pin SO
MAX4105	5	430	5-pin SOT23, 8-pin SO
MAX4305	10	350	5-pin SOT23, 8-pin SO

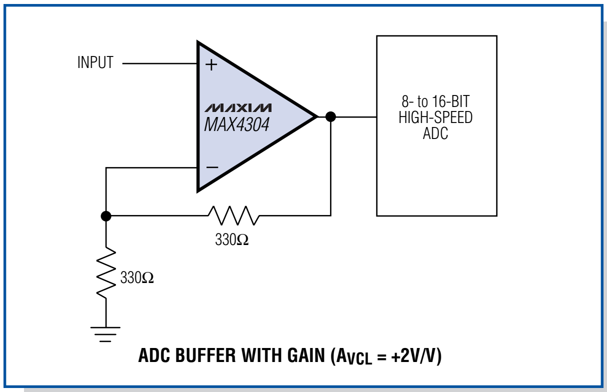

Figure 5. This op amp is configured as an ADC buffer with a noninverting gain of +2V/V.

architecture provides an SFDR of 63dB at 5MHz. Furthermore, these high-speed op amps have a wide output-voltage swing (±3.2V with a ±5V supply) and a substantial current-drive capability of 80mA **(Figure 6)**.

Finally, the MAX4108/MAX4109/MAX4308/MAX4309 op-amp family combines ultra-high speed with ultra-low distortion. At 5MHz, V_{OUT} = 2Vp-p and R_L = 100Ω, the MAX4108 SFDR is an unprecedented -93dBc. High speed, high slew rate, low (or ultra-low) noise, and low, stable distortion levels make these op amps well suited for use as buffer amplifiers in high-speed ADC applications **(Figure 7)**.

Buffer performance also depends on the ADC input structure

In addition to the considerations discussed above, a key concern in selecting a buffer (drive amplifier) is the ADC's input structure. For example, flash converters are among the most difficult to drive because they have a large nonlinear input capacitance. ADCs that have the newer switched-capacitor architectures also require close attention.

The task of driving a switched-capacitor ADC is simplified if you recognize that the ADC draws a small transient of input current at the end of each conversion, when the internal sampling capacitors switch back to the input for acquisition of the next sample. To avoid errors, the buffer circuitry must recover from this transient and settle before the next conversion starts. This can be accomplished using either of two methods.

One method requires driving the ADC with an op amp that settles from a load transient in less than the ADC's acquisition time. (Many new ADCs include such wideband sample/holds on-chip.) Fortunately, most op amps settle from a load transient much more quickly

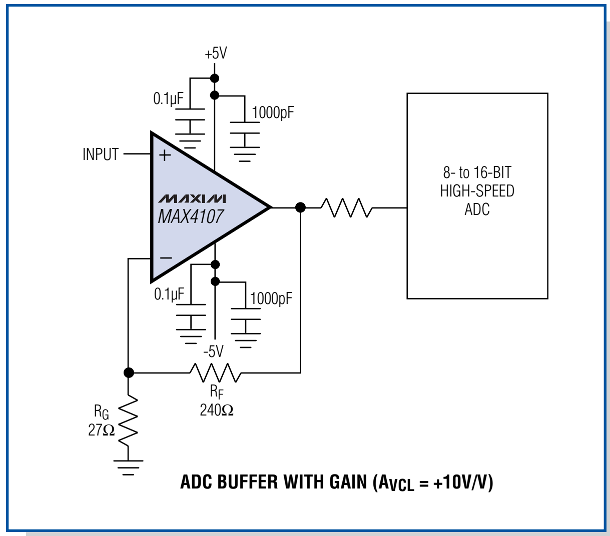

Figure 6. Operating with a noninverting gain of +10V/V, this ADC buffer suits high-frequency applications.

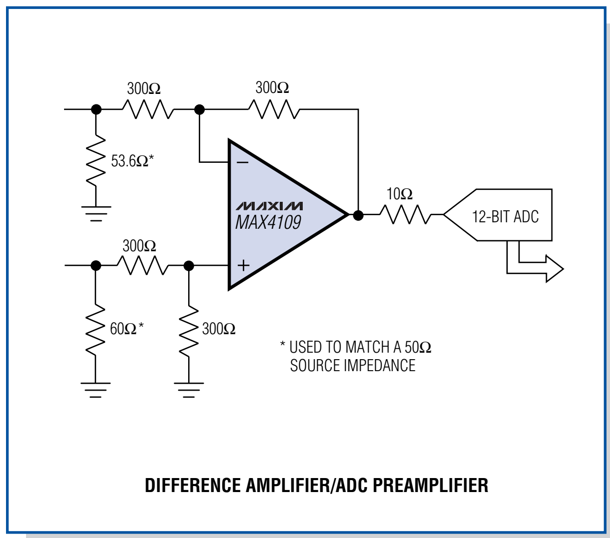

Figure 7. The buffer in this high-speed ADC application operates as a difference amplifier/preamplifier.

than from an input step, so this requirement is not too difficult to meet with an external buffer. A second method involves adding an RC filter at the input whose capacitor is much larger than the ADC's input capacitance. This larger capacitor eliminates the transient by providing charge for the sampling capacitor **(Figure 8)**. To absorb transient glitches, Maxim often recommends using a capacitor of 1000pF or more between the ADC input and ground.

An RC filter also reduces the possibility of amplifier-stability problems when driving a capacitive load. A small resistor in series with the capacitor helps to

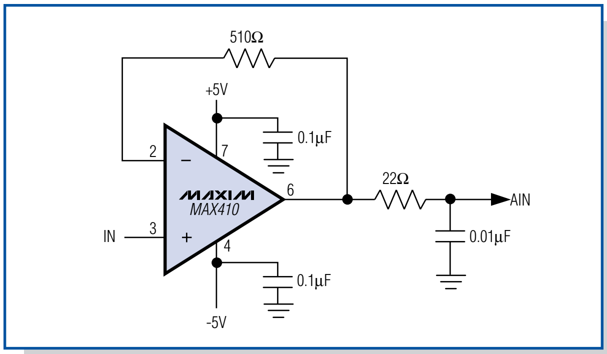

Figure 8. The 22Ω/0.1µF output filter absorbs transients from the ADC and helps stabilize the amplifier.

prevent ringing and oscillation. At higher capacitive loads, AC performance is controlled by the interaction of the load capacitance and the isolation resistor.

Another key concern is to ensure that the amplifier maintains low output impedance over all input frequencies of interest. Op amps with high output impedance cannot respond quickly to changes in the ADC's input capacitance. Nor can they handle the transient currents produced by the ADC. Nonlinearities result when the op amp does not settle in time for the next conversion.

Remember that high loop gain is necessary for low output impedance, according to the equation $R_{OUT} = R_O/(1 + A_{VO}\beta)$, where R_O is the open-loop output impedance and $A_{VO}\beta$ is the loop gain. $A_{VO}\beta$ decreases as you approach the op amp's unity-gain crossover frequency, leading to increased output impedance (**Figure 9**). Higher output impedance makes it difficult for the amplifier to handle current spikes from the ADC.

Thus, the low-impedance requirement leads to a requirement for wide bandwidth. Because higher bandwidth op amps have higher loop gain and therefore lower output impedance at higher frequencies, it makes sense to use a 500MHz op amp in front of a 50Msps ADC. The high-bandwidth op amp is more effective than a lower bandwidth amplifier in absorbing current transients produced by the ADC.

Limited loop gain error can affect overall gain accuracy

The Bode diagram of Figure 9 also depicts, for the noninverting circuit, the relationships between open-loop gain (A), the feedback-attenuation factor (β), noise gain (1/β), and loop gain (Aβ, or $A_{VO}\beta$ at DC) as functions of frequency. Figure 9 shows the variation of open-loop gain vs. frequency for a typical operational amplifier. At very low frequencies, the DC open-loop gain (A_{VO}) is near 100dB. Also note that the logarithm of the feedback-attenuation factor is negative because it represents a reduction in the signal amplitude.

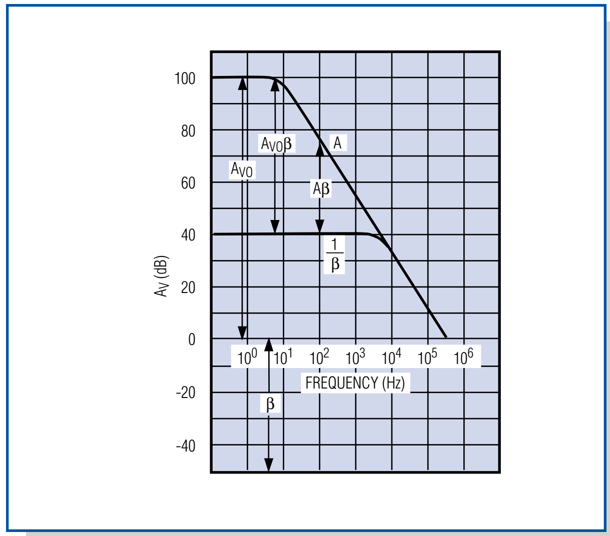

Figure 9. Output impedance generally rises with frequency.

Loop gain is depicted in the figure as the sum of the open-loop gain and the feedback attenuation factor (+100dB + (-40dB) = 60dB at very low frequency), or as the difference between the open-loop gain and the noise gain, 1/β [+100dB - (+40dB) = 60dB]. For a given value of β, observe that as frequency increases, the loop gain Aβ decreases. To obtain a greater amount of loop gain at higher frequencies, either increase the open-loop gain of the amplifier or increase the feedback factor β (i.e., decrease the noise gain).

These observations lead to a key equation in feedback systems. Referring to the unity-gain noninverting amplifier,

$$A_{CL} = V_{OUT}/V_{IN} = 1/(1 + 1/A\beta). \qquad [3]$$

This equation indicates that the closed-loop gain (A_{CL}) depends on both the open-loop gain and the feedback factor. Both of these quantities are functions of frequency, so loop gain is a function of frequency as well. The amount of loop gain at the operating frequency is the key measure of how closely an amplifier configuration approaches the ideal.

To understand the effect of open-loop gain on overall gain accuracy, consider a practical example based on equation [3]. Assuming an op amp with 40dB open-loop gain at the frequency of interest, the closed-loop gain has an error of 1%. This error drops to 0.1% at 60dB gain, and to 0.01% at 80dB gain. Therefore, 80dB is the minimum allowable open-loop gain that will maintain unity closed-loop gain while properly driving a 12-bit ADC. To accommodate a higher closed-loop gain, modify equation [3] as follows:

$$A_{CL} = V_{OUT}/V_{IN} = (1/(1 + 1/A\beta))(R_F + R_I)/R_I \qquad [4]$$

where R_F and R_I are the feedback and input resistors, respectively. Depending on the level of closed-loop gain required, even higher open-loop gain may be needed to maintain the required accuracy.

Output impedance vs. frequency

Low impedance vs. frequency has made video amplifiers such as the MAX4100 very popular as ADC drivers in medical ultrasound applications (**Figure 10**). At the sampling frequency typical for the newest 10-bit ADCs in ultrasound systems (50MHz), the MAX4100 exhibits an output resistance of less than 0.2Ω. The MAX4100 is a voltage-feedback, high-speed, unity-gain-stable amplifier that delivers a 500MHz unity-gain bandwidth, a 250V/µs slew rate, and a settling time of 35ns (to 0.01%) or 18ns (to 0.1%).

Despite the availability of new ADC architectures and other technology improvements, companies like Maxim answer many questions about missing codes and poor linearity. The cause of these problems is generally assumed to be poor performance in the ADC, but it often stems from a poor choice of drive amplifier instead. **Tables 2** and **3** give an overview of the ADC-drive amplifiers, enabling a selection of single-supply (down to +2.7V) vs. dual-supply types, and fastest vs. most-accurate types.

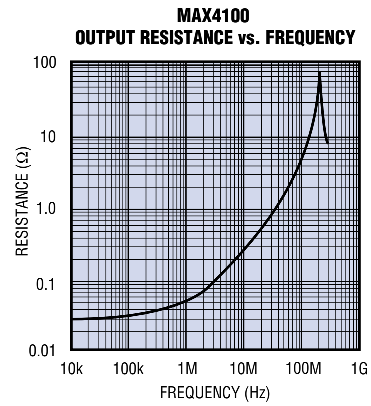

Figure 10. The MAX4100 exhibits less than 0.2Ω output resistance at 50MHz.

Table 2. ADC drive-amplifier selection, single op amps, single supply (+2.7V to +5.5V)

DEVICE	GAIN STABILITY	GBW (MHz)	VOLTAGE-NOISE DENSITY (nV/√Hz)	CURRENT-NOISE DENSITY (pA/√Hz)	MAX OFFSET (±mV)	OFFSET TEMPCO (µV/°C)	SLEW RATE (V/µs)	SETTLING TIME TO 0.01% (µs)	THD (%)
MAX495	1	0.5	25	0.1	0.500	2.0	0.2	12.0	0.003
MAX4330	1	3	28	0.4	1.500	3.0	1.5	4.0	0.003
MAX4331	1	3	28	0.4	0.600	3.0	1.5	4.0	0.003
MAX4250	1	3	7.9	0.0005	0.750	0.3	6.7	0.3	0.0004
MAX4251	1	3	7.9	0.0005	0.750	0.3	6.7	0.3	0.0004
MAX4122	1	5	22	0.4	1.000	2.0	2.0	2.0	0.003
MAX4123	1	5	22	0.4	0.600	2.0	2.0	2.0	0.003
MAX4322	1	5	22	0.4	2.000	2.0	2.0	1.3	0.003
MAX4323	1	5	22	0.4	2.500	2.0	2.0	1.3	0.003
MAX4165	1	5	26	0.4	1.000	3.0	2.0	2.1	0.003
MAX4166	1	5	26	0.4	1.000	3.0	2.0	2.1	0.003
MAX4130	1	10	22	0.4	1.000	2.0	4.0	2.0	0.003
MAX4131	1	10	22	0.4	0.600	2.0	4.0	2.0	0.003
MAX4255	10	22	7.9	0.0005	0.750	0.3	1.6	2.1	0.0012
MAX4256	10	22	7.9	0.0005	0.750	0.3	1.6	2.1	0.0012
MAX4124	10	25	22	0.4	1.000	2.0	10.0	1.3	0.003
MAX4125	10	25	22	0.4	0.600	2.0	10.0	1.3	0.003
MAX4012	1	200	10	6.0	20.000	8.0	600.0	0.045*	-75dB
MAX4212	1	300	10	6.0	12.000	8.0	600.0	0.045*	-75dB
MAX4213	1	300	10	6.0	9.000	8.0	600.0	0.045*	-75dB

* To 0.1%

Table 3. ADC drive-amplifier selection, single op amps, dual supplies (±5V)

DEVICE	GAIN STABILITY	GBW (MHz)	VOLTAGE-NOISE DENSITY (nV/√Hz)	CURRENT-NOISE DENSITY (pA/√Hz)	MAX OFFSET (±mV)	OFFSET TEMPCO (µV/°C)	SLEW RATE (V/µs)	SETTLING TIME TO 0.01% (µs)	THD (dB)
MAX400	1	0.6	11	0.17	0.015	0.3	0.3	N/A	N/A
MAX410	1	28	2.4	1.2	0.250	1.0	4.5	1.3	-98
MAX4103	2	180	5	1	8.000	5.0	350	0.03	-76
MAX4101	2	200	6	0.8	8.000	15.0	250	0.035	-65
MAX4309	10	200	6	2	8.000	13.0	1200	0.012	-83
MAX4308	5	220	6	2	8.000	13.0	1200	0.012	-83
MAX4109	2	225	6	2	8.000	13.0	1200	0.012	-90
MAX4180	1	240	2	4	7.000	12.0	450	0.02*	-73
MAX4102	1	250	7	1	8.000	5.0	400	0.03	-78
MAX4113	2	270	2.2	13	8.000	10.0	1800	0.035	-62
MAX4181	2	270	2	4	7.000	12.0	450	0.02*	-73
MAX4107	10	300	0.75	2.5	3.000	1.0	500	0.018	-63
MAX4106	5	350	0.75	2.5	3.000	1.0	275	0.018	-63
MAX4305	10	350	2.1	3.1	6.000	2.5	0.025	1400	-67
MAX4108	1	400	6	2	8.000	13.0	1200	0.012	-93
MAX4112	1	400	2.2	13	8.000	10.0	1200	0.035	-68
MAX4105	5	430	2.1	3.1	6.000	2.5	1400	0.025	-74
MAX4100	1	500	8	0.8	8.000	15.0	250	0.035	-70
MAX4224	2	600	2	3	6.000	2.0	1100	0.005*	-68
MAX4304	2	730	2.1	3.1	6.000	2.5	0.025	1000	-88
MAX4104	1	880	2.1	3.1	6.000	2.5	400	0.025	-88
MAX4223	1	1000	2	3	6.000	2.0	1100	0.008*	-65

* To 0.1%

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1. Maxim Integrated Products, Full-Line Data Catalog on CD-ROM, 1998 Ed., version 2.0.
2. Crystal Semiconductor, Application Note AN06, January 1995.
3. Linear Technology Corp., Application Note 71, July 1997.
4. Burr-Brown Corp., Application Bulletin AB-098, April 1995.

DESIGN SHOWCASE

Tiny light sensor with logic output draws less than 10µA

A light-sensing circuit that consumes very little power can serve as an automatic backlight sensor in portable instruments. This function is easily implemented with a logic gate or Schmitt-trigger inverter, but those approaches draw a considerable amount of supply current. The circuit IC1 (**Figure 1**) offers a different—and better—solution.

A logarithmic graph of supply current vs. supply voltage (**Figure 2**) illustrates a comparison. As expected for CMOS circuits, the 74HC inverter and 74HC14 Schmitt-trigger inverter draw very little current (<1µA) when their inputs are near the supply rails. Near midscale, however, the 74HC04 at 5V draws more than 10mA! The 74HC14 is better, but still draws more than 0.5mA at midscale. These currents pose a problem because the midscale condition in a light-sensing circuit can persist for a long time.

+3V power supplies reduce the supply currents by an approximate factor of three, but the currents are still significant. Adding hysteresis also helps, but there will remain a point just above or below the switching threshold at which these CMOS devices draw excessive class-A supply currents.

The lowest curve, representing the supply current for IC1, varies only slightly over the signal range and never exceeds 7µA. The external light sensor and bias resistor draw a maximum of 3µA with a +5V supply, so the circuit's total supply current, independent of light level, is less than 10µA. Unlike the other approaches, this circuit compares the light level (represented by a voltage on R1) with a fixed reference voltage rather than a loosely specified logic-switching threshold.

Supply voltage can range from +2.5V to +11V, with the supply current measuring several microamps at +11V. IC1 also comes in an open-drain version (MAX836) whose output (tied to a pull-up resistor) can exceed the supply voltage in a mixed-voltage system. If minimum power consumption is more important than size, choose the MAX931 comparator/reference IC. It comes in a shrink SO-8 package called µMAX (versus the MAX837 SOT package), but its maximum supply current is only 3µA. The built-in hysteresis of the MAX837 obviates the need for external hysteresis resistors.

A similar idea appeared in the 4/6/98 issue of Electronic Design.

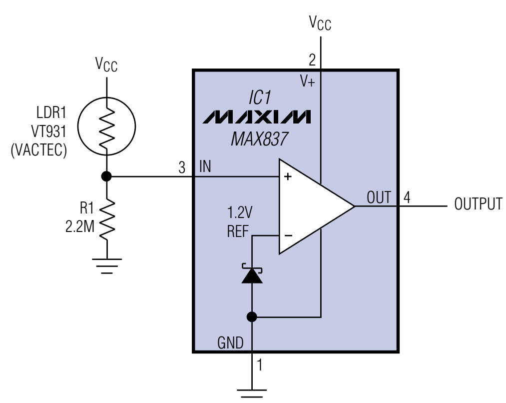


Figure 1. This light sensor provides a low-to-high output transition at a light level determined by the value of R1.

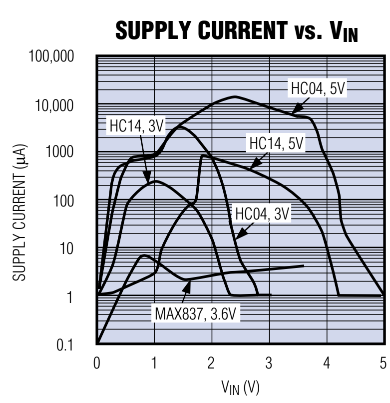


Figure 2. These curves compare the supply current drawn by IC1 of Figure 1 (the lowest curve, labeled MAX837, 3.6V) with that of alternative devices.

-12V to -5V/400mA regulator ensures sequencing with 5V rail

The circuit in **Figure 1** steps down a nominal -12V to a regulated -5V. It allows -5V to come up only after a separately regulated +5V has come up, and if the +5V collapses, it automatically shuts down the -5V. This is useful in ±5V supplies for A/D and D/A converters, which often require such power-supply sequencing to avoid latchup.

IC1 is a conventional boost regulator, but the overall circuit is a negative buck regulator. The boost-regulator topology is correct for the switching control, but the regulator's feedback signal—which monitors an output voltage referred to the converter's positive rail and compares it with a reference voltage referred to the converter's negative rail—requires a level shift. The Q3/Q4 current mirror provides this shift, with emitter resistors R8 and R9 included to minimize the V_{be}-mismatch error.

IC1 includes a comparator and a 1.5V reference, normally used for low-battery detection via LBI and LBO, which monitors the +5V rail as follows: the current in Q1, mirrored by Q2, flows through R4 and develops a voltage proportional to the +5V rail. If this rail falls below a nominal 4.2V, the LBO output pulls R5 to the negative rail. That connection causes a current increase in the diode-connected Q4 which, mirrored by Q3 and flowing in R3, causes a rise in FB voltage to the regulator.

Feedback as described above tells the regulator that no additional output energy is required, so it complies with a shutdown in which the internal pulse-frequency modulation (PFM) suspends all power-conversion cycles. Connecting a minimum load of 10kΩ will prevent leakage through D1 from charging up the output capacitor (C2) while in this state. When IC1 operates with a +5V input and as a boost converter (as intended), it delivers about 150mA from a +12V output. The buck-regulator configuration, on the other hand, delivers 400mA at -5V using similar high-current components.

Efficiency vs. load current measures 85% at 100mA, 89% at 250mA, and 90% at 400mA. The measured peak-to-peak ripple is less than 25mV for any load. Output-voltage accuracy depends on the 2%-accurate reference in IC1 and the tolerance of feedback-path resistors R1, R3, R8, and R9.

Any difference in V_{be} for transistors Q3 and Q4 introduces an additional error. V_{be} measures about 550mV for the transistors used, and the maximum V_{be} difference measured among Q1–Q4 was 9mV. With respect to the Q3–Q4 base voltage (-1.24V), this 9mV contributes another 0.75% error in the output voltage. To match the V_{be} drops to within 1mV and eliminate the R6–R9 resistors, substitute a dual transistor such as the Rohm UMT1N (available in a SOT23-6 package).

A similar idea appeared in the 9/98 issue of Electronics World & Wireless World (UK).

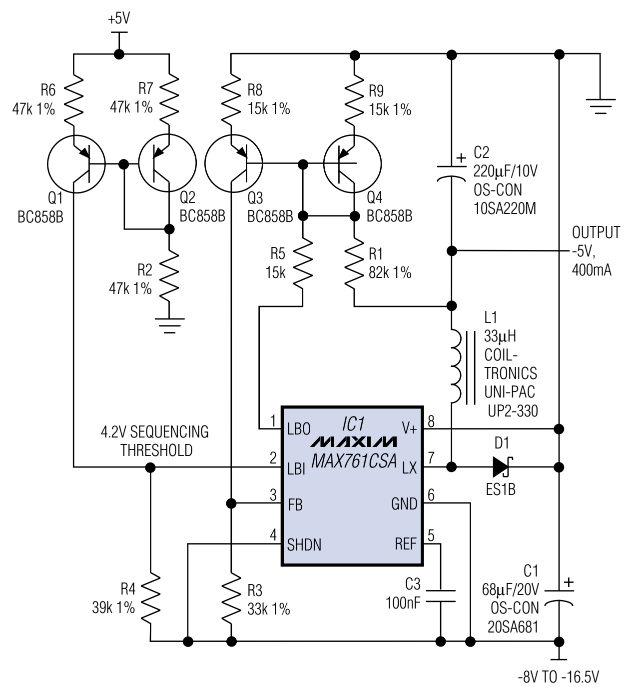


Figure 1. This negative buck regulator generates -5V from a nominal -12V supply and presents it in proper sequence with an independent +5V supply during power-up and power-down.

DESIGN SHOWCASE

Regulated LCD-bias generator requires no inductor

A stringent height limitation on the PC boards for personal digital assistants (PDAs) and palmtop computers compels the use of expensive, low-profile inductors in switch-mode power supplies. As an alternative, however, certain switch-mode circuits can be replaced with one based on a charge pump (**Figure 1**). This example generates a regulated negative voltage suitable for biasing an LCD.

IC1 contains a regulated, inverting charge pump that produces output voltages as high as $-2V_{IN}$, in which the supply voltage (V_{IN}) can range from +1.8V to +5.5V. The IC regulates V_{OUT} through pulse-frequency modulation (PFM), with a maximum frequency of 450kHz. The IC's low quiescent current (30µA) provides excellent light-load efficiency without sacrificing full-load capability.

Inserting an external, discrete charge pump (consisting of C3, C4, and the Schottky diodes) in the feedback path of IC1 produces an "inverter-quadrupler" circuit whose regulated output level is set by the ratio of feedback resistors R1 and R2:

$$V_{OUT} = -V_{IN}(R1/R2)$$

Configured as shown, the circuit provides up to 15mA at V_{OUT} = -18V, with 76% efficiency and 60mV of output voltage ripple. Lower V_{OUT} allows higher output currents: V_{OUT} = -15V yields 20mA, and V_{OUT} = -12V yields 30mA.

A similar idea appeared in the 3/9/98 issue of Electronic Design.

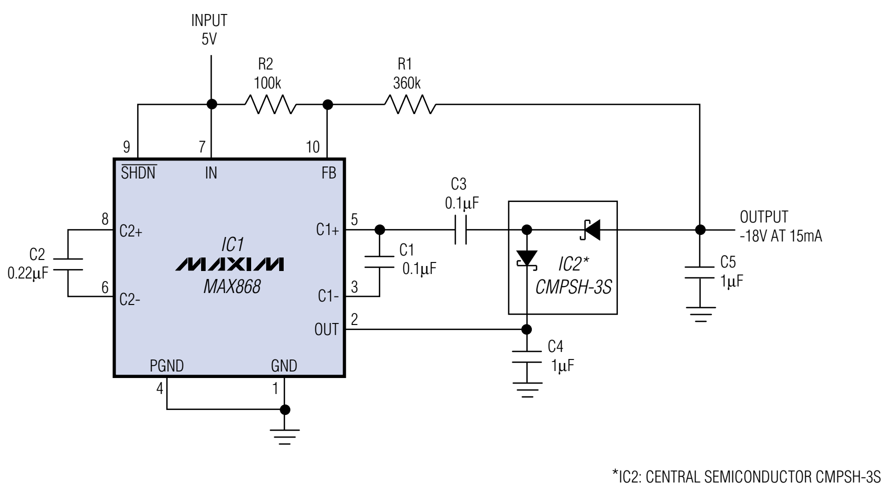


Figure 1. Adding a few inexpensive components in the feedback path of IC1 enables the generation of regulated output voltages nearly as high as $-4V_{IN}$.

DESIGN SHOWCASE

Redundant-transceiver RS-232 link has ±40V overvoltage protection

The RS-232 standard is intended primarily for point-to-point communications between one transmitter and one receiver, but in some circumstances it may be necessary to connect more than one transceiver to the link. For example, redundant transceivers provide extra reliability in safety-critical applications.

Multiple transceivers load the data bus, however. For instance, if two transmitters—one from each of two separate MAX211 transceivers—are connected in parallel (to the same link), the unused device (whether shut down or with power removed) will adversely affect the active device by loading the data bus. **Figure 1's** circuit avoids this problem while increasing the overvoltage protection from that of the transceivers to that of the line protectors (±40V).

Each of the parallel RS-232 transceivers (IC1 and IC2) is buffered by a 2-terminal, multichannel line protector (IC3 and IC4). The line protectors normally exhibit about 60Ω between each input-output pair, but that resistance goes to a high impedance if power is removed or if either terminal rises to within 1.5V of a supply rail. The line protectors are powered by charge pumps internal to the transceivers, so either will lose power if its associated transceiver loses power or is shut down. Thus, an inactive transceiver is automatically disconnected from the line.

To ensure that the line protectors have sufficient power-supply headroom to accommodate the transceivers' |±5V| transmitter-output specification, external diode-capacitor charge pumps boost the transceivers' V- outputs to a more negative level. The 100kΩ resistors discharge this negative rail when the transceiver is shut down or turned off. The system's various states are summarized in **Table 1**.

Table 1. System States

Tx CONDITION	Tx (V+)	Tx (V-)	LINE-PROTECTOR (V-)
Active	~2V_{CC}	~-2V_{CC}	~-3V_{CC}
Shutdown	V_{CC}	Ground	Ground
Power Off	Ground	Ground	Ground

A similar idea appeared in the 12/96 issue of Electronic Product Design (UK).

[continued]

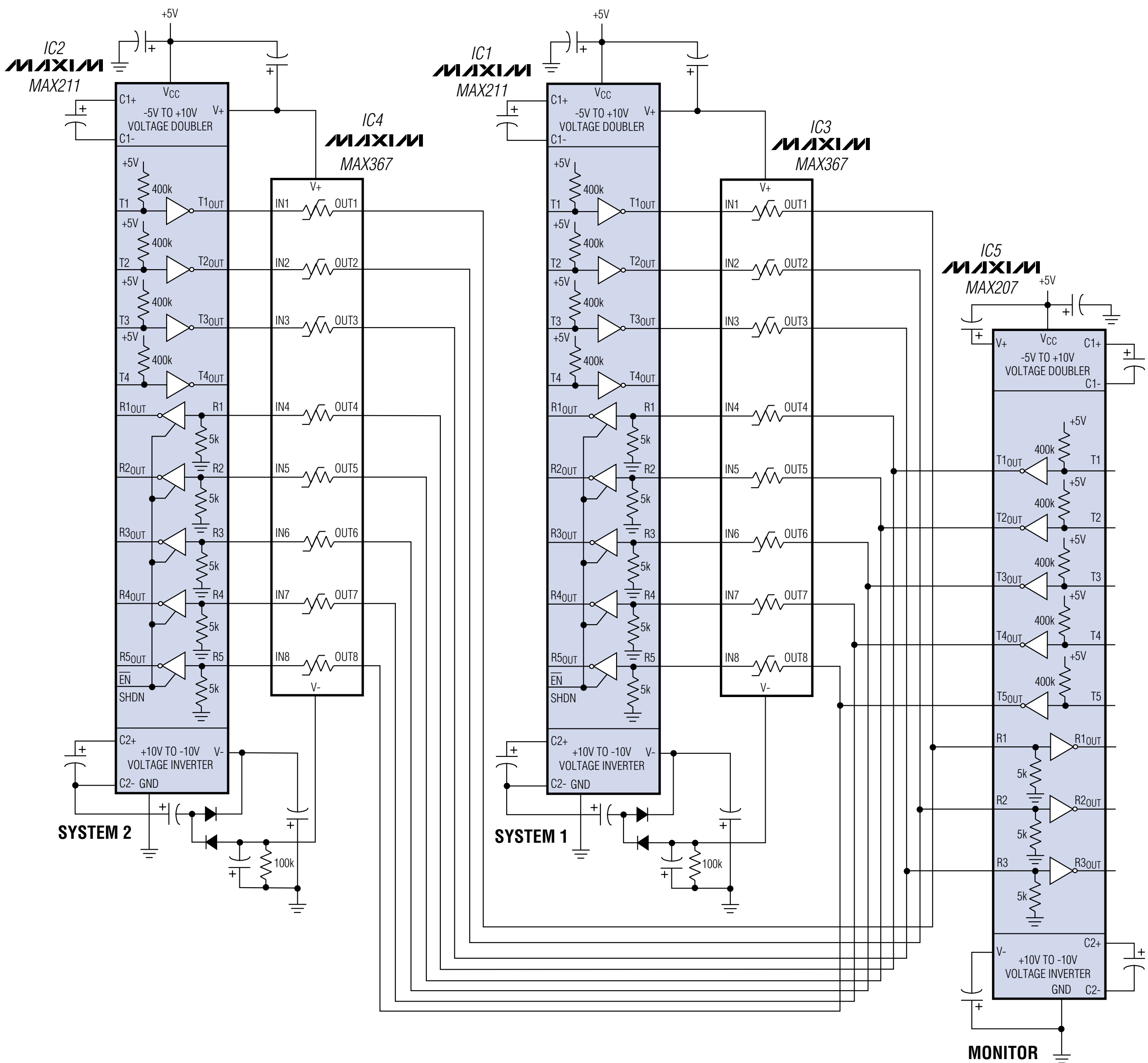


Figure 1. Line protectors IC3 and IC4 prevent either of the two parallel transceivers (IC1 and IC2) from loading the data bus while they are inactive (shut down or turned off).

NEW PRODUCTS

10- and 12-bit serial-input ADCs fit 8-pin µMAX

The MAX157/MAX159 10-bit A/D converters (ADCs) operate on a single supply voltage of +2.7V to +5.25V. They combine a 6.4µs successive-approximation ADC, automatic power-down, fast wake-up (2.5µs), an on-chip clock, and a high-speed 3-wire serial interface in an 8-pin DIP or µMAX package. The MAX144/MAX145 are pin-compatible 12-bit upgrades to the MAX157/MAX159. They combine a 5µs successive-approximation ADC with all the features of the 10-bit version. The converters' low-power operation, excellent dynamic performance, ease of use, and small package are well suited for battery-powered data acquisition and other applications.

Power consumption for V_{DD} = 3.6V is only 3.2mW at the maximum sampling rate (108ksps). At lower throughput rates, using the 0.2µA shutdown mode between conversions can reduce power consumption even further. The MAX144/MAX157 have two single-ended inputs; the MAX145/MAX159 have one pseudo-differential input. All devices accept inputs ranging from 0 to V_{REF}. Applying an external clock provides access to the output data via a 3-wire serial interface that is compatible with SPI™, QSPI™, and MICROWIRE™ standards.

These devices are available in 8-pin DIP and µMAX packages. The 10-bit ADCs (MAX157/MAX159) are priced starting at $2.79; the 12-bit ADCs (MAX144/MAX145) are priced starting at $4.24 (1000 up, FOB USA).

SPI and QSPI are trademarks of Motorola, Inc.

MICROWIRE is a trademark of National Semiconductor Corp.

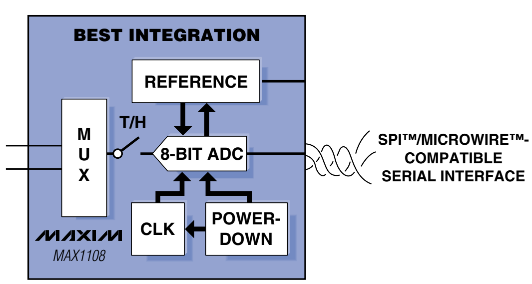
8-bit, 2-channel, serial-input ADCs fit 10-pin µMAX

The MAX1108/MAX1109 ADCs combine an internal track/hold, voltage reference, clock, serial interface, and battery-monitoring capability with software-configurable analog inputs that allow unipolar/bipolar and single-ended/differential operations. The converters' low-power operation, excellent dynamic performance, ease of use, and small package are well suited for battery-powered data acquisition and other applications.

The MAX1108 is specified to operate from a single +2.7V to +3.6V supply, and draws a supply current of 105µA. The MAX1109 is specified from +4.5V to +5.5V and draws 130µA. The full-scale analog input range is determined either by the internal reference voltage of 2.048V (MAX1108) or 4.096V (MAX1109), or by an externally applied reference in the 1V to V_{DD} range. Both ADCs feature a software power-down mode that lowers the supply current to 0.5µA when the device is not in use.

These converters have a 4-wire serial interface that connects directly to SPI, QSPI, and MICROWIRE devices without external logic. They are capable of data rates to 50kbps, using either the internal clock or an external serial-interface clock.

The MAX1108/MAX1109 ADCs are available in 10-pin µMAX packages, with prices starting at $1.55 (1000 up, FOB USA).



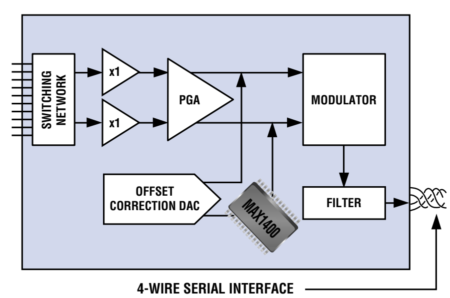
18-bit sigma-delta ADCs guarantee 0.0015% INL

The MAX1400/MAX1402 are multichannel, 18-bit ADCs that guarantee 16-bit performance (0.0015% INL) at 480sps. For conversion rates as high as 4800sps, the devices maintain 12-bit performance (0.024% INL) while performing coarse measurements 10 times more quickly. Their high accuracy is ideal for applications requiring a wide dynamic range, such as industrial process control and pressure transducers.

Both parts operate from a +5V analog supply or a +3V or +5V digital supply. Power consumption is a low 1.5mW, dropping to less than 50µW in shutdown. The MAX1402 provides matched 200µA current sources for sensor excitation. The MAX1400 provides direct access to the ADC input for inserting additional signal-conditioning circuitry.

These ADCs save board space and design time by combining a switching network, programmable-gain amplifier (PGA), two buffers, system-offset-correction DAC, internal oscillator, on-chip digital filter, modulator, and bidirectional serial interface into a 28-pin SSOP package. System offsets (up to 117% of the selected full-scale range) can be corrected with the offset-correction DAC, and the analog inputs can be configured either as five fully differential channels or as five pseudo-differential and two differential channels. Other features include user-configurable automatic channel scanning, a continuous-data output mode, and a convert-on-command mode.

The MAX1400/MAX1402 are available in 28-pin SSOP packages, with prices starting from $8.95 (1000 up, FOB USA).



NEW PRODUCTS

12- and 13-bit DACs guarantee <10ppm/°C reference

Devices in the MAX5120/MAX5130 family of 12- and 13-bit digital-to-analog converters (DACs) feature serial inputs, voltage outputs, an internal Rail-to-Rail® output amplifier, and a precision bandgap reference. Unlike comparable devices with on-chip voltage references, these guarantee <10ppm/°C reference tempcos over the extended-industrial temperature range (-40°C to +85°C). The devices that operate on +5V also guarantee ±$^1/_2$LSB integral nonlinearity and monotonicity (±1LSB max differential nonlinearity).

Four of these low-power DACs operate on a single +3V supply; the other four operate on +5V. They draw only 500µA of supply current (only 3µA in power-down mode). During power-up, an internal power-up reset minimizes output glitches by allowing the user to select either zero or mid-scale for the initial output state. The internal amplifier's output and inverting input are accessible, allowing the user to configure for specific gain values, remote sensing, and high output drive for a wide range of force-sense applications. The buffered output can drive 5kΩ/100pF loads or 4–20mA current loops.

Voltage-output devices are the 12-bit MAX5120/MAX5121 and the 13-bit MAX5130/MAX5131. Force-sense versions (to be released soon) are the 12-bit MAX5122*/MAX5123* and 13-bit MAX5132*/MAX5133*. These DACs are offered in space-saving 16-pin QSOP packages, with prices starting at $3.80 (1000 up, FOB USA).

** Future products—contact factory for availability.*

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

16-bit, 1Msps, self-calibrating ADC features 4-cycle latency

The MAX1200 is a 16-bit, 1Msps, self-calibrating ADC. Intended for instrumentation, communications, and imaging applications, this CMOS IC employs a self-calibrating pipelined architecture that secures 16-bit linearity at full 1Msps sample rates. Unlike high-resolution converters such as the sigma-delta and integrating types, the MAX1200 maintains ±0.5LSB differential nonlinearity (DNL) and reduces the latency interval to just four clock cycles. Low latency time is an important consideration for data-acquisition systems in which the sample identity and system throughput must be maintained while the channels are being multiplexed.

For communications applications, the MAX1200 delivers 91dB SFDR, 87dB SNR, and 87dB THD at an analog-input frequency of 100kHz. Nyquist AC performance is ensured by a fully differential input track/hold that accepts input swings of ±V_{REF}. The MAX1200 uses parallel, three-state, CMOS-compatible outputs with a two's complement data format. It dissipates a low 273mW (typ) while operating from single +5V (or +3V digital) supply.

The MAX1200ACMH guarantees 1LSB DNL max and no missing codes; prices start at $25.35 (1000 up, factory direct FOB USA). The MAX1200BCMH is specified for AC-only applications; prices start at $19.00 (1000 up, factory direct, FOB USA). Both are available in 44-pin MQFP packages. To save design time, an evaluation kit is available for $95.50.

Fixed-gain, rail-to-rail amps occupy SOT23 packages

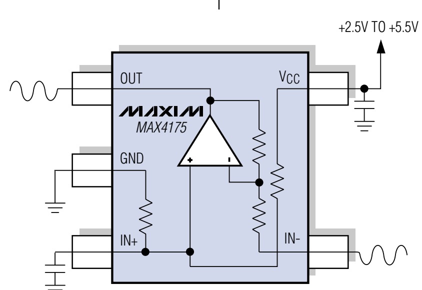
Members of the MAX4174/MAX4175 Gain-Amp™ family (op amps with internal-gain setting and V_{CC}/2-biasing resistors) have factory-trimmed internal resistors that minimize the size and cost of circuit layouts while providing 0.1% gain accuracy.

Operating from a single supply (+2.5V to +5.5V), these Gain-Amps provide inverting gains from -0.25V/V to -100V/V or noninverting gains from +1.25V/V to +101V/V—27 different gains in all. They achieve gain-bandwidth products as high as 23MHz, and their input high-voltage fault protection prevents excessive current draw while operating with input voltages as high as ±17V.

Two versions of the Gain-Amps are available: fixed gain (MAX4174) and fixed gain plus internal V_{CC}/2 bias at the noninverting input (MAX4175). The standard gain values available are listed in Maxim's *Product Selector Guide*. Frequency compensation has been optimized for the high-gain versions.

Gain-Amp outputs can swing rail-to-rail, and they maintain excellent DC accuracy while driving 1kΩ loads. Each amplifier is stable for capacitive loads up to 470pF. Package options for the Gain-Amp family include the 5-pin SOT23, 8-pin SO, and 8-pin µMAX. Prices start at $0.68 (1000 up, FOB USA).

Gain-Amp is a trademark of Maxim Integrated Products.



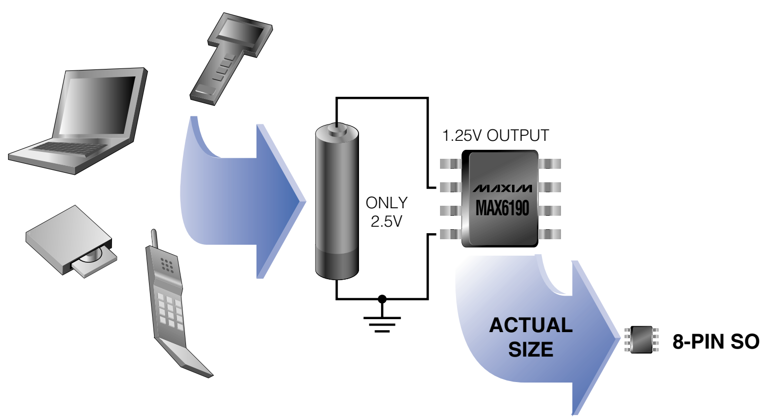
NEW PRODUCTS

Precision micropower voltage references have low dropout voltage

Devices in Maxim's new family of low-dropout, precision voltage references (MAX6190/MAX6191/MAX6192 and MAX6194/MAX6195/MAX6198) have outputs of 1.250V, 2.048V, 2.500V, 4.500V, 5.000V, and 4.096V, respectively. Each is available in three grades of output tempco (5ppm/°C, 10ppm/°C, or 25ppm/°C), with initial accuracy grades of ±2mV, ±5mV, and ±10mV. A 3.000V-output version will be available soon.

Quiescent supply currents are low (35µA max) and virtually immune to input-voltage variations, making these series-mode bandgap references ideal for battery-powered instruments. Their proprietary internal curvature-correction circuitry and laser-trimmed precision thin-film resistors provide very low tempcos of 5ppm/°C max.

Line regulation is 8µV/V, and load regulation (0.12µV/V) is guaranteed for source and sink currents up to 500µA. These devices are internally compensated and stable for capacitive loads up to 2.2nF. The dropout voltage at 500µA load current is only 100mV. All references are offered in 8-pin SO packages, with prices starting as low as $2.50 (1000 up, FOB USA).



Audio/video crosspoint switches have clickless mode

The MAX4550/MAX4570 analog crosspoint switches are well suited to audio/video multimedia applications. These programmable devices contain two identical crosspoint-switch arrays, each consisting of four inputs and two outputs, plus two additional crosspoint inputs (SA and SB) that can serve as shunts for improving off-isolation. Each output can be programmed for clickless or regular-mode operation.

The MAX4550 has a fast 2-wire serial interface that is compatible with the I²C™ serial-interface standard; the MAX4570 has a 3-wire serial interface that is compatible with the SPI, QSPI, and MICROWIRE standards. The 43Ω on-resistances are matched to within 5Ω and flat to within 4Ω.

Each device features 0.014% total harmonic distortion (THD). Off-isolation measures at least -110dB in the audio-frequency range and -78dB at 4.2MHz. Crosstalk is -95dB in the audio-frequency range and -54dB at 4.2MHz. For AC-coupled applications, a set of internal resistive voltage-dividers provides a DC bias for each output.

The MAX4550/MAX4570 are available in 28-pin SSOP packages, with prices starting at $3.16 (1000 up, FOB USA).

I²C is a trademark of Philips Corp.

SPST, CMOS, dual analog switches have 1.25Ω on-resistance

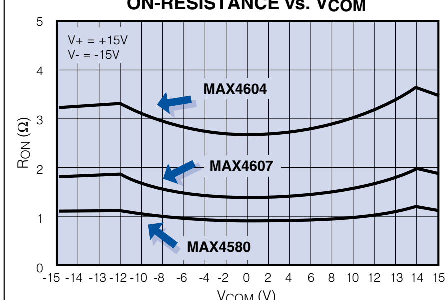
The MAX4580/MAX4590/MAX4600 dual SPST analog switches feature low on-resistances of only 0.9Ω (1.25Ω max), matched (within the IC) to within 0.5Ω max, and flat (over the specified signal range) to within 0.5Ω max. All switches handle rail-to-rail analog signals.

The MAX4580 has two normally closed (NC) switches, the MAX4590 has two normally open (NO) switches, and the MAX4600 has one of each. Because these switches save board space, offer low-power operation, and are more reliable than mechanical relays, they are preferred over mechanical relays in current-switching applications and in automatic test equipment. They also excel in applications that require low distortion.

The MAX4580/MAX4590/MAX4600 operate from a single +4.5V to +36V supply or from dual ±4.5V to ±20V supplies. All digital inputs have 0.8V/2.4V logic thresholds, which ensures TTL/CMOS-logic compatibility when operating on +12V or ±15V. ESD protection >2kV is guaranteed per Method 3015.7.

These devices are available in space-saving 16-pin SSOP packages, as well as DIP and narrow SO, with prices starting at $2.93 (1000 up, FOB USA).

ON-RESISTANCE vs. V_{COM}



NEW PRODUCTS

Serially controlled analog switches offer clickless operation

The MAX4571–MAX4574 are programmable switch arrays that minimize the number of controller-I/O port assignments while maximizing the number of switches per package. Individual switches in each device can be programmed through the serial interface, either for a soft-switching mode that provides clickless audio or for standard audio/video operation. The MAX4571/MAX4573 include 11 single-pole/single-throw (SPST) switches, and the MAX4572/MAX4574 include 6 single-pole/double-throw (SPDT) and 2 SPST switches.

The MAX4571/MAX4572 feature a 2-wire, I^2C-compatible serial interface, and the MAX4573/MAX4574 feature a 3-wire, SPI™/QSPI™-compatible serial interface. All four operate from a single +2.7V to +5.5V supply. They offer typical on-resistances of 25Ω, with typical crosstalk and off-isolation of -90dB. Applications include multiple-signal routing in audio, video, multimedia, and industrial systems.

The MAX4571–MAX4574 are available in 28-pin QSOP, SSOP, and wide-SO packages. Prices start at $4.04 (1000 up, FOB USA).

Single 8-to-1/ dual 4-to-1 cal-muxes operate to ±20V

The MAX4578 (8-channel) and MAX4579 (dual 4-channel) calibration multiplexers (cal-muxes) have internal precision-resistor networks that provide accurate voltage-level outputs, enabling each device to monitor and calibrate an external system or ADC. They operate from dual supplies of ±4.5V to ±20V.

Asserting the CAL and EN pins simultaneously allows the three address pins (A0, A1, A2) to select various calibration and system-monitoring functions. The multiplexers offer 400Ω on-resistances matched to within 15Ω max, with extremely low off- and on-channel leakages (less than 50pA at +25°C). Each switch handles rail-to-rail analog signals. All digital inputs are TTL/CMOS-compatible (with 0.8V/2.4V logic thresholds), and each device offers >2kV ESD protection per Method 3015.7.

The MAX4578/MAX4579 are available in small 20-pin SSOP, SO, and plastic DIP packages. Prices start at $2.78 (1000 up, FOB USA).

8-channel mux offers multiple operating modes

The MAX4598 low-voltage CMOS analog multiplexer (mux) can be configured for eight single-ended channels or four differential channels. All channels handle rail-to-rail analog signals. The device can monitor its own supply voltages (in addition to its input channels) through additional internal switches that connect V+ and GND to the output. Further, internal address latches enable operation as either a standard or "latched" multiplexer.

The MAX4598 operates from dual ±6V supplies or from a single supply in the +2.7V to +12V range. It has low on-resistance (75Ω max), low charge injection (2pC typ), and its digital inputs are TTL-compatible when operating from +5V or ±5V supplies. Off-leakage currents are only 0.1nA at +25°C and 2nA at +85°C. ESD protection is >2kV per Method 3015.7.

The MAX4598 is available in 20-pin DIP, SSOP, and SO packages, with prices starting at $2.78 (1000 up, FOB USA).

Quad SPST analog switches have 2.5Ω on-resistance

The MAX4601/MAX4602/MAX4603 are quad SPST analog switches featuring low on-resistances of 2.5Ω max, matched to within 0.5Ω max and flat to within 0.5Ω max over the specified signal range.

Because they offer low-power operation, small size, and higher reliability than that of mechanical relays, these CMOS switches are ideal for low-distortion applications. They are preferred over mechanical relays for use in current-switching applications and automatic test equipment.

The MAX4601 has four normally closed (NC) switches, the MAX4602 has four normally open (NO) switches, and the MAX4603 has two of each. Each switch can handle rail-to-rail analog signals, and off-leakage current is only 2.5nA max at +85°C. These devices operate from a single +4.5V to +36V supply or from dual ±4.5V to ±20V supplies. When operating with +12V or ±15V supplies, the digital inputs' 0.8V/2.4V switching thresholds ensure compatibility with TTL/CMOS logic. ESD protection of >2kV is guaranteed per Method 3015.7.

The MAX4601/MAX4602/MAX4603 switches are available in 16-pin DIP, wide SO, and SSOP packages, with prices starting at $2.66 (1000 up, FOB USA).

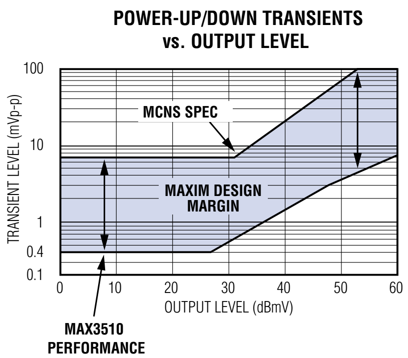
NEW PRODUCTS

Upstream CATV amplifier has programmable gain

The MAX3510 programmable power amplifier is designed for CATV upstream applications. Operating through a 2:1 voltage-ratio transformer, it delivers continuous-wave outputs as high as 64dBmV. Its variable gain is controlled in 1dB steps through a 3-wire serial digital-data bus. The operating frequency range is 5MHz to 65MHz.

To improve performance in TDMA systems, the MAX3510 has a transmit-disable mode that minimizes output noise by shutting down the output stage between data bursts. This mode also places the device in a high-isolation state and reduces the supply current to 25mA. Output transients do not exceed 25mV when entering and leaving the transmit-disable mode.

Two power-down modes are available. The software shutdown powers down all analog circuitry while maintaining the programmed gain setting. Full shutdown disables all circuitry and reduces the supply current to below 10µA. The MAX3510 is available in a 20-pin QSOP package.



622Mbps, 4:1 data serializer includes clock synthesis and LVDS inputs

The MAX3693 4:1 data serializer, designed primarily for SDH/SONET and ATM/SONET applications, converts 4-bit-wide, 155Mbps parallel data to 622Mbps serial data. Other applications include add/drop multiplexers and digital cross connects.

The MAX3693 operates on +3.3V and consumes 215mW. It accepts low-voltage differential-signal clock and data inputs, and delivers a 3.3V PECL serial-data output for interfacing with high-speed digital circuitry. A fully integrated phase-lock loop synthesizes the internal 622Mbps serial clock from an external reference signal of 155.52MHz, 77.76MHz, 51.84MHz, or 38.88MHz.

The MAX3693 is available in a 32-pin TQFP package.

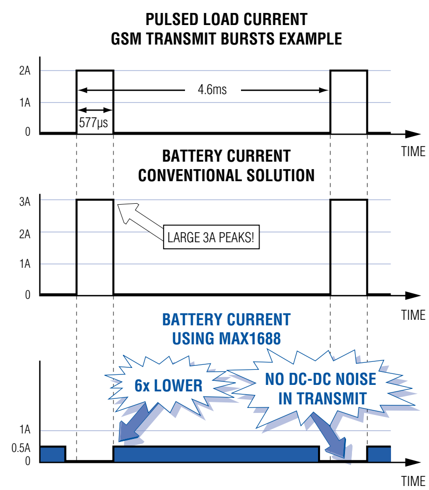
ICs drive 2A GSM transmit burst while drawing 6-times lower battery current

The MAX1687/MAX1688 are step-up DC-DC converters that prevent battery glitches and minimize peak battery current during the transmit cycle of GSM phones and wireless LANs.

To drive the RF power amplifier (PA) in a typical cell phone, the 3.6V battery voltage (three NiCd cells or a single Li-Ion cell) must be boosted to 5V. For pulsed load currents such as the transmit burst of a GSM phone (with a 1:8 duty cycle), the MAX1687/MAX1688 devices employ a proprietary control scheme (patent pending) that lowers current drain from the battery by recharging a reservoir capacitor during the off time. During the transmit pulse, the DC-DC converters are turned off—both to isolate the battery from load transients and to eliminate noise at the PA.

To deliver the 2A required by a typical 5V PA while transmitting, a conventional DC-DC converter would pull nearly 3A from the battery—i.e., 2A [5V/(3.6V plus efficiency losses)]. In contrast, the MAX1687/MAX1688 draw zero current during the transmit burst and less than 0.5A (a 6-times improvement) while recharging the reservoir capacitor during the off time. The MAX1687 lets the user set the maximum battery current. The MAX1688 samples the output-voltage droop and automatically adjusts the peak inductor current to minimize battery drain, all while charging the output capacitor within the GSM timing cycle.

The MAX1687/MAX1688 require no external FETs, and their internal synchronous rectifiers boost efficiency to over 90% while eliminating the need for external Schottky diodes. Package options include standard 8-pin SOs and small 16-pin TSSOPs (which are less than 1.1mm high). An evaluation kit (MAX1688EVKIT), preassembled with recommended external components, is available to reduce design time. Prices start at $2.20 (1000 up, FOB USA).



NEW PRODUCTS

High-accuracy bias supply enables use of low-cost color ECB LCDs

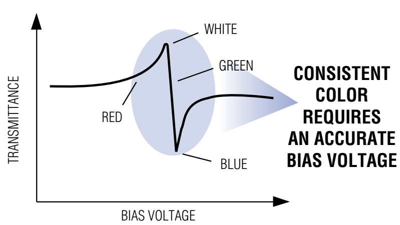
The MAX1729 step-up DC-DC converter is designed to drive a type of color LCD that exhibits electrically controlled birefrigence (ECB). ECB LCDs provide low-cost color displays with minimal battery drain for cell phones, PDAs, and other small hand-held devices. The ECB display also requires an accurate temperature-compensated bias voltage.

The MAX1729 provides a high-accuracy bias voltage (within ±1%) and a precise on-chip temperature monitor that ensures consistent color and contrast in the display as the temperature and input voltage vary. The device includes a low-power boost converter that draws only 60µA of quiescent current, followed by a low-dropout linear regulator that minimizes noise and ripple, an accurately adjustable output voltage, and a temperature sensor that allows the display controller to match the display's color and temperature characteristics.

An evaluation kit (MAX1729EVKIT), preassembled with recommended external components, is available to reduce design time.

The MAX1729 is available in a tiny, 10-pin, 1.09mm high µMAX package that is half the size of a standard 8-pin SO. Prices start at $2.45 (1000 up, FOB USA).

MAX1729
ECB COLOR vs. VOLTAGE



Tiny switcher for low-voltage logic supply surpasses LDO regulators

The MAX1692 is a step-down DC-DC converter that capitalizes on the trend toward lowering core-logic supply voltages—for example, from +3.3V down to +2.5V and +1.8V. This trend should extend the battery life in portable equipment by reducing power consumption, but the frequent use of low-dropout (LDO) regulators for this purpose actually wastes energy in the form of heat and dissipated power within the LDO. The compact, high-efficiency MAX1692 avoids this power loss while delivering up to 600mA from regulated outputs as low as 1.25V.

In stepping down the nominal 3.6V of a Li-ion battery (to 1.8V at 500mA in a cell phone), the maximum possible efficiency for a perfect LDO is the ratio of output to input, i.e., 50%. To deliver 900mW of output power, the LDO must dissipate 900mW as heat. Under the same conditions, the MAX1692 has 90% efficiency and dissipates only 90mW—an improvement of 10:1.

The MAX1692 requires no external FETs and comes in a tiny, 10-pin, 1.09mm high µMAX package that is half the size of a standard 8-pin SO. It employs an internal synchronous rectifier to eliminate an external Schottky diode and achieves efficiencies as high as 95%. Its high switching frequency (750kHz) allows use of a very small inductor, running in the fixed-frequency PWM mode for lowest noise or in Idle Mode™, which reduces the no-load quiescent current to only 85µA. A logic-level shutdown further reduces the supply current to 0.1µA.

An evaluation kit (MAX1692EVKIT), preassembled with recommended external components, is available to help speed designs. Prices start at $2.40 (1000 up, FOB USA).

Idle Mode is a trademark of Maxim Integrated Products.

Compact DC-DC converter generates main supply and 28V LCD bias

The MAX1677 is a dual-output DC-DC step-up converter that delivers up to 350mA from the main output (either 3.3V or adjustable from 2.5V to 5.5V), plus an adjustable secondary output that delivers an LCD bias (either positive or negative, up to 28V) from 1- or 2-cell battery inputs. The resulting power system—compact and highly integrated—is well suited for battery-powered hand-held devices such as PDAs and GPS receivers.

The MAX1677 requires no external FETs and employs an internal synchronous rectifier that eliminates a Schottky diode and boosts efficiency as high as 95%. The device has two operating modes: a 300kHz, fixed-frequency PWM mode for lowest noise in wireless applications, and a low-current PWM mode whose low quiescent current (30µA) extends battery life. Logic-level shutdown allows the LCD regulator to be shut down independently of the main supply. When both regulators are off, the quiescent current drops to below 1µA.

A polarity-control input lets the user configure the LCD regulator for positive or negative outputs up to 28V. This output is useful for high-voltage, low-current requirements such as LCD bias or varactor tuning. Also included is a precision reference and an uncommitted comparator, which are useful as a low-battery detector or as a reset.

An evaluation kit (MAX1677EVKIT), preassembled with recommended external components, is available to reduce design time.

The MAX1677 comes in a 16-QSOP package that occupies no more space than that of a standard 8-pin SO. Prices start at $3.25 (1000 up, FOB USA).

NEW PRODUCTS

Step-down controller for notebook CPUs has digital control

The MAX1711 step-down controller, intended as a DC-DC converter for the core CPU in notebook computers, offers ultra-fast transient response, high DC accuracy, and the high efficiency needed in leading-edge CPU power supplies. Maxim's proprietary quick-response, constant-on-time control scheme (QUICK-PWM™) handles wide ratios of input/output voltage with ease and maintains a relatively constant switching frequency while providing a 100ns "instant-on" response to load transients.

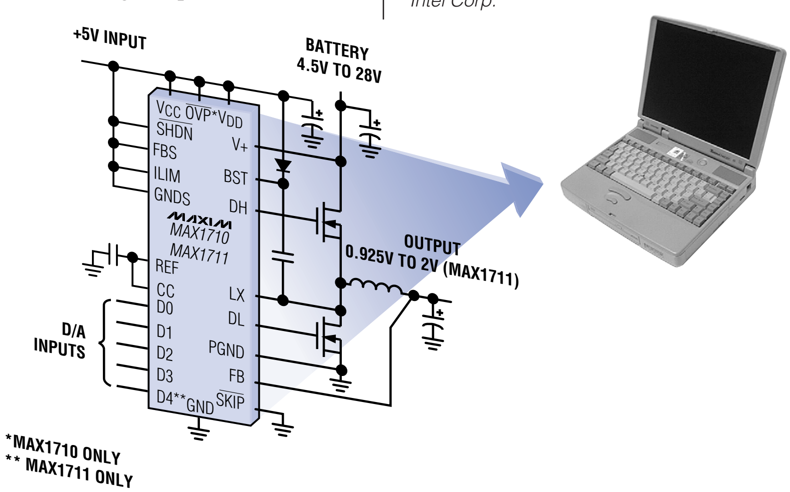
DC precision is ensured by a 2-wire remote-sensing scheme that compensates for voltage drops in the supply rail and the ground bus. An internal 5-bit DAC sets the output voltage in accordance with specifications of the Mobile Pentium II® CPU. The output-adjust range is 0.925V to 2V, and the reference-voltage output is 2V ±1%.

The MAX1711 achieves high efficiency at reduced cost by eliminating the current-sense resistor found in traditional current-mode PWMs. Efficiency is further enhanced by its ability to drive very large synchronous-rectifier MOSFETs, made possible by powerful internal gate drivers with anti-shoot-through circuitry.

By stepping down high battery voltage directly, the MAX1711's single-stage buck conversion enables the highest possible efficiency. As an alternative, you can achieve the minimum physical size by employing a higher switching frequency and by stepping down the +5V system supply instead of the battery—making it a two-stage conversion. The internal switching frequency is pin-programmable up to 550kHz, allowing the use of small, low-profile resistors and capacitors. The MAX1711 is available in a small 24-pin QSOP package, with prices starting at $3.89 (1000 up, FOB USA).

QUICK-PWM is a trademark of Maxim Integrated Products.

Mobile Pentium II is a registered trademark of Intel Corp.

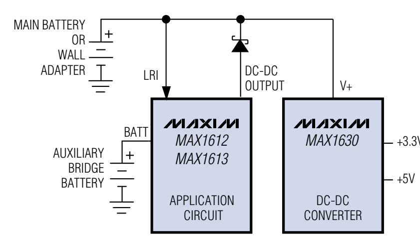


Backup controllers charge bridge batteries in notebook CPUs

The MAX1612/MAX1613 controllers charge the bridge battery (also called a hot-swap or auxiliary battery) in a notebook computer or other portable system. By boosting the 2- or 3-cell voltage of a bridge battery to the same level as the main battery, an internal, step-up DC-DC converter reduces the number of cells otherwise required for diode-OR bridging schemes. The ICs accept supply voltages in the +4V to +28V range and draw quiescent supply currents of only 18µA.

The ICs differ only in their preset, linearly regulated output voltage: 5.0V for the MAX1612 and 3.3V for the MAX1613. Both include a trickle-charge timer that minimizes the battery damage caused by constant charging. Once the bridge battery is topped off, this timer eliminates the drain of trickle-charge current from the main battery. The ICs also include a high-precision, low-battery-detection comparator and a micropower linear regulator that is useful for RTC/CMOS backup and for powering a microcontroller.

The MAX1612/MAX1613 come in 16-pin QSOP packages, with prices starting at $2.89 (1000 up, FOB USA).



Robust switch debouncers handle ±15kV ESD without external components

The MAX6816/MAX6817 single/dual switch debouncers provide a clean interface between mechanical switches and a digital system. By introducing a short preset qualification delay between a bouncing input and the digital output, they remove both the switch-opening and switch-closing bounces.

The robust switching-signal inputs handle voltage levels to ±25V and are also ESD-protected to ±15kV, making them ideal for use in harsh industrial and automotive environments. Both devices operate on a single +2.7V to +5.5V supply, and their low quiescent supply currents (6µA) make them suitable for interfacing µPs to noisy mechanical and membrane switches in portable applications. Undervoltage-lockout circuitry ensures the correct output state at power-up.

The MAX6816 is available in a 4-pin SOT143 package, and the MAX6817 is available in a 6-pin SOT23 package. Prices start at $0.99 for the MAX6816 and $1.48 for the MAX6817 (2500 up, FOB USA).

NEW PRODUCTS

Supervisors monitor trip thresholds down to 1.6V

The MAX6332–MAX6337 µP supervisors are designed to monitor supply rails of 1.8V to 3.3V in µP and digital systems. The devices reduce cost and increase circuit reliability by eliminating external components and adjustments. The MAX6335/MAX6336/MAX6337 also include a debounced manual-reset input. Their supply currents are only 3.0µA.

The MAX6332–MAX6337 assert a reset signal whenever V_{CC} declines below a preset threshold, and they maintain the signal for a preset interval after V_{CC} returns above the threshold (or until the manual reset is deasserted). The parts differ only in their output structures: the push/pull (MAX6333/MAX6336) and open-drain (MAX6334/MAX6337) devices have an active-low $\overline{\text{RESET}}$ output, while the push/pull (MAX6332/MAX6335) devices have an active-high RESET output. (Power-on resets are available in pulse widths of 1ms, 20ms, and 100ms.) The MAX6332/MAX6333 and MAX6335/MAX6336 are guaranteed valid for V_{CC} down to 0.7V; the MAX6334/MAX6337 are guaranteed valid down to 1.0V.

The internal reset comparators are designed to ignore fast transients on V_{CC}. Their factory-trimmed reset thresholds vary in approximate 100mV increments from 1.6V to 2.5V, resulting in a family of 30 standard versions (minimum order 2500 pieces). For availability of nonstandard versions (minimum order 10,000 pieces), please contact the factory. The MAX6332/MAX6333/MAX6334 come in 3-pin SOT23 packages, and the MAX6335/MAX6336/MAX6337 come in 4-pin SOT143 packages. Prices start at $0.98 for the MAX6332/MAX6333/MAX6334 and $1.05 for the MAX6335/MAX6336/MAX6337 (2500 piece minimum, FOB USA).

Integrated IrDA and RS-232 transceivers save space and power in hand-held apps

The MAX3130/MAX3131 transceivers integrate an IrDA and RS-232 interface for portable and low-power applications. Both devices save valuable board space by integrating an infrared (IR) transceiver, IR encoder/decoder (ENDEC), charge pump, and RS-232 interface into one surface-mount package. The infrared transceiver is IrDA 1.2-compatible, supporting data rates of 2.4kbps to 115kbps. The RS-232 interface includes two drivers and two receivers that support data rates up to 120kbps.

Both devices consume 370µA in normal operation and only 1µA while in shutdown (with RS-232 receivers active). Their low-dropout transmitters and proprietary high-efficiency, dual-charge-pump power supplies combine to deliver true RS-232 and IrDA performance from a single +3.0V to +5.5V supply. The IR transmitter includes a high-power LED driver capable of delivering 200mA, and the IR receiver includes a high-gain, low-noise PIN-diode amplifier that rejects 200µA of ambient DC current. The internal ENDEC enables communication with non-IrDA UARTs by stretching and compressing signals that pass between the IR transceiver and the UART.

The MAX3130, whose IR-transmitter input and receiver output are multiplexed with one RS-232 transmitter input and receiver output, is optimized for applications using one UART for both IR and RS-232 communications. The MAX3131's IR and RS-232 transceivers have separate data lines for input and output. Both devices are available in 28-pin SSOP packages, with prices starting at $4.53 (1000 up, FOB USA).

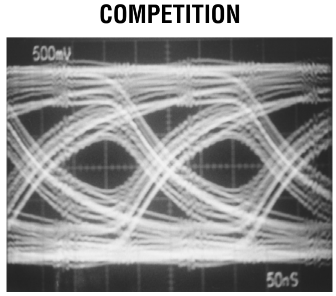
Internal preemphasis enhances RS-485/RS-422 Tx performance

The MAX3291/MAX3292 data transceivers include driver-preemphasis circuitry that extends the maximum distance for reliable communications by reducing the intersymbol interference caused by long cables. The MAX3291 is optimized for a 10Mbps data rate, and the MAX3292 data rate can be set in the 38.4kbps to 10Mbps range by programming the preemphasis interval with a single external resistor.

Both are full-duplex devices. They operate from a single +5V supply and feature a shutdown mode that reduces the supply current to 100nA. Other features include driver-output short-circuit current limiting and a fail-safe receiver input that guarantees a logic-high output when the input is an open circuit. The transceivers' receiver-input impedance ($^1/_4$ unit load) allows up to 128 transceivers on a single bus.

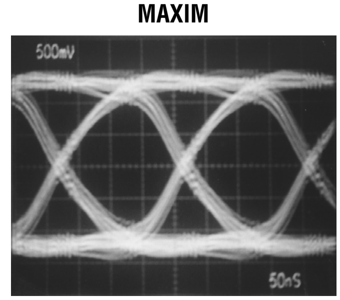
The MAX3291/MAX3292 are available in 14-pin DIP and SO packages, with prices starting at $2.70 (1000 up, FOB USA).

COMPETITION



'75180 Transceiver (no preemphasis) Driving 1000-foot Cable at 5Mbps

MAXIM



MAX3291/MAX3292 (featuring preemphasis) Driving 1000-foot Cable at 5Mbps

NEW PRODUCTS

Monolithic buffer amps replace 15 discrete components

The MAX2470/MAX2471 monolithic buffer amplifiers offer high isolation, low cost, and ease of use. Designed to replace equivalent discrete-component circuits, each 6-pin SOT device replaces 15 components in a comparable discrete design.

Providing 15dB gain, 64dB isolation, and -29dBc harmonic suppression at a -5dBm differential output, these devices are well suited for protecting discrete and module-based VCOs from the common problem of load-impedance variations. They also eliminate bulky passive transformers when used as an active balun.

The MAX2470 has a single-ended input and a user-selectable frequency range to save current: 10MHz to 200MHz (3.6mA) or 10MHz to 500MHz (5.5mA). The MAX2471 has a differential input and a frequency range from 10MHz to 500MHz. Both have differential 50Ω outputs capable of driving either a 100Ω differential load or two 50Ω single-ended loads; this makes them ideal for applications that require the oscillator to drive two circuits simultaneously, such as a PLL or transmit and receive mixers.

The MAX2470 operates from a single supply of +2.7V to +5.5V, drawing only 5.5mA in the high-frequency range and 3.6mA in the low-frequency range. The MAX2471 has the same supply range and draws 5.5mA. Both are available in an ultra-small 6-pin SOT23 plastic package. Prices start at $0.75 (1000 up, FOB USA).

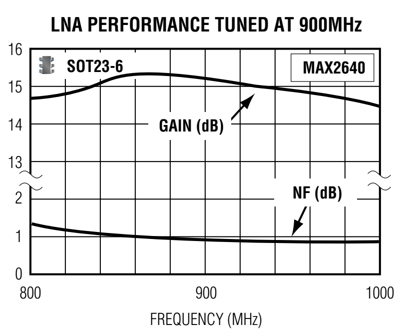
3V, ultra-low-noise SiGe amps operate to 2.5GHz

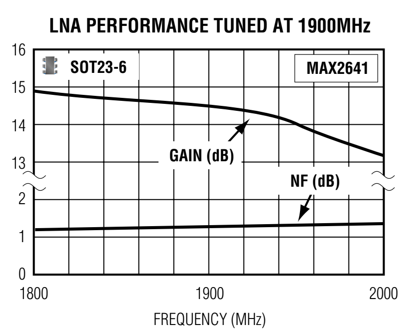
The MAX2640/MAX2641 are broadband, low-noise amplifiers designed for applications in the cellular, PCS, GPS, and 2.4GHz ISM-frequency bands. Powered by a single +2.7V to +5.5V supply, they operate from 400MHz to 2500MHz while drawing quiescent currents of only 3.4mA. Applications include cellular/PCS and cordless phones, GPS receivers, and wireless LANs.

The MAX2640 is optimized for applications in the 400MHz to 1500MHz range, with a typical gain of 15.1dB and a noise figure of only 0.9dB at 900MHz. The MAX2641 is optimized for applications from 1400MHz to 2500MHz, with a typical gain of 14.4dB and a noise figure of 1.3dB at 1900MHz. For GPS applications at 1575MHz, the MAX2641 provides 15.7dB gain and a 1.2dB noise figure. For 802.11 WLAN applications at 2450MHz, the MAX2641 provides 13.5dB gain and a 1.5dB noise figure.

These amplifiers have an internal bias that eliminates the need for external bias resistors. The only external components required in a typical application are the input and output blocking capacitors and a V_{CC} bypass capacitor.

The MAX2640/MAX2641 are available in ultra-small SOT23-6 packages, with prices starting at $0.80 (1000 up, FOB USA).





Wideband SiGe downconverter mixers operate from 400MHz to 2.5GHz

The MAX2680/MAX2681/MAX2682 low-cost, miniature downconverter mixers are designed for low-voltage operation. Featuring a low noise figure and a high input third-order intercept point (IIP3), they are ideal for use in portable communications equipment. They employ double-balanced mixers to downconvert a 400MHz to 2.5GHz RF frequency range to a 10MHz to 500MHz IF frequency range.

The mixers require a single +2.7V to +5.5V supply, which allows direct operation from a single lithium cell or a 3-cell NiCd battery. Supply current is constant over the specified range of supply voltage, and each device has a low-power shutdown mode that reduces the supply current below 1µA. To optimize receiver dynamic range, the mixers come in multiple versions offering various combinations of supply current, conversion gain, and input IP3 (see Maxim's *Product Selector Guide*).

The MAX2680/MAX2681/MAX2682 are designed on an advanced high-frequency, low-noise, silicon-germanium process. They are available in 6-pin SOT23 packages, with prices starting at $0.92 (1000 up, FOB USA).