analog dialogue

MULTIFUNCTION BREAKTHROUGH – ANALOG IC COMPUTES $Y(Z/X)^M$, etc. (page 3)

Low-Cost V/F Converter in Plastic Mini-DIP: +5-V Operation, up to 500 kHz FS (page 10)

Double-Buffered 14-Bit Monolithic CMOS MDAC: Monotonic over Temperature (page 14)

24 × 24-Bit Fixed-Point CMOS Digital Multiplier (page 8)

OUTPUT = Y

▷ **ANALOG DEVICES**

Editor's Notes
TWENTIETH ANNIVERSARY

In 1985, Analog Devices observes the twentieth anniversary of its founding. It has been a period of our leadership in products and technologies, of growing business and financial success, and a time in which our teams of creative and productive engineers, scientists, and many others worldwide have come together and recognized, in the results of their combined efforts, their marks as individuals.

But above all, it has been a time in which ADI's efforts have been central to the forward march of science and technology. No one knows better than the readers of this Journal that our products (components in particular), though small and not outwardly differentiated, are apt to be found at the heart of everything important in measurement and control—from CAT scanners to process industry, from measuring instruments to arc welders, from tractors to seismographic equipment. It has been an exciting time.

But what of the future? The growth of Analog Devices to this point must seem a hard act to follow. Is it possible to continue to innovate, to grow, to deal with the issues that arise in the larger enterprise that we have become? And what about the external issues: For us, our customers, and our competitors (especially within the U.S.A.), the clouds loom large and black on the horizon. You name it, there are problems: the challenges of international competition—and the corresponding threat of parochial protectionism; national (and individual) deficit financing; social and political ferment; inflation (momentarily quiescent)—and the threat of deflation; the aforementioned challenges of peace—and the threat of wars (nuclear and otherwise). . .

There's not much to say about these global issues that hasn't been propounded at much greater length and with incredible diversity of views by people with much more wisdom than our small share, but in the more than one-half century we have been observing this world, there always seem to have been vexing and insoluble problems. Yet somehow, practical people—from farmers to engineers to bus drivers to business men and women, to politicians—doing what they do best, have managed to muddle through and to manage change. Furthermore, to many, planning to solve the problems of the individual, the family, the work unit, and the community often seems far more immediate, manageable, and productive than worrying about the global problems that batter us daily in lurid newspaper headlines and the grim theatre of TV news.

As to the future prospects for Analog Devices, it pays to examine our past, because—in the words of the poet—"What's past is prologue." It is hard to lose habits, especially good ones—such as innovation, entrepreneurship, growth, planning, looking at things through the customer's eyes, getting the best people and eliciting their best efforts (whether in design engineering, processing, applications, sales and marketing, finance, or human resources), and building up momentum. These have been the keys to our sustained growth in the past 20 years, and there is no reason that they will not be key to comparable growth in future years—despite the many global questions that seem so troubling today. ▶

Dan Sheingold

ADI AUTHORS

Lew Counts (page 3) is a Division Fellow at Analog Devices Semiconductor (ADS). A complete biographical sketch and photo appear in a recent issue, *Analog Dialogue* 18-1, page 29.

Mike Curtin (page 14), an Applications Engineer at Analog Devices BV, in Limerick, Ireland, is a B.Sc. graduate of the National Institute of Higher Education in Limerick. Before joining Analog Devices, he was a design engineer with Moog GmbH (Stuttgart) and a project engineer at N.I.H.E.

David Fair (page 8) is a Marketing Specialist in the DSP Division at Analog Devices. He has a BA in physics from Pomona College (Claremont CA) and a Ph.D. in the philosophy of mathematics, logic, and physics from Princeton University. Before joining ADI, he worked at the Strategic Planning Institute, in Cambridge MA, and taught at the University of Vermont, Burlington. David's leisure-time activities include hiking, cycling, jogging, and windsurfing.

Kathryn Kasper (page 13) is a Marketing Engineer with ADI's Interface Products Division. She has an SM in Management from M.I.T. and a BES in Chemical Engineering from the Johns Hopkins University—and she is now working toward an MSEE at Northeastern University. Kathryn joined Analog Devices in 1984 as a Marketing Analyst in Corporate Strategic Information and recently moved to her current assignment.

Chuck Kitchin (page 3) is a Technical Support Specialist at Analog Devices Semiconductor. For the past nine years, he has designed IC application circuits and assisted in product development at ADS. Holder of an ASEE from Wentworth Institute, and now attending the University of Lowell, he previously worked for Kybe Corp. and radio stations WMEX and WCRB (Boston). Chuck's leisure activities include jogging, astronomy, and wine tasting. A photo of Chuck can be found in a recent issue, *Analog Dialogue* 18-1, page 29.

COMPLETE MONOLITHIC ANALOG MULTIFUNCTION CHIP
AD538 Embodies Y(Z/X)^M with High Performance and Wide Dynamic Range
Performs Multiplication, Division; Computes Powers, Roots, Logs, Antilogs

by Lew Counts, Charles Kitchin, and Steve Sherman

The AD538* is a Real-Time Analog Computational Unit (ACU) in an 18-pin DIP. It performs the function,

$$\text{OUTPUT} = Y \left[\frac{Z}{X} \right]^M \qquad (1)$$

where the OUTPUT is a positive voltage and the variables, X, Y, and Z, represent inputs in the form of positive voltage or current. The AD538 can be used for multiplication and division (simultaneously), powers and roots, logarithms and antilogarithms. Its repertoire of analog computing operations makes the device useful in ratio measurements, signal conditioning, linearization, measurement of energy and stochastic quantities, and control.

The AD538's versatility is the serendipitous result of a quest for a monolithic analog division circuit that could accurately compute ratios over a wide dynamic range of denominator values; indeed, this is its most important application. With a 1000:1 dynamic range ($V_z = V_x = 10$ mV, $V_y = 10$ V, $V_o = 10$ V), the maximum total error (AD538B) is only 2.5% of output – with no external trims.

Conventional IC analog multipliers, configured and optimized for division, have yet to achieve even the modest 100:1 dynamic range specification that might be considered practical for many divider applications; for example, the premium AD535K* (*Analog Dialogue* 12-2, 1978) is specified to have maximum total error of 2% over a 50:1 dynamic range of denominator input, with no external trims.

Besides overcoming the dynamic-range limitations of dividers based on multipliers, the AD538 has low input offsets (100 μV or less) and low noise, essentially proportional to output for outputs above 10 mV; for 1-volt output in a 1-kHz bandwidth, peak-to-peak output noise is about 1.4 mV. In addition to performing one-quadrant multiplication, it can also be configured for division in two quadrants, i.e., a bipolar numerator by a unipolar denominator; and it can calculate a wide range of powers or roots, whether positive (direct) or negative (inverse), integer or fractional (for example, 2.25, ½, −2). With feedback, it can be configured to perform rms and vector operations.

Though generally similar in function—and many of its applications—to the Model 433* module (see *Analog Dialogue* 6-2 (1972) and Chapter 3-6 of the *Nonlinear Circuits Handbook*[1]), the AD538 is considerably more versatile and much lower in cost. Figure 1 is a combined block diagram and pinout of the AD538; it comprises five precision op amps—laser-trimmed to less than 100 μV of offset voltage, an accurate reference source (configurable for + 10V or + 2V), and an error-corrected computing core. Functionally, the device is disposed into a *log-ratio* section, an *antilog* section, and a *voltage reference*. High performance, with the high-yield bipolar process employed, is the result of advanced circuit design and a thermally balanced chip layout.
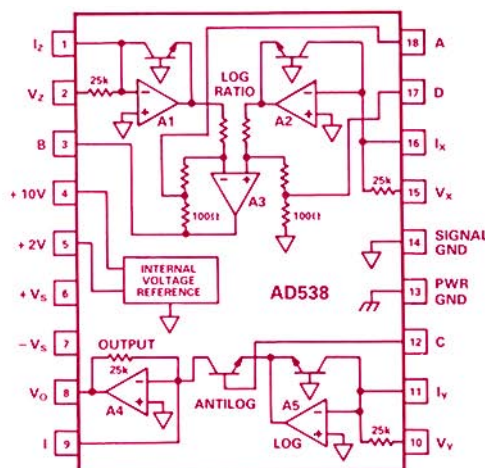

Figure 1. Block diagram and pin connections of the AD538.

Functions are determined by the choice of inputs and appropriate connections of the device's pins. In some cases, one or two external resistors will be required. In addition to the overall transfer function, the constituent log-ratio and antilog functions—and the reference—are available for independent use.

*For technical data, use the reply card.
[1]See REFERENCES on page 6.

CHARACTERISTICS

Although its sub-functions can be used independently, the AD538 is designed and specified as a complete analog computing system, with overall performance specified for both voltage and current inputs. Its dynamic range is 80dB for voltage signals—from 1mV to 10V, and its current input range is 0.1 to 400μA (72dB).

For flexibility, the summing junctions at the inputs of four of the five amplifiers are accessible for external connections. This makes it possible to sum several signals—including feedbacks and signals from current sources—into the same input terminal, and to add offsets or change the scaling for input voltages.

The wide range of dual power-supply voltages that can be used—from ±18 volts to ±4.5 volts—gives the user many options, including standard ±15-volt supplies, the increasingly popular ±12-volt supplies, and even ±5 volts (employing the 2-volt reference connection).

Multifunction devices that nominally perform the $Y(Z/X)^M$ function have been on the market since 1972, in the form of modules and—later (in less-complete form)—hybrids. The AD538 is the first monolithic IC on the market to perform this function. As Table 1 indicates, though monolithic, it sacrifices neither performance nor completeness—and in fact adds some hitherto unavailable features.

	Monolithic IC (AD538B)	Hybrid IC	Module (433)
Max error (as a multiplier)			
100:1 dynamic range	±0.5% of output ±250μ V^A	50mV^B	50mV^A
0 to 10V wide range^C	±1.0% of output ±250μ V^A	N/S	N/S
Max bandwidth	400 kHz	500 kHz	100 kHz
Internal reference voltage	10 V, 2 V	N/A	9 V
Supply voltage range	±4.5 V to ±18 V	±12 V to ±18 V	±12 V to ±18 V
Upper limit	±18 V	±18 V	±18 V
Lower limit	±4.5 V	±12 V	±12 V
Supply current	4.5 mA	10 mA	10 mA
Package	18-pin DIP (IC)	14-pin (.8″×.5″)	1.5″×1.5″×.62″

NOTES
^A With NO external trims
^B With 3 external trims
^C See Equation 10

Table 1. Examples of salient features of multifunction device technologies.

HOW IT WORKS

Logarithm

The upper portion of the circuit shown in Figure 1 computes the logarithm of the ratio of inputs Z and X. The inputs may be either current (I_z and I_x), voltage (V_z and V_x), or any combination. Voltage inputs, applied at the V_z and V_x terminals, are converted to current by the (nominally) 25 kΩ resistors; the resulting currents, flowing through the feedback transdiodes, develop logarithmic voltages at the outputs of A1 and A2. The difference between the output voltages, taken by subtractor A3, is proportional to the logarithm of the ratio of the input voltages. The output of A3 is available at pin 3, labeled "B".

$$V_B = \frac{kT}{q}\ln I_z - \frac{kT}{q}\ln I_x = \frac{kT}{q}\ln\frac{V_z}{V_x} \qquad (2)$$

k is Boltzmann's constant, q is the charge on an electron (k/q = 86.17μV/K), and T is absolute temperature in kelvins (°C + 273.2K). At T = 300K (26.8°C), V_B = 25.85mV for each power of ϵ, or 59.52mV per decade. This voltage constitutes a basic logarithmic output; however it would be useful: to scale the 60-millivolt output to a more convenient level, to compensate for the 86μV/K (or 3,330 ppm) temperature sensitivity

(dV_B/dT = 86.17μV/K), and to buffer the output. This can be readily done, as will be seen in the Applications section.

Antilogarithm

For multiplication and division, it is necessary to add a voltage representing the logarithm of V_y or I_y and take the antilogarithm, or exponential. This operation is performed in the lower portion of Figure 1. The total input current at the summing point of amplifier A5, determined by V_y, I_y, and/or any additive currents from sources wired to that point, flows through the feedback transdiode and develops a negative voltage at the output of A5 proportional to the logarithm of that current.

Amplifier A4 is connected to perform a current-to-voltage conversion, which results in an antilogarithmic operation. With C (pin 12) grounded, and no offset current added at 1 (pin 9), the output voltage will be equal to the effective Y-input voltage (all currents at I_y referred to V_y). When C is connected to the log-ratio output of A3 (B), its positive voltage is summed in series with the transdiode base-emitter voltage drops, and A4 performs the balancing operation (inputs and outputs of this section referred to V_y and V_o):

$$V_C + \frac{kT}{q}\ln\frac{V_y}{V_o} = 0 \qquad (3)$$

therefore,

$$\frac{qV_C}{kT} = \ln\frac{V_o}{V_y} \qquad \text{and} \qquad V_o = V_y\epsilon^{\frac{qV_C}{kT}}$$

V_C may be derived from an external voltage for direct antilogarithmic operations; however, in the case of multiplication and division, since $V_C = V_B$ and, from (2),

$$V_B = \frac{kT}{q}\ln\frac{V_z}{V_x} \quad (4) \qquad \text{then} \qquad V_o = V_y\frac{V_z}{V_x} \quad (5)$$

Powers and roots

If the output of A3 is amplified (by connecting resistance between terminals A and D to attenuate its feedback), or attenuated (by connecting a voltage divider between B and C), the gain or attenuation of the log signal affects the exponent of the (Z/X) term. If M is the multiplication factor of the resistor-programmed gain or attenuation, Equation (4) becomes

$$V_C = MV_B' = M\frac{kT}{q}\ln\frac{V_z}{V_x} \qquad (6)$$

where V_B' is the voltage at B when M = 1. Thus, Equation (1), expressed in voltage, is:

$$V_o = V_y\left[\frac{V_z}{V_x}\right]^M \qquad (7)$$

When the AD538 is used for two-variable analog division (ratios)—or powers and roots—the V_y input is used to set a convenient scale factor. Amplifier A4 buffers and scales the antilog section output. The output amplifier's summing junction has been made available to provide for offsetting or external trimming of the output stage—and to allow direct connection of the log-ratio section to this stage, thus permitting it to provide the amplified, buffered output of a straight log amplifier.

Reference

At pins 4 and 5 are output voltages from a stable (15ppm/°C typical) bandgap voltage reference, provided to eliminate the need for an external source of the necessary reference voltages. The reference portion of the AD538 makes available +10 volts (buffered) and +2 volts at the tap of a 5:1, 20-kΩ laser-trimmed voltage di-

vider (3,200-ohm nominal output resistance). Amplification of the 1.2-V bandgap voltage is determined by the resistance ratio. If 10-volt output is not desired (for example, in operation on ±5-volt power supplies), a buffered 2-volt reference may be obtained by jumpering pins 4 and 5 together.

APPLICATIONS

The following circuits show the basic connection modes for the AD538 and may suggest a variety of uses.

Multiplier
Figure 2 shows the basic connections for multiplication. B is connected directly to C, (i.e., M = 1), and the reference voltage is connected as V_x. If the 10-volt reference is used, the output is $V_o = V_y V_z / 10V$.
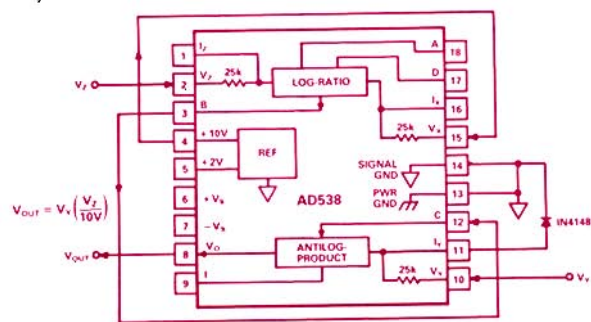

Figure 2. Basic connection for multiplying two voltages.

One-Quadrant Divider
Figure 3 shows the basic connections for division. B is connected directly to C and M is set to 1.0; the reference voltage is connected as V_y. If the 10-volt reference is used, the output voltage becomes $V_o = 10V V_z / V_x$.
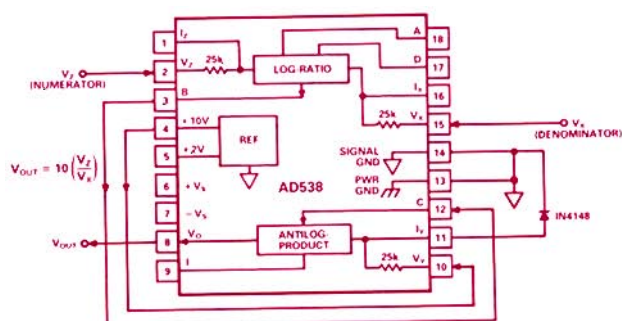

Figure 3. Basic connection for dividing two variables.

As a divider with 10-volt scaling, the AD538 has a −3-dB bandwidth of about 370kHz for 1 to 10-volt levels; at lower amplitudes, the bandwidth decreases gradually to about 200kHz at the 2-millivolt input level. The input dynamic range is approximately 74dB, from the 2-mV noise threshold to the 10-volt + clipping level. Figure 4 compares the performance of the AD538 as a divider with a typical contemporary multiplier-type divider.

High-Performance Multiplier-Divider
Figure 5 shows how the AD538 is configured as a high-performance one-quadrant multiplier/divider, to compute the three-variable function, $V_y V_z / V_x$. Conventional 4-quadrant analog multipliers cannot handle three variables, and—as noted earlier—are all but unusable with denominators having wide dynamic range.

The circuit has a typical bandwidth of 400kHz for values of V_x varying over a 100:1 range, from 100mV to 10 volts. The maximum error, over a 0 to 10-volt range for the other two variables, will be approximately ±0.5% of reading. With the external
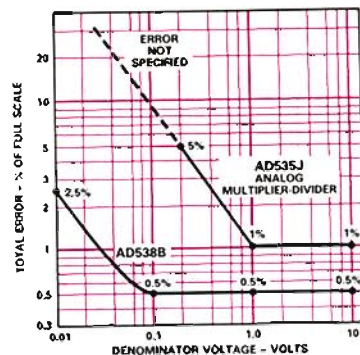

Figure 4. Comparison of division errors in the AD538 and the AD535, when connected for division.

scale-factor and the offset-trim scheme shown in Figure 5, the error can be reduced to ±0.25% of reading. The offset trim current is summed at the I_z input. This scheme may be used for any of the AD538 applications, and offset trim currents may be applied to any of the current-summing inputs for optimizing particular modes of operation.
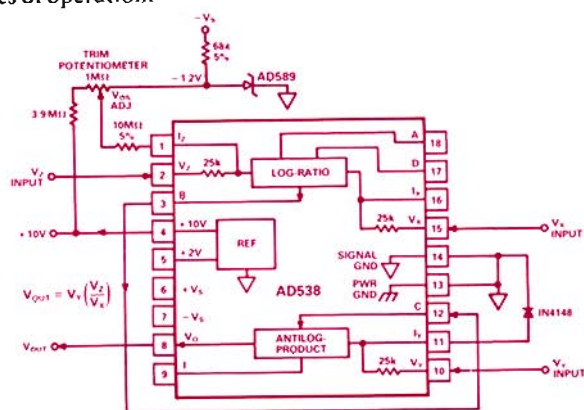
Figure 5. Connection of the AD538 for multiplication and division (YZ/X), with offset trim for improved accuracy.

Division with 2-Quadrant Numerator
Figure 6 shows how the AD538 divides a numerator that can swing positive or negative by a positive denominator voltage. To insure that the current flowing through the "Z" transistor is positive, the numerator and denominator voltages (Z and X) are translated to reduced currents (I_z and I_x) through external 34.8-kΩ resistors; the denominator is translated into an additional current that is summed into the numerator input, V_z, by its on-chip 25-kΩ

Figure 6. Basic connection for division with bipolar numerator.

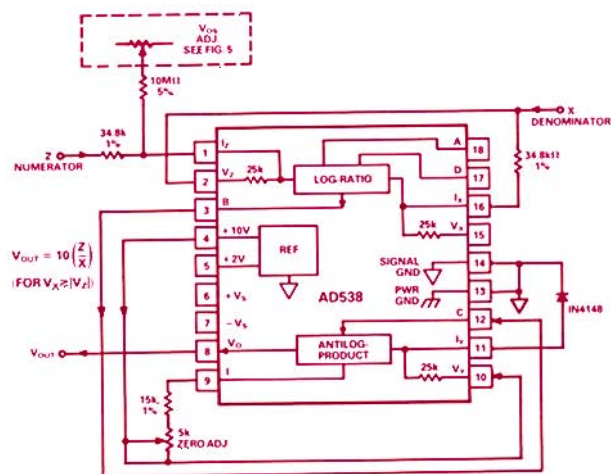resistor. As long as the magnitude of numerator signal, Z, is less than that of X, the current into the Z amplifier will be positive, with the signal inputs attenuated by a factor, A (= 25/34.8), relative to the additional numerator input. Thus,

$$V_{out} = V_y \frac{AZ+X}{AX} = V_y \frac{Z}{X} + V_y \frac{1}{A} \qquad (8)$$

With V_y constant, $V_y (1/A)$ is constant, and its dc value can be subtracted out—if desired—by summing an appropriate current into input I, pin 9. Trims provide cancellation.

Log Ratio

Figure 7 shows the basic connections for log ratio, using the log-ratio section and the output amplifier. An overall gain of 15.9 V/V is distributed to minimize errors contributed by the output amplifier: the gain is 5 in the input section and about 3.2 in the output section. The log-ratio output, at B, is connected to the summing junction of the output amplifier (I_o, pin 9) via a temperature-variable resistor consisting of two resistors in series—a 90.9-ohm, 1% metal-film resistor and a 1,000-ohm, +3,500 ppm/°C temperature-compensation resistor. Together, they have a resistance of 1,091 ohms with a 3,300 ppm/°C tempco. The nominal relationship (if the feedback resistance = 25,000 ohms) is
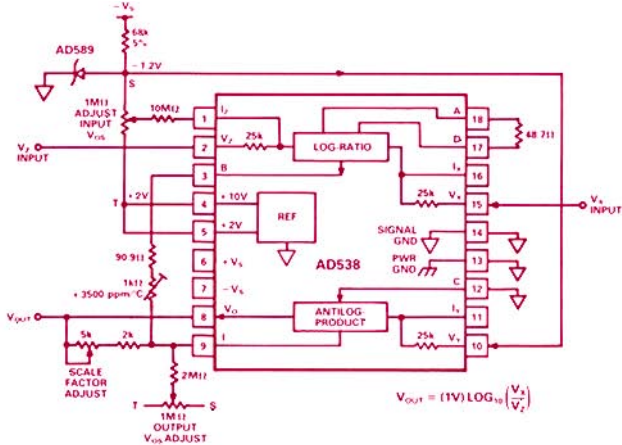
$$V_o = 1.0V \log_{10} \frac{V_x}{V_z} \qquad (9)$$

Figure 7. Connection for high-accuracy log ratio.

In order to minimize any influence from the V_y input, it should be returned to a small negative voltage. If a 1.2-volt AD589 is used to obtain regulated negative voltage (−1.2 V) for offset adjustment (as in the high-accuracy multiplication circuit of Figure 3), V_y can be tied back to − 1.2 volts.

Powers, Including Roots

Often it is necessary to raise a quantity, which may be a ratio, to a power, which may be positive or negative, greater or less than unity, and either an integer or a mixed fraction. The AD538 offers a convenient way to achieve any positive or negative power, from 1/5 to 5, with the addition of one or two external resistors.

For powers less than 1 (i.e., *roots*), a simple voltage divider attenuates the log-ratio output in the connection between B and C, as shown in Figure 8. For powers greater than 1, the gain of the subtractor must instead be increased, by connecting resistance (R_A in the table of Figure 8) between points A and D to attenuate the subtractor's feedback. For negative powers, inputs Z and X are interchanged (but this works only if the Y input is not active—for convenience, it may be set at 1.0 volts). The resistances listed are the nominal resistance values specified for standard 1% metal-film resistors.

ERROR SPECIFICATIONS OF ANALOG DIVIDERS

Since there are many sources of error in a multifunction component, specifying each individually could, in concept, provide a means of determining the maximum error for any condition. However, it is often more useful to have a single *total error* specification that serves as an explicit predictor of performance in a particular configuration, such as division.
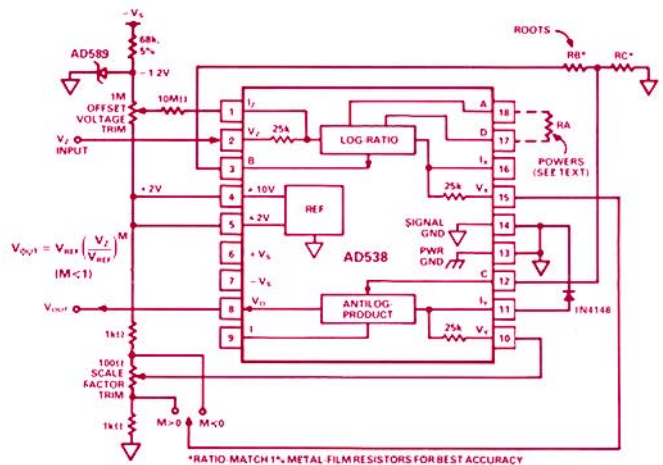
Total error, in the multiplier or divider mode, is the sum of three terms reflecting nonlinearity, output offset, and numerator offset:

$$1.0\% \text{ (reading)} + 250\mu V + \left[\frac{V_y + V_z}{V_x} \cdot 150\mu V \right] \qquad (10)$$

for V_y = 1mV to 10V, V_x = 10mV to 10V, and V_z = 0 to 10V.

The AD538A's 100:1 divider accuracy specfication is ±1% of reading ±500μV. The B-grade specification is ±0.5% of reading ±250μV. AD538 prices start at $17.00 in 100s (A-grade in an 18-pin DIP).

In many cases, the internally trimmed performance of the AD538 will be more than adequate for the application; but for the best possible dynamic range and accuracy, some form of external trimming should be used. Offset trims have already been discussed, in relation to Figure 5. Scale-factor trims can be implemented by adding variable resistance in series with (voltage) inputs Z or Y, to reduce gain, or X, to increase gain. This is yet another demonstration of the flexibility of the AD538. Figure 8 shows a way of implementing scale-factor trims for positive and negative roots.

Figure 8. Connections for raising to powers less than 1.0 (roots), with offset and gain trims; tables of resistance values for selected powers and roots.

POWERS > 1	
M	$R_A = \frac{196\Omega}{M-1}$
1.21	931Ω
2	196Ω
3	97.6Ω
4	64.9Ω
5	48.7Ω

POWERS <1 (ROOTS)		
M	R_B	R_C
1/2	100Ω	100Ω
1/3	100Ω	49.9Ω
1/4	150Ω	49.9Ω
1/5	162Ω	40.2Ω

$R_B + R_C \leq 200\Omega$

$\frac{R_B}{R_C} = \frac{1}{M} - 1$

REFERENCES

Counts, Lew, Charles Kitchin, and Steve Sherman, "One-Chip 'Slide Rule' Works with Logs, Antilogs for Real-Time Processing," *Electronic Design* (2 May 1985)

Counts, Lew, and Fred Pouliot, "Versatile New Module: Y[Z/X]^M at Low Cost," *Analog Dialogue* 6-2 (1972).

Sheingold, Daniel H., ed., *Nonlinear Circuits Handbook*. Norwood: Analog Devices, 1974 ($5.95). ▶

DUAL 12-BIT MICROPROCESSOR-COMPATIBLE DAC IN 0.3" DIP
AD7549 Is Double-Buffered, 12-Bit Monotonic over Temperature
Has Separate Reference Inputs, Performs 4-Quadrant Multiplication

WHAT IS IT?

The AD7549* consists of two 12-bit CMOS multiplying DACs sharing a common digital bus on a single monolithic chip, mounted in a 20-pin 0.3"-wide dual in-line plastic or ceramic package (it is also available in a 0.35" × 0.35" leadless chip carrier—LCC).

As Figure 1 shows, the DACs are double-buffered, and each is loaded via three 4-bit nybbles—a flexibility that permits the AD7549 to be used with any bus that has a width of 4 bits or more. The double-buffering scheme permits data to be loaded piecewise into either DAC's nybble registers in any order without affecting the DAC outputs; the DACs may then be updated individually at any time. In addition, a $\overline{UPD}$ control input permits both DACs to be updated simultaneously, and a CLR input makes it possible to clear all registers, setting the DAC outputs to zero, with one command.

The DACs, like the one employed in the single-channel AD7542,* are a pair of switched 12-bit R-2R ladders, generally used in the current-output configuration, i.e., connected to the summing point of an external inverting operational amplifier. Each has its own analog reference input that independently accepts dc or ac voltage, of either polarity, up to ±25 volts. This permits each DAC to function either as a fixed-reference DAC with positive or negative output—or as a digital gain control for analog signals. Feedback resistors, which track the ladder resistance, are furnished on-chip for connection to the outputs of a pair of external output op amps—for example, the AD644* dual FET-input op amp.

Not only do the feedback resistors track the ladder resistance; the ladder resistances of the DACs are matched to one another to within 3% maximum (typically 1%), and they tend to track with temperature; also, the gain errors of the two DACs tend to track with temperature. This is important for applications in which two identical DACs are needed.
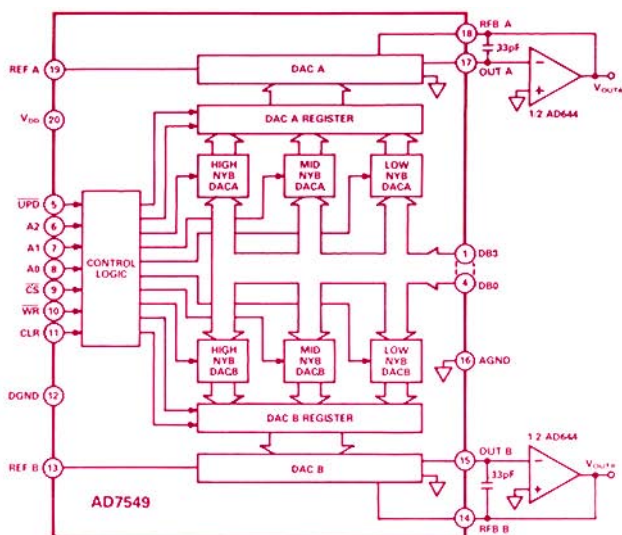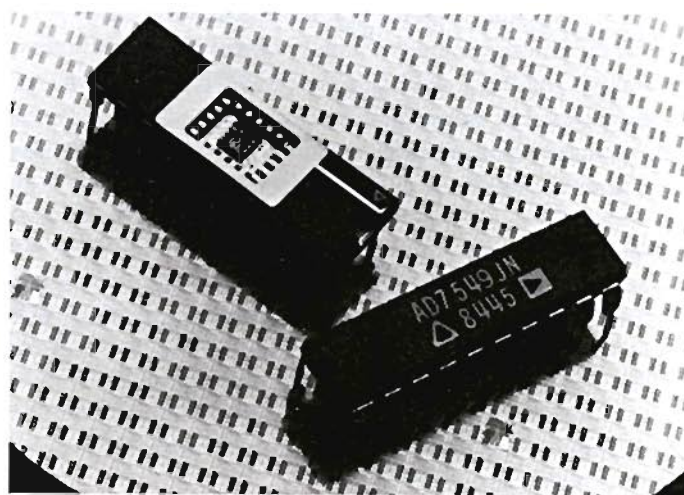

WHERE IS THE AD7549 USED?

There are many uses for dual DACs. They include: *programmable filters*—which can take advantage of the matching and tracking of the DAC pair's resistors in state-variable filtering; *automatic test equipment*—which generally needs DACs with at least 12-bit accuracy and a small footprint, so that many DACs can be concentrated in a small space; *microcomputer-based process control*—which relies critically on the DACs' monotonic behavior over the entire temperature range; *audio systems*—for example, digitally programmed gain control in 2-or-more-channel stereo, which requires the DAC to act as a pair of digitally controlled pots, having negligible distortion for the analog signal; *resolver applications*, which generally call for controllable paired (sine and cosine) operations; and *programmable (tracking) power supplies*.

The AD7549 is protected against latchup, and all grades are guaranteed monotonic over the full temperature range. Maximum full-scale error over temperature, including gain variation and leakage current, is 3LSBs for K/B/T grades and 6LSBs for J/A/S grades; relative accuracy error is ½ and 1LSB maximum for the same grades.

Channel-to-channel isolation is typically 62dB at 100kHz (20-V p-p sine wave), and digital crosstalk *impulse* (DAC output pulse with zero reference and the other DAC code stepped from all-0's to all-1's) is typically 10mV-μs. The AD7549 is speed-compatible with TTL, 74HC, or 5-volt CMOS logic levels; it dissipates 75 mW maximum when operated with a + 15-volt power supply.

The AD7549 is fabricated using a self-aligned polysilicon-gate process, or LC^2 MOS (Linear-Compatible CMOS); the benefits of this new process include lower device capacitance, more functions per unit area, and significantly improved speed characteristics. When two or more 10- or 12-bit DACs are required, the AD7549 uses less board space and costs less per DAC than any alternative existing solution.

Six grades are available: plastic-packaged JN and KN—specified for 0°C to + 70°C, ceramic AD and BD grades—for − 25°C to + 85°C, and ceramic-packaged SD and TD grades—for − 55°C to + 125°C. Prices (100s) start at $16.95. ◼

Figure 1. Block diagram of the AD7549, showing its DACs connected to a pair of op amps for voltage output.

* For technical data, use the reply card.

24 × 24-BIT FIXED-POINT CMOS DIGITAL MULTIPLIER

ADSP-1024KG Computes Full 48-Bit Product in Less Than 200 ns
Dissipates Less Than 200 mW; Packaged in Space-Saving 84-Pin Grid Array

by David Fair and Bill Windsor

The ADSP-1024* is a 24 × 24-bit CMOS digital multiplier. It computes the product of two 24-bit twos-complement input factors and produces a multiplexed fixed-point 48-bit output. It is housed in a space-saving 84-pin grid-array package, which actually requires less board space than a 64-pin DIP. Prices start at $154 in 100s.

The ADSP-1024 is the first commercially available 24-bit integrated-circuit digital multiplier. The K-grade part performs a multiplication in 195 nanoseconds maximum and dissipates only 200 milliwatts. This combination of precision, speed, and power makes the device an ideal choice in many applications where 16-bit fixed-point arithmetic is "not enough" to meet accuracy, speed, and cost requirements simultaneously.

If coefficients are not sufficiently accurate or too few bits are maintained in the results of intermediate calculations, the results of a DSP or graphics algorithm may have an unacceptable level of digital noise (truncation or roundoff error). Until now, if an error analysis has revealed that the signal-to-noise ratio achieved with an algorithm employing 16-bit fixed-point multipliers is unsatisfactory, the available choices have been limited.

One alternative would be to perform double-precision operations, using either several passes through one multiplier or several multipliers in parallel—and encounter the obvious tradeoff between time and money. A second alternative is to use *floating-point* devices; however, floating-point solutions are expensive and some have nearly five times the latency (total time from input to output) of the ADSP-1024. A third alternative is to implement *block floating point* with fixed-point multipliers; with industry-standard multipliers, this solution requires many support chips and a great deal of design and programming effort.

Thus, the ADSP-1024 fills the precision gap between 16-bit fixed-point and 32-bit floating-point requirements, with low cost and high speed. Configured with external adders, it can also be used as a building block of a 195-ns, 32-bit floating-point multiplier. With its OVF, NORM, and shift capabilities, it also has the hooks to greatly simplify block floating-point implementation.

The ADSP-1024 has two input ports and one output port. The MSP (more-significant product) and LSP (less-significant product) are multiplexed through the output port in a single cycle, producing a full 48-bit product without sacrificing throughput.

ARCHITECTURE AND FUNCTIONING

As Figure 1 shows, there are two input registers—for inputs X and Y, a 24 × 24-bit asynchronous multiplier array, a pair of internal 24-bit product registers, flags to indicate normalization and overflow (a feature unique to the ADSP-1024), a three-level output shifter, three-state output drivers, and digital controls.

The ADSP-1024 accepts two inputs in twos-complement format, and performs the multiplication according to the multiplication

*Use the reply card to request technical data.
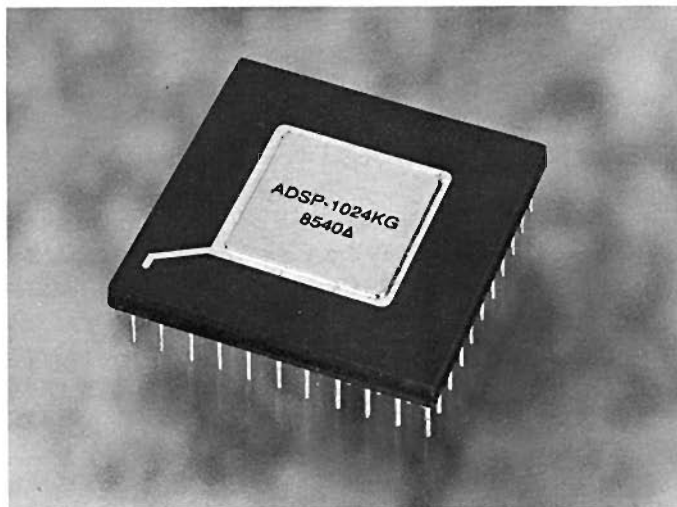
rules for twos complement. In order to promote understanding of the use of the flags, here is a brief review of twos-complement principles.
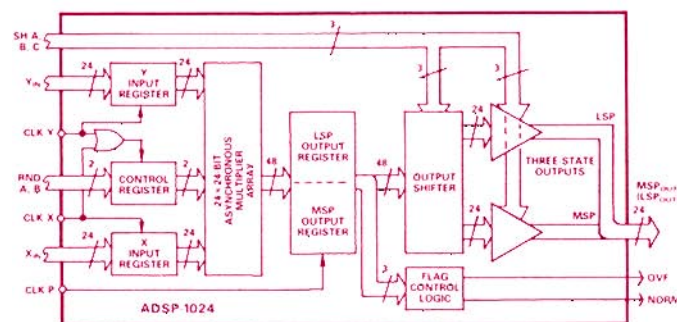

Figure 1. Functional block diagram of the ADSP-1024.

A brief word on twos complement:

A twos-complement word consists of a sign bit—0 positive, 1 negative—in the most-significant-bit position, followed by the magnitude bits. The twos-complement relationship between positive and negative numbers is expressed by the rule: *to change the sign, complement the entire word and add 1 LSB*. For example, + 3 in 4-bit twos complement can be expressed by the binary word, 0011. The twos complement of it would be: 1100 + 0001 = 1101; and the twos complement of 1101 is: 0010 + 0001 = 0011. The sum of + 3 and − 3 is zero; so is the sum of 1101 and 0011, if the final carry is ignored.

When multiplication in twos complement is performed arithmetically, a result of the multiplication is to double the polarity bit; for example, (+ 3)(− 2) = − 6 = (00 11)(11 10) = 1111 1010. The redundant bit can be removed by shifting the output 1 bit to the left. An exceptional case is when both inputs are at negative full scale (1000 . . . 0); in that unique instance, the two leftmost bits (P47 and P46) will be 0 1, thus differing from one another, and the OVF flag will so indicate (Figure 2).

Normalization:

The normalization flag, NORM, is asserted when the most-significant magnitude bit, P45, is 1 for positive values of output, or 0 for negative values of output, while OVF is 0; this indicates that the magnitude of the output number is greater than or equal to ½, but less than unity, for fractional twos-complement format. This means that the number is properly normalized, since its scale cannot be increased by shifting without overflowing into the sign bit.

Shifting:

The *shifting control* permits three degrees of leftward shift for both the MSP (bits 47 to 24) and the LSP (bits 23 to 0): no shift, one bit, and two bits; at the same time that one of these words is shifted, it is also gated onto the output bus. This is done without affecting the data in the product registers.

Shifting is useful in several circumstances. One bit of shift eliminates the redundant sign bit, thus providing the MSP with 23 significant bits. Two bits of shift can be used if the product is always of the same polarity, thus making a sign bit unnecessary; this enables the MSP that is outputted to make full use of 24 significant bits. Two bits of shift is also useful in normalizing numbers, and—more generally—for scaling.

Rounding:

It should be evident that, if the full 48-bit double-precision output word is to be used in further computations, shifting makes little difference and provides no special accuracy advantage. However, if the 24-bit MSP alone is to represent the product, it is better for it to have 24 bits of magnitude significance rather than 22 bits. In order for the MSP to represent accurate rounding of all the lower-order bits, a pair of roundoff-control inputs provides enough rounding choices to make it possible to obtain proper roundoff in any of the above circumstances.

For example, with no shift, if 1 is added to bit 23 of the LSP, the MSP will be properly rounded. Similarly, if 1 is added to bit 22 of the LSP, the MSP will be properly rounded when the left-shift is 1 bit; finally, if 1 is added to bit 21 of the LSP, proper rounding occurs when the left-shift is 2 bits.

WHEN 16 BITS AREN'T ENOUGH

A principal advantage claimed for DSP systems is that, once the signal is in digital form, further contamination by noise becomes less of a problem. This is credible in the hardware sense, since carefully designed and constructed digital circuitry will do an excellent job of discriminating be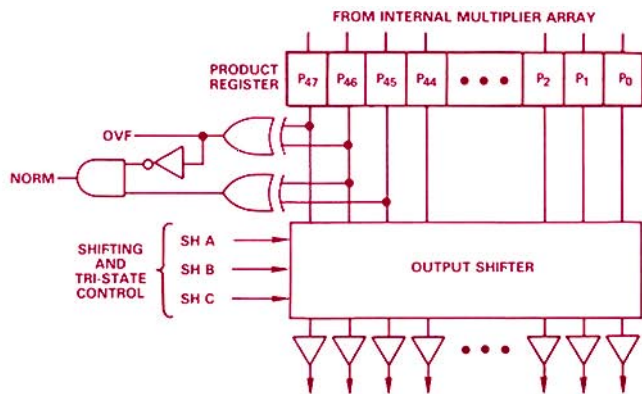tween 1's and 0's. However, there remains a form of digital noise that is inherent in all DSP systems, even those having perfect electrical performance; it is related to what converter buffs call *quantization noise*, and others call *roundoff* or *truncation* errors.

The crux of the matter is that, when a digital quantity is rounded off or (worse) truncated, no information is available as to exactly what value the LSB represents within ± ½LSB, once the remaining bits have been detached.

For a graphic example of an instance in which a 24-bit multiplier, using a 24-bit bus, provides much better speed and accuracy than a 16-bit system, consider what might be required for adequate accuracy in a 16-bit system with 16-bit buses and 16-bit fixed-point arithmetic elements. In such a system, the results of a 16-bit multiplication are generally rounded to the most-significant 16 bits for transfer to the system bus. Suppose that we're computing the difference of two squares, $0.105^2 - 0.095^2$. That difference is equal to $0.011025 - 0.009025 = 0.002000$; in fractional binary, it is equal to the sum of a pair of twos-complement numbers,

```
  0 0000 0010 1101 0010 1000 1000 110..
  1 1111 1101 1011 0000 1000 1001 101..
  0 0000 0000 1000 0011 0001 0010 011..
```

If this sum is performed with the MSP outputs from a 16-bit multiplier, rounded to 16 bits, including the sign bit,

```
  0 0000 0010 1101 001
  1 1111 1101 1011 000
  0 0000 0000 1000 001
```

there are only 7 bits of information, and the last two are questionable because of truncation. Of course, double-precision computations could be used, employing both the MSP and the LSP of the 16-bit multiplier, but the extra time required could be a severe handicap.

If instead, the 24-bit multiplier's MSP were used with a 24-bit bus, the computation would result in nearly 16-bit resolution, without employing double-precision.

Clearly, not all algorithms have a computational pattern that exacerbates digital noise. However, many useful computations in speech recognition, telecommunications, graphics, and radar are susceptible to this type of noise. For these applications, higher-precision arithmetic becomes a necessity.

Another way of lessening the effects of digital noise is to use floating-point arithmetic, which decreases the effect in two ways: First, relative errors on 24-bit mantissas are minimized in the same way as they are with fixed-point 24-bit numbers; second, after all arithmetic operations, results are re-normalized, so that their full precision is maintained. In the above 16-bit example, the problem could have been ameliorated right from the beginning if the input numbers had been in floating point, since the numbers operated on would have filled the input and output registers of the multiplier, and the difference would have been magnified.

The ADSP-1024 can be used at the heart of a 24-bit 195-ns floating-point multiplier built to handle such standard formats as MIL-STD 1750, which calls for a 24-bit twos-complement mantissa. Floating-point operands can be fed to the ADSP-1024 at a pipeline rate of 5 MHz; the added peripheral control circuitry produces a typical input-to-output FP multiply time of 250ns. An example of a floating point multiplier can be found in the ADSP-1024 data sheet. ▶

Figure 2. Flag and shift logic.

LOW-COST VOLTAGE-TO-FREQUENCY CONVERTER CHIP
AD654 Is Easy to Use, Features Low-Power 5-Volt Operation
Operates with Full-Scale Frequencies Up to 500 kHz

by Paul Klonowski

The AD654JN* is a monolithic V/F converter, packaged in an 8-pin plastic mini-DIP. Capable of operating on a single 5-volt supply, and drawing 2.5-mA maximum quiescent current, it requires only three external components—a resistor and a capacitor to set the frequency scale (for frequencies up to 500 kHz), and an external pullup resistor to set the current from the open-collector output stage. The AD654's small size, low power drain, excellent performance, and ease of use are accompanied by low price. (Price is $3.30 in 100s, $2.95 in 1000s).

Output frequency is proportional to input voltage or current. As with the AD537*[1,2], the AD654's output is a square wave, rather than the fixed-width pulse common to most other VFC types. This makes the device much easier to ac-couple, and it can be used to generate symmetrical analog functions having voltage-controlled frequency.

Typical applications of the AD654 can be found in such diverse fields as power monitoring, motor control, temperature measurement, energy management, and analytical instrumentation; the functions it can enhance include a/d conversion, long-term integration of analog signals, transducer readout and isolation, generation of frequencies controlled by analog or digital sources, measurement of frequency with phase-locked loops, frequency doubling, etc.[3]

PRINCIPLE AND PERFORMANCE

Figure 1 is a simplified block diagram of the AD654, showing its pin connections. An input operational amplifier controls the emitter current of a feedback transistor. For an input voltage, V_{IN}, applied to pin 4, and a resistance, R, connected between the amplifier's negative input terminal (pin 3) and ground, the current through pin 3 (I, the total emitter current), must be equal to V_{IN}/R, if the amplifier approaches ideal performance.
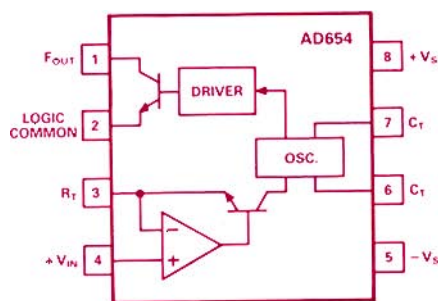

Figure 1. Block diagram and pinout of the AD654.

*For technical data, use the reply card.

[1]Barrie Gilbert and Dave Kress, "Versatile Monolithic V/F or I/F Converter," *Analog Dialogue* 10-2, 1976 (6-8).

[2]Gilbert, B. A., "A Versatile Monolithic Voltage-to-Frequency Converter," *IEEE Journal of Solid-State Circuits*, vol. SC-11, December 1976 (852-864).

[3]A free 28-page Application Note, "Operation and Applications of the AD654 IC V-to-F Converter," by Walt Jung (1985), is available from Analog Devices. Use the reply card.
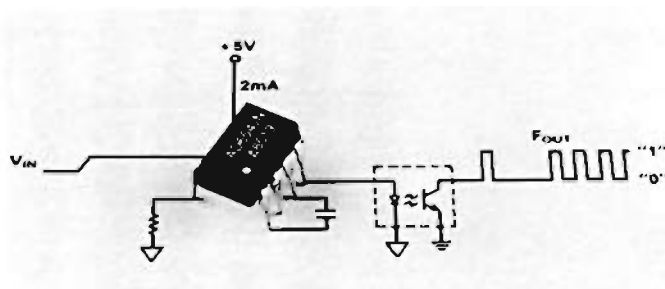
A current proportional to I flows either positively or negatively through the capacitor, via terminals 6 and 7, and generates a linearly increasing or decreasing voltage; the direction of flow is determined by precision thresholds, established by comparing the capacitor voltage with a voltage derived from an internal bandgap reference. When a threshold is reached, the current switches direction, and the input to the driver switches from one level to the other, or back, starting the multivibrator cycle again.

The result—for constant input—is a symmetrical triangular wave of voltage across the capacitor, and a 50%-duty-cycle square wave at the driver. Since the time to reach a threshold is directly proportional to both R and C, the period is inversely proportional to their product and directly proportional to the input voltage, viz.,

$$f_o = \frac{V_{IN}}{(10\,V)\,R\,C} \tag{1}$$

The driver's state is made available via an output transistor capable of driving up to 12 TTL loads, as well as opto-couplers, long cables, or similar loads. Since it essentially floats, the output transistor may be used with any appropriate supply and ground-level voltages within the device's ratings.

Operation is guaranteed over an 80-dB dynamic range (better than 13-bit resolution). Other key features add to the AD654's application flexibility: The converter operates with either single (+5V to +36V) or dual (±5V to ±18V) supplies; maximum nonlinearity is ±0.1% for 250-kHz full-scale—and ±0.4% for 500-kHz full-scale; analog input ranges from 0 to 100mV to ±30V permit the device to work well with low-level transducer outputs, as well as with system-level voltages; offset adjustment of the low-drift input op amp is made unnecessary in most applications by the low maximum offset specification of 1mV; and the 4μV/°C drift rate provides stability over the 0°C to 70°C temperature range.

OPERATION AND APPLICATIONS

V/F Conversion with Positive Input Voltage.
The timing resistance, R_T, sets the full-scale current value, and the timing capacitance, C_T, sets the corresponding full-scale frequency. Figure 2 shows how the AD654 is connected for positive input voltages. The input amplifier presents a very high (250-megohm) impedance to the input voltage, which is converted into the proper value of drive current by the scaling resistance, R_T, from pin 3 to common. Resistors R1 and R2 are selected to provide
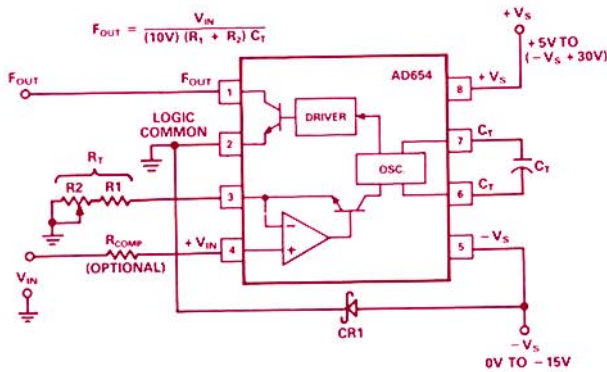
$$F_{OUT} = \frac{V_{IN}}{(10V)(R_1 + R_2)C_T}$$

Figure 2. Standard connection for positive input voltages.

1 mA of full-scale current, with enough trim range to accommodate tolerances on component parameters and device gain. The positive input range is from $-V_s$ (ground in single-supply operation) to 4 volts below the positive supply; thus, with a single $+5$-volt supply, the maximum input range is from 0V to $+1V$.

With a 0.01-μF timing capacitor and 1 mA full-scale drive current, full-scale frequency is 10 kHz; 0.001 μF gives 100 kHz with 1-mA drive current. Since the scale factor can be trimmed with R2, the capacitance need not be specified for tight parametric tolerance; however, for good linearity, the capacitor should have low dielectric absorption, and, for stable operation with temperature, it should have a small temperature coefficient. Polystyrene, polypropylene, or Teflon capacitors are preferred for this application. The capacitor is wired as closely as possible to the socket. The Schottky diode prevents the voltage at logic common from being more than one diode drop below $-V_s$ at any time; it is not required if V_s and logic common are at the same voltage.

Analog/Digital Conversion at Lowest Cost.
In Figure 3, the AD654 provides a/d conversion for an 8048 single-chip microcomputer by making use of the 8048's on-chip event counter. The AD654 is configured for 1-volt full-scale input and
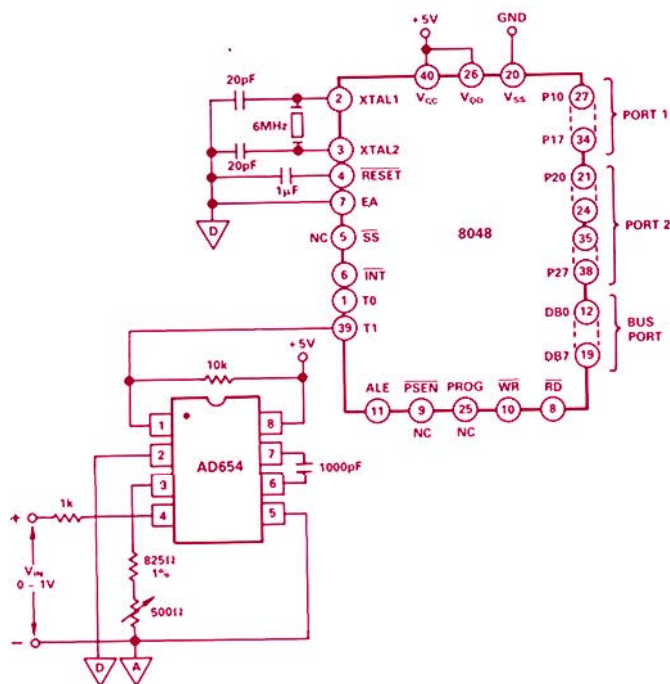
100-kHz output frequency; its output is connected to the timer/counter input pin, T1, of the 8048. The system operates on a single $+5$-volt supply.

The 8048's counter is triggered on negative edges from the AD654. After the STRT CNT instruction is executed, each high-to-low transition from the VFC increments the counter. The maximum rate at which the counter may be incremented is once per three instruction cycles; with a 6-MHz crystal, at 2.5 μs per instruction cycle, this corresponds to once every 7.5 μs, for a maximum frequency of 133 kHz—thus it is easily capable of counting the 100-kHz maximum output from the AD654.

The counter, which has a maximum capacity of 8 bits, overflows after each 256 counts, enabling the timer interrupt. Each overflow causes a jump to a subroutine in which a register is incremented. Meanwhile, another register, decremented at regular intervals, has been preset to the number of times necessary to establish the desired count time; when it times out, the STOP TCNT instruction is executed, stopping the count.

After the STOP TCNT instruction is executed, the total number of counts is equal to the contents of the counter plus 256-times-the-contents of the overflow register. This count is proportional to the input voltage. For example, if a 1-volt full-scale input voltage produces a 100-kHz VFC output, and the count period is 100 milliseconds (0.1s), then the total count will be 10,000. Thus, a count of 5,000 would indicate an average input of 0.5 volts.

Since the count in effect performs an integration of the input signal, the longer the time employed for counting, the greater the resolution of the input signal's average value.

Digitally Controlled Clock Generator (D/F Converter).
Figure 4 shows an example of a digitally controlled frequency source with true (monotonic) 12-bit resolution and 10-bit linearity. It employs an AD7240JN* 12-bit voltage-output CMOS DAC, with a 1.235-volt AD589* synthetic-Zener bandgap reference, as the input voltage source for the VFC. The AD7240 multiplies the reference voltage by the fractional binary input, producing a digitally set output voltage very much like the output of a potentiometer.

In this example, the AD654 is scaled for 1-mA full-scale current; with a C_T of 1,000 pF, the full-scale output frequency will be 100 kHz (adjust R4 for all-1's frequency of 99,976 Hz). The timing capacitor can be changed as appropriate for other full-scale frequencies, e.g., 0.01 μF for 10 kHz—as shown. ▶
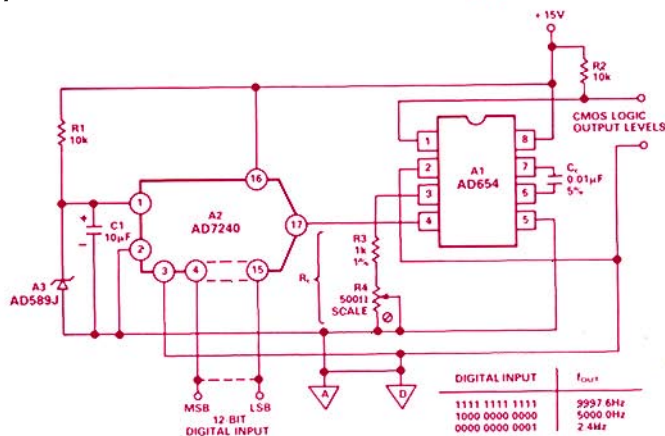

Figure 3. The AD654 as an a/d converter for an 8048 single-chip microcomputer.

DIGITAL INPUT	f_{OUT}
1111 1111 1111	9997.6 Hz
1000 0000 0000	5000.0 Hz
0000 0000 0001	2.4 Hz

MSB — LSB
12-BIT DIGITAL INPUT

Figure 4. Digital-to-frequency converter with 12-bit resolution.

HIGH-PERFORMANCE PRECISION HYBRID ISOLATION AMPLIFIER

AD295 Has Three-Port Isolation, 2,500-Volt CMV Input-to-Output
User-Configurable Input Amplifier, ± 0.012% Max Nonlinearity (AD295C)

The AD295* is a high-accuracy, high-reliability hybrid isolation amplifier designed to protect persons, equipment, and data in industrial, instrumentation, and medical applications. A 3-port device comprising mutually isolated *input*, *output*, and *power* sections, linked by two transformers, it provides gain from 1 to 1,000 V/V, with 2,500-volt peak continuous isolation between input and output. It is packaged in an epoxy-sealed "40-pin" ceramic package with input-to-output pin spacing that complies with NEMA (ICS1-111) separation specifications.

Designed for measuring signals in harsh *industrial environments*, the AD295 provides high accuracy with complete galvanic isolation and protection from transients, ground faults, and high common-mode voltage for process controllers, current-loop receivers, motor controls, and weighing systems. In *data acquisition systems*, it provides common-mode rejection and signal conditioning for thermocouples, strain gages, and other low-level signal sources, where high performance must be combined with system protection. In *biomedical and patient-monitoring* equipment, the AD295 provides the benefits of high gain with low input noise (2μV p-p at gain of 1,000 V/V) and high common-mode rejection (106dB at 60Hz), while at the same time providing protection from potentially lethal ground-fault currents.

FEATURES

Figure 1 shows the basic circuitry of the AD295. It uses an 80-kHz carrier and transformer coupling, to permit both signals and power to be transferred between stages. Isolated amplification is provided by producing variable duty-cycle pulses from a signal-biased triangular-wave (derived from the carrier), coupling them to the output stage, demodulating them and filtering the result.

Besides providing high noise immunity and low nonlinearity, this scheme makes it possible to incorporate adjustable-gain input and output amplifiers, and to provide isolated power outputs (± 15 V
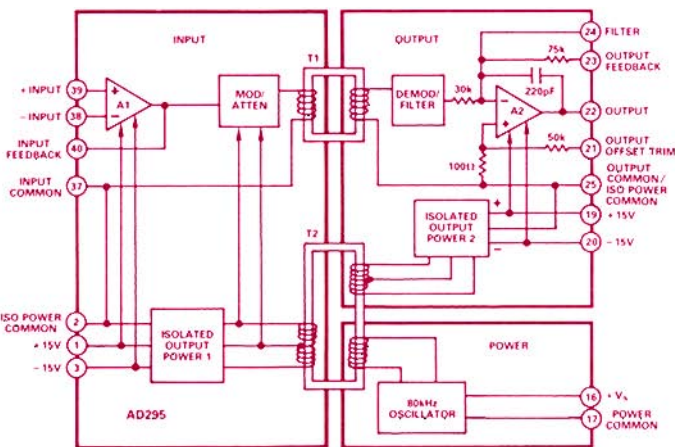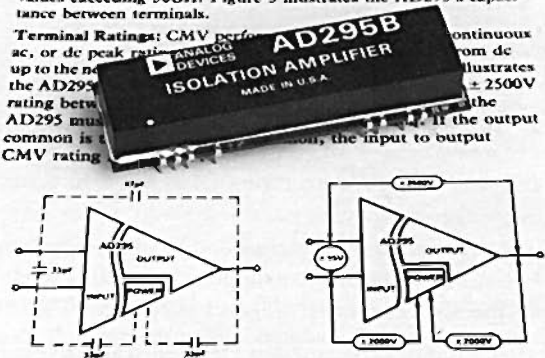

Figure 3. Interelectrode Capacitance and Terminal Ratings

at 5 mA, −4% maximum load regulation) at both ports—for floating signal conditioners, front-end buffers, remote transducers at the input, and other external circuitry at the output.

The uncommitted *input* amplifier can be configured by the user as needed—as a buffer, inverter, subtractor, attenuator, adjustable-gain amplifier, filter, etc. The *output* amplifier can be connected to provide additional adjustable gain and filtering, if necessary. Figure 2 shows a connection for gain-of-100 in the input stage; note that the floating supplies are useful for providing input and output offset adjustments when necessary.

PERFORMANCE

The AD295 can be operated or stored at temperatures from −40°C to +100°C; specified operation is from −25°C to +85°C. Key performance specifications are available in three grades, A/B/C: maximum nonlinearity, ±0.05%/0.025%/0.012%; maximum input offset drift, ±10/3/1.5 μV/°C; maximum output offset drift, ±450/300/150μV/°C. Performance for all grades includes ± 1.5% typical gain accuracy and ± 60 ppm/°C gain drift, 4.5-kHz small-signal bandwidth (gain from 1 to 100), 550μs settling time to 0.1%, and maximum offset specifications of ± 18mV maximum at the output and ± 3mV max at the input. Prices (100s) are $78.75/$90/$101.25. ▶

Figure 1. Block diagram of the AD295, showing relationship of ports.
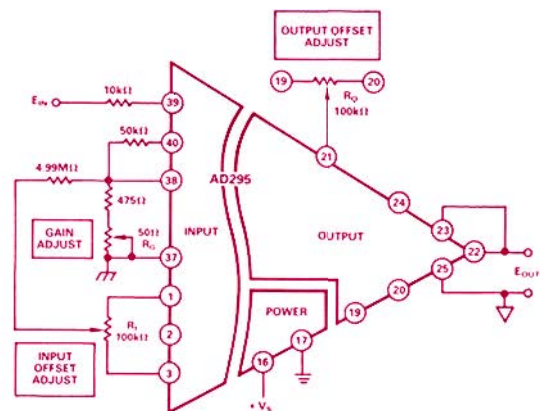
*For technical data, use the reply card.

Figure 2. Connections for gain of 100 V/V.

NEW PLUG-IN SIGNAL-CONDITIONING MODULES FOR 3B SERIES
3B47 Isolates, Amplifies and Linearizes Thermocouple Outputs (J,K,T,E,R,S,B)
3B17 Provides Excitation and Amplification for LVDTs and RVDTs

by Kathryn Kasper

The 3B Series Signal Conditioning I/O Subsystem is continually evolving to meet new and changing signal-conditioning needs and retain its reputation as the most versatile solution for signal-conditioning problems. Its capabilities have been extended with the introduction of two new input modules: the 3B47 Linearized Thermocouple Conditioner and the 3B17 LVDT Signal Conditioner.

The 3B Subsystem,* a fully integrated, modular signal-conditioning front end designed for tough industrial environments, provides a versatile, low-cost means of interconnecting real-world analog signals with a data-acquisition, monitoring, or control system.
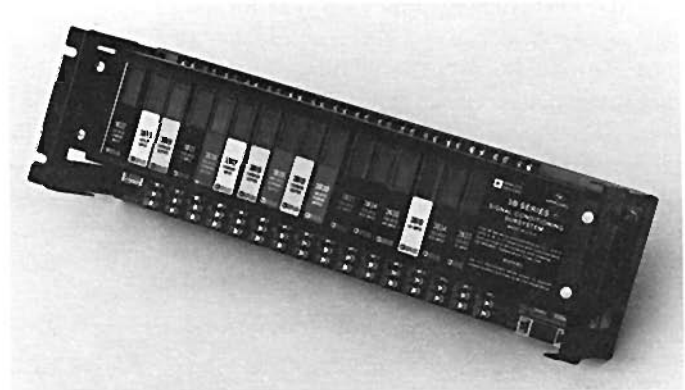
The 16-channel system, pictured here, consists of a 19" powered relay-rack-compatible backplane and a family of plugin input and output signal-conditioning modules. Besides the 16-channel system, 8- and 4-channel backplanes are also available. Each backplane incorporates screw terminals for field connection to sensor inputs and current (4-20mA or 0-20mA) outputs, plus a connector for high-level single-ended voltage outputs to the user's equipment.

The input modules are uniform in size (3.150" × 0.775" × 3.395") and pin-connection pattern. Offered in both isolated and non-isolated versions, they feature signal-conditioning circuitry optimized for specific sensors or analog signals, and they provide simultaneous voltage and current outputs. The output modules accept single-ended high-level signals and provide process current signals.

LINEARIZED THERMOCOUPLE CONDITIONER

The 3B47* (Figure 1) is an isolated, linearized thermocouple input module that accepts its signal from a Type J, K, T, E, R, S, or B thermocouple and puts out a 0 to +10-volt signal that is linear with temperature. This linearized output is a useful analog interface for devices such as programmable controllers and chart recorders, which ordinarily cannot themselves perform linearization.

The 3B47's input circuitry has 1,500-V peak maximum isolation, employing transformer-coupling, and is protected against 220-volt rms faults. The input is cold-junction compensated with an accuracy of 0.5°C, chopper-amplified (with low drift and excellent long-term stability), and filtered. The output voltage has a range of ± 5% zero- and span trim adjustment, via potentiometers accessible at the front. The 3B47 has only a voltage output; current output can be made available via an optional adjacent 3B19 module. Standard and custom ranges are available.

LVDT CONDITIONER

The 3B17* (Figure 2) is a wideband input module that accepts inputs from 4-, 5-, or 6-wire LVDT or RVDT transducers and provides ± 10-volt and 4-20 mA outputs. LVDTs (linear variable differential transformers) and RVDTs (rotary variable differential transformers) are linear, rugged position transducers, used in machine tools, industrial automation, and product test. In addition to conditioning the output, the 3B17 also provides low-distortion sinusoidal excitation, ranging from 1 to 5 volts at up to 20mA rms, at frequencies in the range from 1kHz to 10kHz. The 3B17's standard output bandwidth is 100Hz, but custom modules may be configured for bandwidth up to 1/10 of the excitation frequency. 130-volt rms fault protection is provided for input, current-output, and excitation circuitry.

The LVDT provides an ac difference output, which the 3B17 amplifies to high levels. A synchronous demodulator automatically compensates for any phase error between the primary and secondary coils of the LVDT and also eliminates residual quadrature or null voltage. ▶
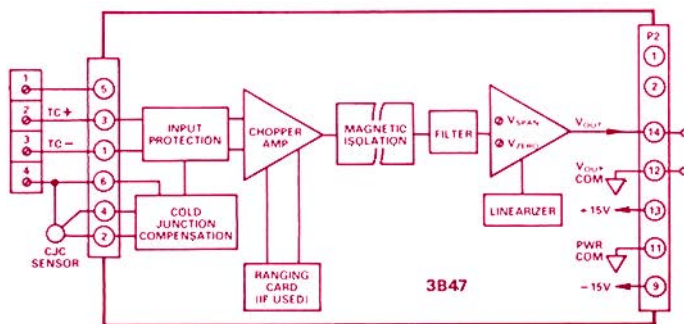

Figure 1. Block diagram of the 3B47 thermocouple conditioner.
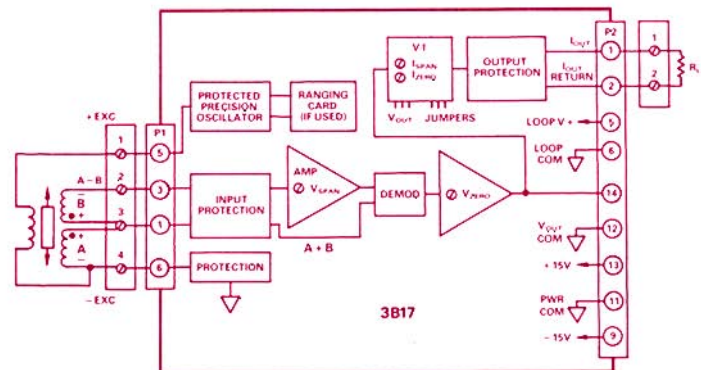
*Use the reply card for technical data.

Figure 2. Block diagram of the 3B17 LVDT conditioner.

DOUBLE-BUFFERED 14-BIT MONOLITHIC CMOS MULTIPLYING DAC
All Grades of AD7535 Are 14-Bit Monotonic over Full Temperature Range
Low Leakage and Gain Tempcos, Double-Buffered μP-Compatible Inputs

by Mike Curtin

The AD7535* is a monolithic CMOS 14-bit double-buffered multiplying digital-to-analog converter, capable of full 4-quadrant multiplication. Manufactured with the Analog Devices LC² MOS (linear-compatible CMOS) process and employing thin-film resistors—laser-trimmed at the wafer stage, for improved linearity—all grades of the device are 14-bit monotonic over temperature. The AD7535 is compatible with most of the popular microprocessors having 8- and 16-bit data buses and is housed in a 28-pin dual in-line package. Maximum relative-accuracy error over temperature is ±2/1LSB (for grades J,A,S/K,B,T), and maximum full-scale error over temperature is ±8/4LSB, including the effects of leakage current and gain tempco. Prices (100s) start at $18.95.

The AD7535 is interfaced via a pair of 8-bit data registers (Figure 1), which can be either paralleled on an 8-bit bus for byte-serial updating, or "broadsided" on a 16-bit bus for one-step updating. Its performance is similar in most respects to that of the AD7534*—which has an 8-bit bus interface and narrow 0.3" 20-pin package—introduced in these pages recently.[1] Typical applications include μP-based control systems, digital audio, precision servo control, and control and measurement in high-temperature environments.
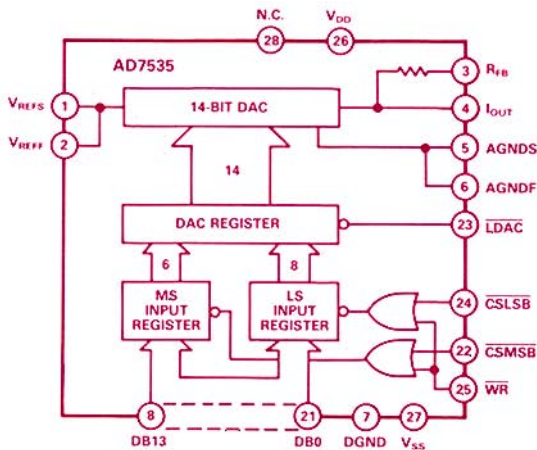

Figure 1. Functional diagram of the AD7535 14-bit DAC.

An important feature of the AD7535 and AD7534 (patent pending) is low leakage current at the output terminal over temperature, specified at ±5nA maximum at 25°C and ±20nA maximum over the full military temperature range ($V_{SS} = -0.3V$). At maximum ladder resistance of 10,000 ohms, the error due to device current leakage is thus only 200μV (1/50,000 of 10-V full scale).

If the V_{SS} terminal is not biased (i.e., $V_{SS} = 0V$), the maximum specified leakage current at +125°C is 150nA. Figure 2 compares output leakage current with the two values of bias voltage over
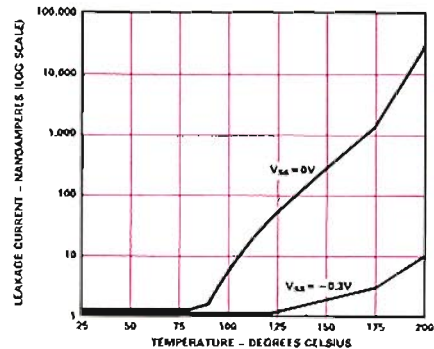

Figure 2. Leakage current as a function of temperature at two values of substrate bias voltage—typical measurement.

temperatures *up to 200°C*, as measured in our laboratory.[2] While the device is not specified for storage or operation at these temperatures, it is instructive to note how well-behaved the leakage current is in the *specified* temperature range (temperatures up to 125°C, S and T grades).

In the same set of tests, device linearity was measured over a 65-hour period at 200°C with $V_{SS} = 0V$ and $V_{SS} = -0.3V$,; with $V_{SS} = 0$, the initial linearity error was 40 least-significant bits, and it varied within a ±10-bit range; with $V_{SS} = -0.3V$, the linearity error was initially 0.7 bits, and it varied within ±0.1 bits.† It is easy to see that errors must be even less in the device's specified temperature range.

Another useful feature of these DACs is the pair of Force-Sense leads at the reference input and analog ground. An external op-amp input is driven at the desired potential, and the Sense lead is fed back to the negative input. The op amp drives the Force lead with whatever current is necessary to force the Sense lead to be equal to the desired voltage. Figure 3 shows how Force-Sense is used with a remote reference. ▶
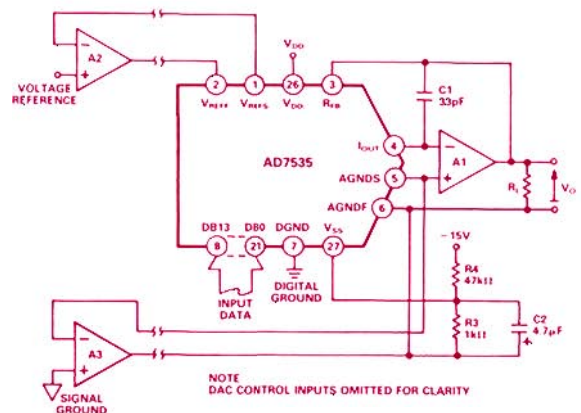

Figure 3. Driving the AD7535 with a remote reference.

[2]For information on these tests, write to Converter Marketing, Analog Devices, Inc., 804 Woburn Street, Wilmington MA 01887.

†Our purpose in collecting and presenting this data is to foster increased optimism about the performance of our devices at *specified* temperatures; readers who seek to duplicate these 200°C tests do so at their own risk.

*Use the reply card for technical data.

[1]"14-Bit CMOS DAC" (New-Product Brief), *Analog Dialogue* 18, no. 2, 1984 (p. 25).

LOW-COST 8-BIT MONOLITHIC ADC CONVERTS IN 1.36µs MAX
AD7820 Includes Track-Hold Function, 4-4 Flash Conversion with Subranging
Has Fully Specified Max Conversion Time for All Modes & Temperature Ranges

by Dick Meaney

The monolithic AD7820* is a fast, µP-compatible, 8-bit ratiometric a/d converter housed in a narrow (0.3") 20-pin DIP. It employs two 4-bit "flash" a/d converters and a 4-bit d/a converter in a subranging configuration to provide a fast maximum conversion time of 1.6µs over temperature—1.36µs max at 25°C—when conversion is started by a Write command. It includes a track-hold function that permits 8-bit conversion with input signals slewing at rates up to 100 mV/µs max, equivalent to a ±2.5-V sine wave at 6.4kHz.

An easy-to-use device, it requires a single +5-volt supply, can use any external reference of up to +5 volts for ratiometric conversion, and doesn't need a clock or a sample-hold (but with a high-performance sample-hold, it can maintain accurate conversions for input sine waves up to the Nyquist frequency, about 250kHz). Applications include speech recognition, digital PCM, disk drives, modems, and sonar. It is available from stock, in plastic for 0°C to +70°C grades (KN/LN), and in ceramic for −25°C to +85°C (BQ/CQ) and −55°C to +125°C (SQ/TQ). Prices start at $9.95 (KN – 100s).

In subranging conversion (Figure 1), the input signal is compared with the reference and converted to digital, with a resolution of 1 part in 16, by the 15 comparators of a 4-bit flash converter; the result of this conversion will form the 4 more-significant bits of the output. The result is also converted back to analog and subtracted from the input; the difference, or "residue," is converted to digital with the second 4-bit flash converter, using an attenuated reference voltage, and forms the 4 less-significant bits of the output. Latched three-state buffer circuitry allows direct connection to a microprocessor data bus or system input port. An additional comparator in the 4-MSB converter provides an overflow indicator, which can also be used when cascading converters for higher resolution.
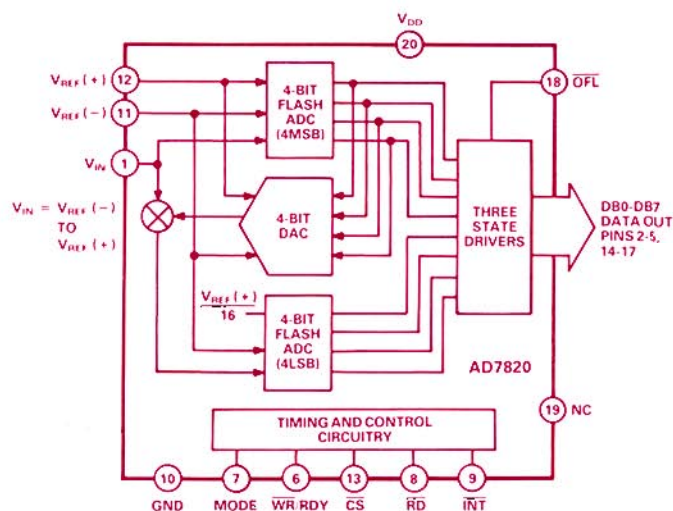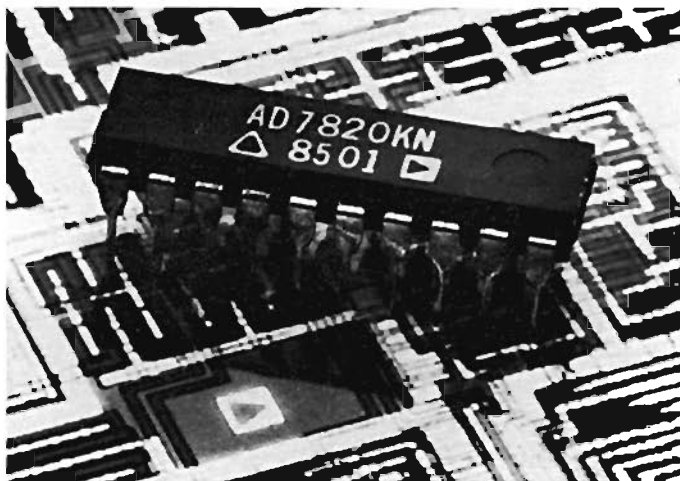
The AD7820 can either stand alone or be used with a microprocessor. There are two modes of operation, read and write-read. In the *Read* mode, a single Read pulse initiates the conversion and then reads the data, a useful mode if the µP can be placed in a Wait state. Maximum conversion time in the Read mode is 2.5µs over the full military temperature range, 1.6µs at +25°C. In the *Write-Read (WR-RD)* mode, the conversion is started by a Write to the converter's address, and the µP can perform a Read 600ns minimum (700ns minimum over temperature) after the rising edge of the Write pulse (minimum width 600ns at any temperature). In the WR-RD mode, the Read can also occur after an interrupt is signalled by the $\overline{INT}$ (status line) going low.

The reference voltage (i.e., full-scale range) is determined by the difference between the voltages applied at the differential reference inputs, V_{REF} (+) and V_{REF} (−); the smaller this difference, the greater the input sensitivity. The reference flexibility allows the input span to be offset from zero. Figure 2 shows some of the configurations that are possible. ▶

Figure 1. Block diagram of the AD7820.

*Use the reply card for technical data.
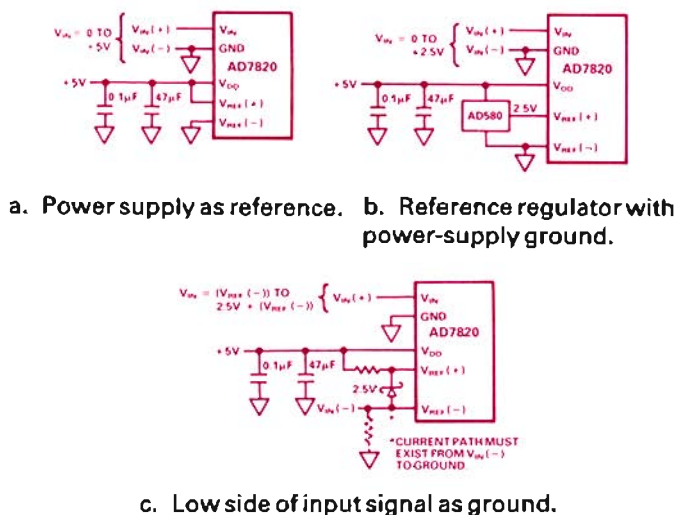
a. Power supply as reference.

b. Reference regulator with power-supply ground.

c. Low side of input signal as ground.

Figure 2. Flexible reference connections.

SPGA-T/H AMPLIFIER FOR DATA-ACQUISITION SYSTEM DESIGN

AD365AM: Software-Programmable Gains of 1, 10, 100, 500; Nonlinearity = 0.005% max
Hybrid in 16-Pin DIP Saves Board Space, Simplifies System Designs

The AD365AM* combines a software-programmable-gain in-strumentation amplifier (SPGIA) and a track-and-hold amplifier in a single 16-pin hermetically sealed metal DIP. It is designed for applications requiring amplification and acquisition of wide-dynamic-range signals, with 12-bit performance. Because it can replace larger numbers of discrete components and ICs, it speeds design time and saves valuable space in portable instrumentation and on analog I/O boards.

The low-noise (0.2μV peak-to-peak, 0.1 to 10Hz) differential-input instrumentation amplifier (Figure 1), based on an AD625* chip, has common-mode rejection of 90-dB, minimum, for amplifying low-level transducer outputs in the presence of com-mon-mode noise. There are four gain steps, programmable by a 2-bit digital input: 1, 10, 100, and 500. The adjustable extension of dynamic range, to up to 2,000,000:1 in 12-bit systems—made available by the choice of programmable gains—permits the AD365AM to condition both high- and low-level signals in multi-channel systems, under the control of a microprocessor.
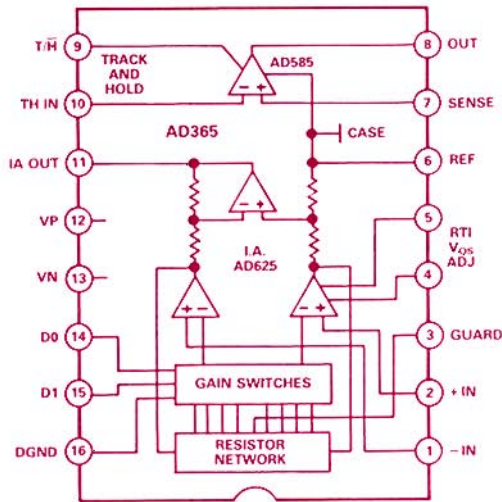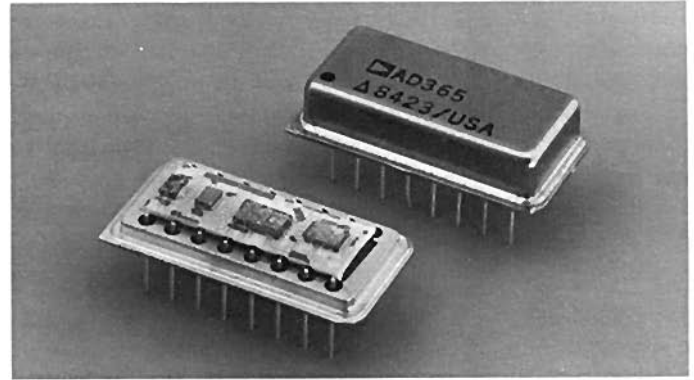

Figure 1. Functional diagram of the AD365.

Guaranteed 12-bit performance is offered by the PGIA and track-hold amplifier combination of the AD365; therefore, the AD365 can be used with any 12-bit converter—for example, the industry-standard AD574* or the high-speed AD578* (Figure 2), and—where called for—with a multi-channel front end appropriately designed to handle the number and kinds of required input signal levels.

Key specifications for the PGIA include 0.005% maximum non-linearity, 10 ppm/°C maximum gain drift, and 15-μs maximum settling time to 0.01% at a gain of 100. Maximum input offset is 200μV (trimmable by an external potentiometer), and typical drift tempco is 0.1 μV/°C over a 100°C temperature span.

The AD585* track/hold amplifier section also guarantees 0.005% maximum nonlinearity, with 3-μs acquisition time for a 10-volt step, 35ns aperture time, and 0.5-ns typical aperture jitter. Maximum droop rate at +25°C is 1mV/ms, and typical full-power bandwidth is specified at 120kHz.

The PGIA and T/H amplifier of the AD365AM are specified inde-pendently; the electrical connection between them is made by external jumpering. This is an especially useful feature where an external anti-aliasing filter is used or if the multiplexer is inter-posed between the PGIA and the T/H amplifier to permit gain ad-justment for a wide-range or low-level channel while allowing the other channels to remain at system level.

The AD365AM dissipates 550mW max (360mW typical) and is specified for operation over a −25°C to +85°C temperature range. The minimum supply voltage is +4.75V/−11V; maximum supply ranges are ±17V. The digital gain-selection and T/H con-trol inputs are TTL and CMOS compatible. The AD365AM is available in a 16-pin hermetic metal DIP. Price in 100s is $61.95.

Typical applications of the AD365AM are as an amplifier with di-gitally controlled gain, an automatic-gain-ranging amplifier, a gain-selection-per-channel amplifier, and a transducer/bridge am-plifier; it can become an essential component of single- and multi-channel data-acquisition systems, wide-range measurement sys-tems, and test equipment. ▶
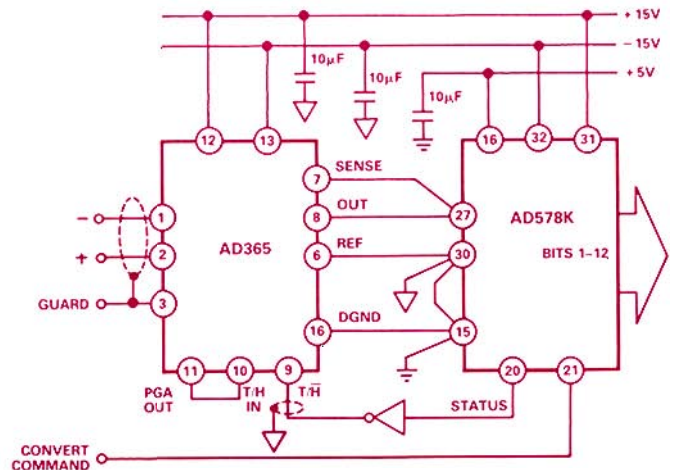

Figure 2. Using the AD365 with a fast 12-bit ADC for 118-kHz throughput.

*Use the reply card for technical data.

HIGH-PERFORMANCE 10-BIT, 800-ns A/D CONVERTER
AD ADC-816: A/D Converter with Improvements over Existing Second Sources
Features: Better Timing Stability, Power-Supply Tolerance, and Price

The AD ADC-816* is a high-speed successive-approximation analog-to-digital converter capable of 10-bit resolution with a maximum conversion time of 800ns at 25°C.

A thin-film hybrid circuit, it is hermetically packaged in a 32-pin dual in-line package. Three models span temperature ranges of 0°C to +70°C (KD), −25°C to +85°C (BD), and −55°C to +125°C (SD). Maximum conversion time of 900ns is guaranteed over the AD ADC-816SD's full operating case-temperature range.

The AD ADC-816 represents an improvement over models of the ADC-816 available earlier in the industry; besides its faster conversion time in extended temperature operation (due to an improved clock circuit), it has three times the tolerance to the +15-volt supply (±0.3V), and it was introduced at a considerably lower price. Prices start at $154 for the KD grade (100's).

Both parallel and serial outputs are available (Figure 1). Serial data is furnished in NRZ (non-return-to-zero) format, with all 10 bits available on negative-going clock edges, making "serial data recovery circuits" (required for some devices available earlier in the industry) unnecessary.

Applications for the a/d converter include radar systems, analytical instruments, real-time waveform analysis, data-acquisition, and color-graphics manipulation. The AD ADC-816 provides savings over the use of lower-grade 12-bit successive-approximation units short-cycled for 10-bit conversion.

Differential nonlinearity is ±½LSB, and there are no missing codes over temperature. For convenience and flexibility, an internal −10-volt reference is provided; when used, it is jumpered to the Reference input. There are three unipolar and three bipolar input ranges, 0 to −5V, −10V, and −20V; and ±2.5V, ±5V, ±10V.
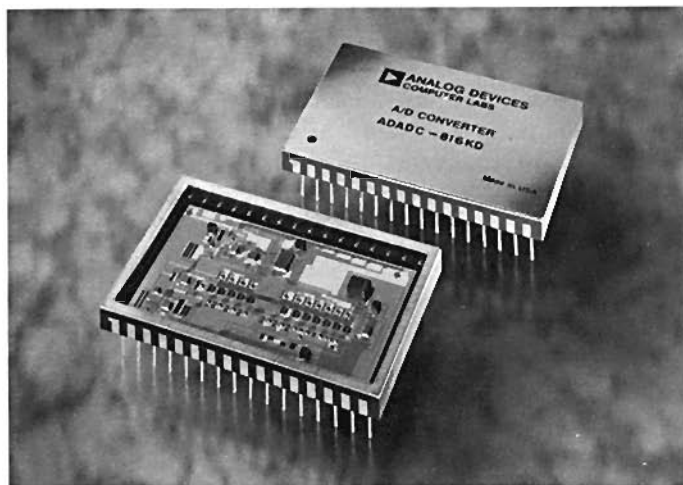
Figure 2 shows a typical application with an HTC-0300A track/hold amplifier, capable of providing 10-bit digital data at word rates as high as 1.1MHz. A 150-ns-wide Encode pulse is used, to ensure that the HTC-0300A acquires the input signal to 10-bit accuracy. Since the pulse is applied to the $\overline{\text{HOLD}}$ input of the T/H, the HTC-0300A will be in the Track mode while the pulse is present and will return to the Hold mode when the Encode pulse returns to 0. (The choice of wiring and timing for—and performance of—the combination depends on the choice of T/H unit; details in the Figure are specific to the HTC-0300A.)

The purpose of the 50+ nanosecond delay is to ensure that the analog output of the T/H, which is frozen by the trailing edge of the Encode command, has settled to its correct value before the conversion process starts. The delays due to acquisition time of the T/H stretch out the overall time required for conversion, reducing the throughput to word rates of about 1.1MHz. ▶

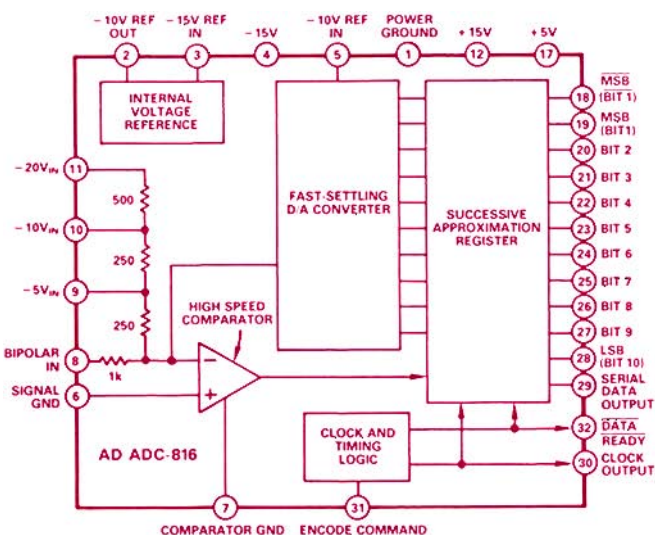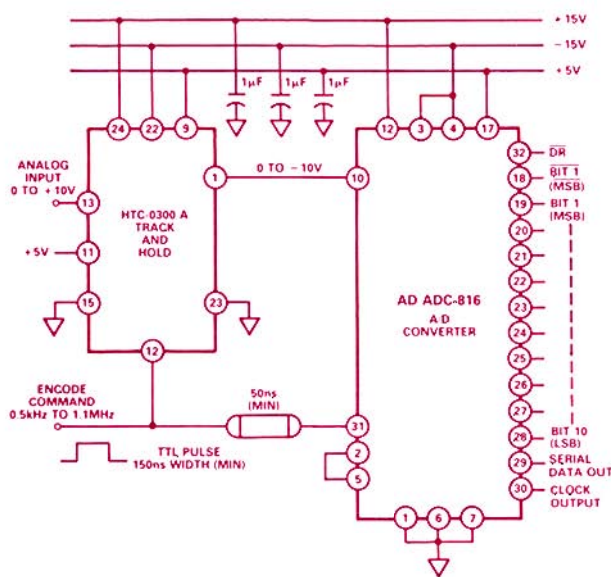Figure 1. Block diagram of the AD ADC-816.

Figure 2. 1.1-MHz a/d conversion system.

REAL-WORLD I/O CARDS FOR THE CMOS STD BUS
Analog and Digital I/O Cards Are Compatible with CMOS STD Bus
RTI-1280/81 Analog Input & I/O; RTI-1282 Analog Output; RTI-1287 Digital I/O

by John Mills

The RTI-1280 Series* comprises four analog and digital I/O cards compatible with the CMOS STD bus. Using newly available analog and digital CMOS technology, the cards offer the advantages of low dissipation, high noise-immunity, and extended temperature operation, from −25°C to +85°C. They provide the kind of reliability and user benefits demanded for industrial environments. They are easy to use, fully documented, and available with a wide variety of options.

The RTI-1280 Series complements Pro-Log's† wide range of digital cards by adding real-world I/O functions to the CMOS STD bus. Until now, most cards available for use with the bus have had to do with the processing, transmission, and control of digital data. However, because the purpose of many applications is to measure and control real-world phenomena—either in the form of analog voltage and current inputs and outputs, or by providing or sensing switch closures and decisions—cards having analog I/O and digital I/O capability were needed, and are now available.

The family consists of the RTI-1280—a 12-bit analog input card, the RTI-1281—the industry's first 12-bit combination I/O card, the RTI-1282—a 12-bit 4- or 8-channel output card—and the RTI-1287, a 24-channel digital I/O card. These cards all interface to the CMOS STD bus, as either memory-mapped or I/O-port-addressed peripherals, as determined by user-selectable jumpers.

Designed for ruggedness, low power drain, and high performance, these cards can be used in harsh environments, remote sites, and situations where only battery power is available. Typical applications include SCADA (supervisory control and data acquisition), well-site supervision and pipeline monitoring, meteorological data collection, process control, battery-powered instrumentation, medical electronics, and energy-management systems.

WHICH CARD FOR THE JOB?

Analog I/O cards are available in a variety of forms. To select the right combination of inputs/outputs for a given application, the user must understand the differences in architecture and the characteristics of the various options.

Data Acquisition

The RTI-1280 (Figure 1) acquires data from 16 single-ended or pseudo-differential channels, or 8 differential channels; the multiplexers are dielectrically isolated and can handle inputs of up to ±35 volts without damage. The card includes an instrumentation amplifier with five jumper-selectable gains: 1, 10, 100, 500—and a user-selectable resistor-programmable gain value, a sample/hold circuit, and a 12-bit analog-to-digital converter that is monotonic from −25°C to +85°C. Specifications include accuracy to ±0.02%, and 12-bit resolution, with throughput speeds of 16,000 conversions per second for single-channel scans and 12,000 conversions per second for multiple-channel scans.

*Use the reply card for technical data.
†Pro-Log Corp., Monterey, CA 93940.
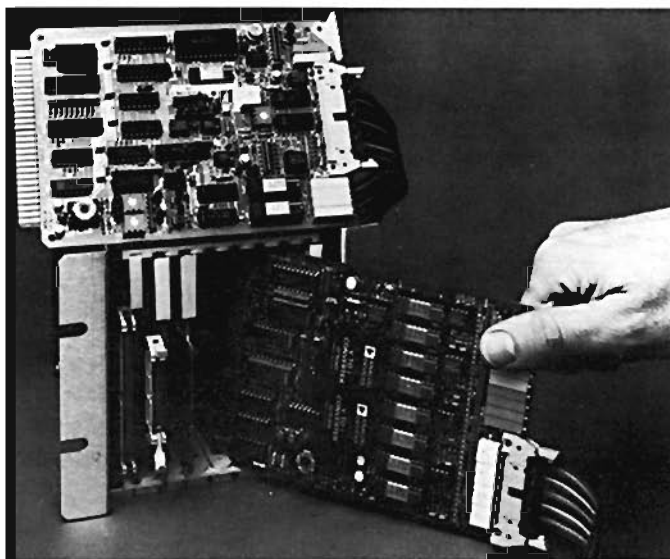
The CMOS design of the RTI-1280 calls for power consumption of only 440mW, for continuous conversions on a single +5-volt power supply. For periods when a/d conversions are not required, a software-selected "sleep" mode puts the analog circuitry into a quiescent state, reducing power consumption by 40%; ±15-volt power is disconnected from all analog circuitry except the input multiplexer (to maintain its input impedance and protect it).
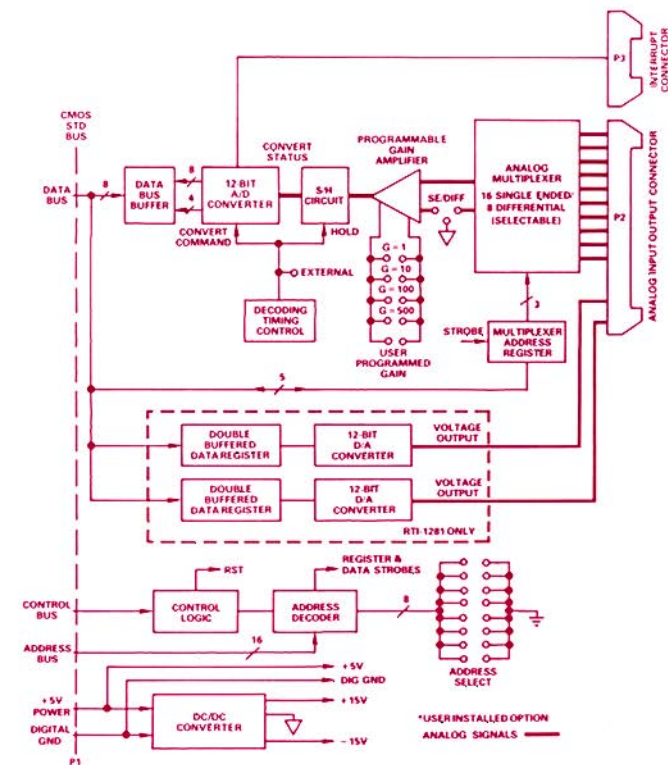

Figure 1. Block diagram of RTI-1280 and RTI-1281 analog input and analog I/O cards.

A/D conversions can be initiated either by software instructions or by an external trigger pulse. Under external control, conversions can take place at intervals as frequent as 60 μs.

Analog Control

The RTI-1281 and RTI-1282 provide independent d/a conversion channels for driving servo actuators, control valves, and other control mechanisms. The RTI-1281 contains two channels of d/a conversion, as well as the RTI-1280's data-acquisition circuitry; it is ideal as a one-board control interface for closed-loop control of simple loops: signal inputs are conditioned and converted on the board, then digitally processed, and the results of the processing produce a pair of outputs from the board; they manipulate a pair of real-world variables, which influence (through the process being controlled) the variables measured by the signal inputs, etc.

The d/a converters are double-buffered from the bus, so that the twelve-bit data can be loaded into each DAC in two bytes without disturbing the DAC output, then strobed in to update the DAC as a single word.

The RTI-1282 provides additional output channels for systems having more output variables to be observed or manipulated. As Figure 2 shows, it is available in two optional forms, either with a full complement of 8 channels (RTI-1282-8), or with 4 channels (RTI-1282-4).

Each converter has a different address. An analog output channel is set by writing a digital code to the appropriate address. The d/a converters have jumper-selectable output ranges of 0 to +5 volts, 0 to +10 volts, ±5 volts, and ±10 volts.
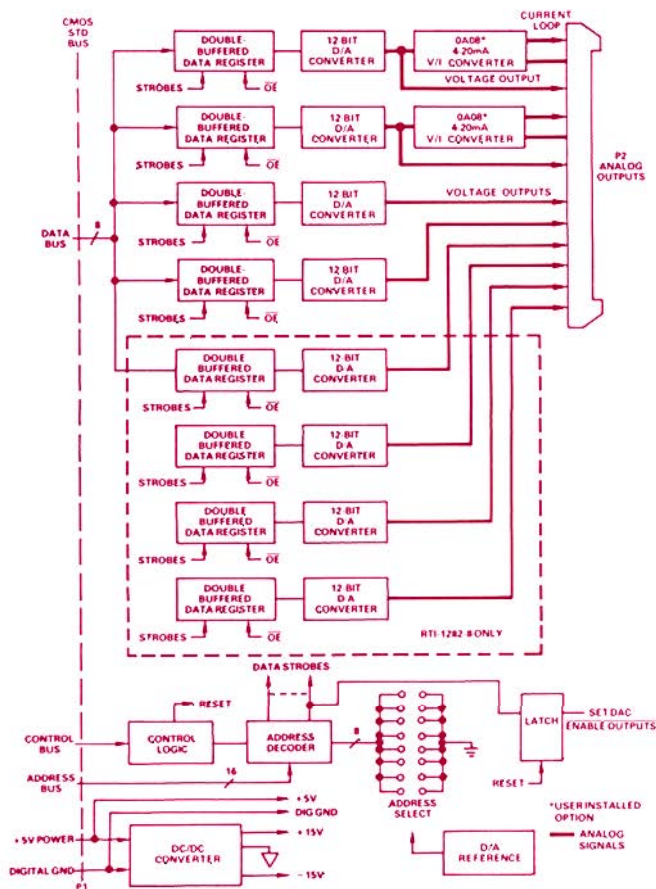
Figure 2. Block diagram of RTI-1282 analog output card.

Since it is often desirable to transmit an analog signal as a current, rather than as a voltage, to prevent degradation of the signal by IR drops and voltage noise picked up in the field wiring, two of the outputs can be converted to 4-to-20-mA currents when an optional voltage-to-current-converter module—powered externally by a +15 to +30-V source associated with the remote load—is installed on the card. (This OA08 module meets all requirements of ISA-S50.1 Standard for Type 3, Class L, nonisolated 4-20-mA current-loop transmitters.)

All of the analog cards have reliable socket and header connectors with locking tabs, which enable flat ribbon cables to be connected. An optional screw-termination panel (AC1585) is offered for simple and convenient field-wire connections.

Digital I/O

The RTI-1287 digital input/output card provides 24 channels of bidirectional I/O via three 8-bit ports (Figure 3). In the active-low Input mode, an input signal is filtered and compared with a threshold—(which can be adjusted by user-installed resistors). As outputs, the I/O terminals are open-collector active low and capable of sinking 20mA, with the option of increased capability (to 100mA), with user-installed resistor networks.

All outputs are protected for inductive kickback, as well as reverse voltage. Connections to the RTI-1287 are made via a 50-pin card-edge connector; the card is compatible with industry's solid-state I/O racks (for example, OPTO-22, Gordos, or equivalent). Power for the rack is jumper-selectable for +5V, +12V (from the STD bus) or an external voltage source up to +30V.

CHARACTERISTICS

The analog cards have an on-board dc-dc converter, allowing them to draw power for their operation from the +5-volt supply provided on the STD bus. Typical power requirements are 440mW for RTI-1280, 500mW for RTI-1281, and 350mW (4-channel RTI-1282). The RTI-1287 runs directly from +5V and typically consumes 30mW.

All cards interface to the STD bus as a block of successive bytes in either memory—or port I/O addressing space. Operating temperature range for the analog cards is −25°C to +85°C, and for the RTI-1287, −40°C to +85°C. Prices (1's) are: RTI-1280, $645; RTI-1281, $795; RTI-1282, $495 (4-channel) and $745 (8-channel); and RTI-1287, $300.

RTI FAMILY

The 1280 series CMOS STD bus cards are the newest members of the Analog Devices real-time interface (RTI) card family.* These products are analog and digital boards that interface directly with popular microcomputer buses, such as VMEbus, MULTIBUS, and STD BUS. The boards plug directly into the microcomputer card cage and are electrically and mechanically compatible with the bus they are designed to interface with. ▷
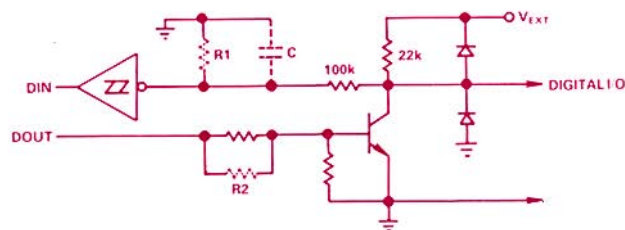
Figure 3. Typical digital input/output circuit on RTI-1287.

THERMOMETER WITH RESOLUTION BETTER THAN 0.0001°C
Precision Absorbed-Dose Calorimeter System Drifts Less Than 80μ°C/h

by Roderick S. McDougall, Ph.D.*

We describe here a graphite calorimeter for measuring absorbed dose produced by ionizing radiation. Besides ease of use, an important feature of such a device is the high-resolution differential thermometer—employing precision thermistors—used for calorimetric measurements of temperature rise of a graphite target when subjected to radiation dosages. Differential temperature can be measured with resolution better than 0.1 millidegree.

We needed a reference standard capable of achieving precision and accuracy of ±1% for radiotherapy, that would be easy to use in practical situations. After careful study of previous calorimeter designs, it became apparent that a new design would be needed to meet our objectives. We sought to minimize maintenance, by avoiding a vacuum system and highly complex electronic circuitry, and to have a measuring system that was easily transportable to the place where the measurement was to be made.

The keys to our design were a high-resolution differential thermometer and a transportable thermistor sensor box which could keep thermal drifts of less than 80 microdegrees per hour with little required maintenance.[†]

Over a twelve-month period, an early version of the design has proven to be reliable, accurate, and inexpensive to maintain. A newer design, employing many of the same principles, but adding a servo-controlled oven for decreased thermal drift (resulting in an effective increase in insulation capability) is able to resolve temperature rises of 50 microdegrees per hour. We have compared its performance with a Farmer graphite chamber in water and graphite. Although the measurements described here are for a specialized application with photon beams of ^{60}Co, 6, and 18MV, the overall design of this calorimeter is such that it can be used for a wide range of precision general calorimetry.

TEMPERATURE SENSING CIRCUIT

The differential thermometer circuit can measure temperature differences to hundredths of a millidegree, using an ultraprecision potentiometer employing a Kelvin-Varley divider capable of 5-decade resolution. Though expensive, it provided considerably better results than 10-turn precision potentiometers.

The earlier version of the instrument used linearized thermistors for measurement, employing the circuit of Figure 9.4, page 148, in the *Transducer Interfacing Handbook* (Figure 1). The key to performance of the circuit is a chopper-stabilized operational amplifier (Model 261K[‡]), with maximum initial offset of 25 microvolts and maximum drift of 0.1μV/°C, used as a floating bridge amplifier, isolated from the rest of the circuitry by an isolation amplifier (Model 277[‡]).
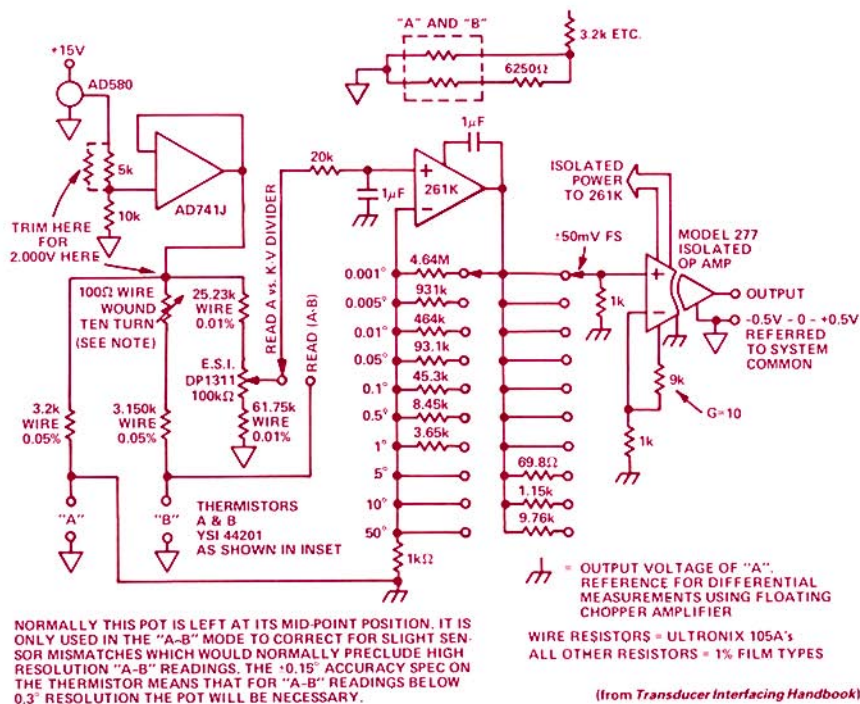

NORMALLY THIS POT IS LEFT AT ITS MID-POINT POSITION. IT IS ONLY USED IN THE "A–B" MODE TO CORRECT FOR SLIGHT SENSOR MISMATCHES WHICH WOULD NORMALLY PRECLUDE HIGH RESOLUTION "A–B" READINGS. THE ±0.15° ACCURACY SPEC ON THE THERMISTOR MEANS THAT FOR "A–B" READINGS BELOW 0.3° RESOLUTION THE POT WILL BE NECESSARY.

⚡ = OUTPUT VOLTAGE OF "A". REFERENCE FOR DIFFERENTIAL MEASUREMENTS USING FLOATING CHOPPER AMPLIFIER

WIRE RESISTORS = ULTRONIX 105A's
ALL OTHER RESISTORS = 1% FILM TYPES

(from *Transducer Interfacing Handbook*)

Figure 1. High-resolution differential thermometer.

Thermistors are low-cost devices capable of operating over a moderate range of temperature and available in a wide variety of standard resistance values (at 25°C and negligible dissipation). Linearized thermistors may be used in two ways, either as resistors with resistance proportional to temperature (2-terminal) or as voltage dividers with ratio proportional to temperature (3-terminal).

The device employed in Figure 1 is 3-terminal Yellow Springs Instrument Co. type YSI 44201, measuring 1mm thick by 1.8mmD. It has excellent stability, high sensitivity, and good response speed. The device used in a more recent circuit is a two-terminal type 44014, which costs less, is available in a wide choice of nominal resistance, and affords ten times the sensitivity.

Thermistor circuits perform two kinds of measurement—the temperature of the thermistor in position A, and the differential temperature between thermistors A and B. The latter is a precision measurement that has been used to collect the central-axis depth dose of a 6-MV treatment beam at D_{max}, 80% dose depth, and 50% dose depth. The instrument's precision has a measured coefficient of variation of 1%.

Because it floats electrically, receiving isolated power from the 277 isolator, the 261K can perform differential voltage measurements with high common-mode rejection. The temperature at thermistor A, in Figure 1, is measured by forming a bridge with the precision divider, and adjusting the divider output for a null, using the 261K as the null amplifier. At null, the precision divider represents the attenuation of the thermistor leg of the bridge; it can be calibrated for temperature by subjecting thermistor A to standard temperatures, noting the divider setting at those temperatures, and interpolating between them. For differential temperature measurements, a bridge is formed between A and B, and the 261K reads out the difference directly.

The appropriate value of gain is set by a string of switched resistors. A fair number of gain steps are provided to permit the sensitivity of the measurement to be increased to the maximum required. The 100-ohm variable resistor is used to standardize the outputs of the two thermistors at the same temperature for measurements with better than 0.001°C resolution.

The 100 nV/°C drift specification of the 261K permits extremely high overall gains to be used. On the most-sensitive gain setting (and when instrumented with all appropriate precautions), the circuit will allow differential temperature changes of 10 microdegrees Celsius at the sensor to be detected.

CONTROLLING THE ENVIRONMENT

In order to permit the detection of small temperature changes, thermal drifts within the sensor housing must be reduced to the lowest possible level. This can be done in two ways—one is by "brute force," interposing a large mass of liquid, thermally insulated from the sensor housing and the outside world. The other approach is to use a much-more-compact insulated servo-controlled oven, which is maintained by feedback (not shown) at a temperature close to the temperature being sensed, thus providing a thermal "guard." The former approach was used for the first model built (with ethylene glycol as the medium in a Dewar flask inside a block of styrofoam), and the latter was used for the most recent model.

Figure 2 is a sectional drawing of the calorimeter-oven assembly.

The calorimeter consists of a graphite rod of diameter 10mm and length 60mm, with a small hole for the thermistor drilled into the side of the rod at a depth of 30mm. After the thermistor is seated, graphite powder is packed in around the thermistor and the hole is sealed with epoxy cement. The graphite rod is positioned in the center of the 15cm (L) by 8cm (D) oven, with a Styrofoam ring acting as a thermal insulator; and a thin aluminum lid—with a small hole for the thermistor wires—is secured as a cover for the oven.

Nichrome tape is wound around the outside of the aluminum cylinder as a heating element. The sensor for the servo loop is a precision thermistor, mounted in a small hole in the aluminum oven. It compares the temperatures of the oven and the sensor, and the applied heat is controlled to make the oven temperature track the sensor.

The oven is securely positioned inside a high-quality Dewar flask (Pope Scientific) 30cm high and 9cm in diameter. It is sealed using a Styrofoam plug with two small holes (for the electrical leads), which are sealed with a Silastic compound. The Dewar flask is then immersed in a Lucite cylinder filled with ethylene glycol to within 1cm of the Dewar-flask top. The whole assembly is then surrounded with a 10-cm thickness of high-density Styrofoam.

Accuracy of measurement systems employing thermistors depends on the quality and precision of the calibration system used. It in turn depends on how far apart the calibration points are, and the method of interpolation. The use of such points as the H_2O triple point, Hg triple point, gallium melting point, indium freezing point, and tin freezing point provide a solid basis for interpolation.

In our case, two points were used for calibration—ice water and a gallium standard traceable to the National Bureau of Standards, producing a temperature of 29.7713°C. In addition, a known amount of energy was being injected into the known volume of graphite (where the thermistor is embedded) over a given period of time; therefore, the temperature rise can be calibrated in terms of energy.
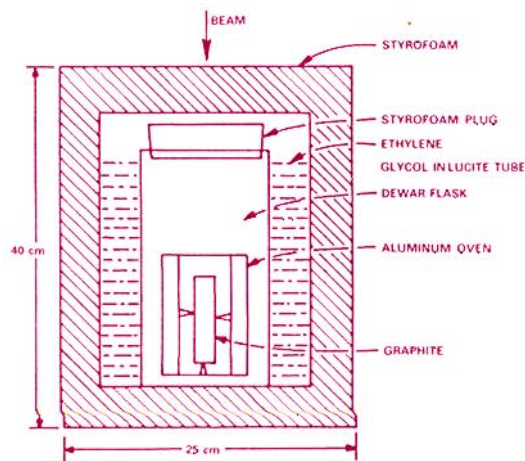

Figure 2. Calorimeter-Oven Assembly.

PERFORMANCE

Over a one-year period, both models of the calorimeter have produced results with a consistency of ± 1.5%, when compared with measurements made with a Farmer graphite chamber, for dosages in the range 50-400 rads. The linearity and reproducibility are excellent in the same dose range. The results show that a practical calorimeter that is easy to use can be built at reasonable cost. ▶

FAST A/D CONVERTER
8-Bit AD7576 Converts in 10 μs
Cool, Low-Cost, μP-Compatible
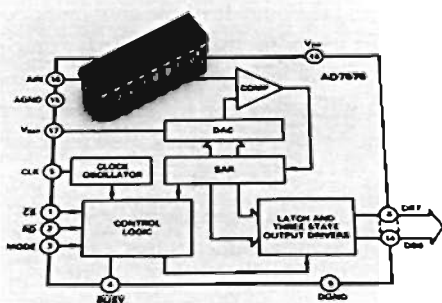
The AD7576* is an 8-bit CMOS a/d converter in a narrow 18-pin dual in-line package. It performs a full-accuracy successive-approximation conversion in 10 microseconds, operates from a single +5-volt supply, and is compatible with most microprocessors—including the fastest versions of the 8085, Z-80, 6502, 6809. It is available in plastic for 0°C to 70°C operation and in cerdip for −25°C to +85°C and −55°C to +125°C.

A general-purpose device, it is ideal for applications, such as modems, where speed, low power dissipation (35 mW max), no-missing-codes over temperature, and single-supply +5-volt operation are important. It is probably worth considering for almost *any* application, because of its low pricing—starting at $4.50 in 100s.

Another factor that makes this ratiometric device suitable for general purposes is its ability to operate with an inexpensive positive 1.23-V external bandgap reference.

As a memory-mapped peripheral, its versatile interface logic allows it to be configured to perform continuous conversions asynchronously—or to convert under control of the microprocessor. In synchronous conversion, it can be made to interface as ROM or slow memory; a Read instruction starts the conversion, and—in the case of ROM—the completed conversion generates an interrupt (or sufficient time passes for an interrupt to be unnecessary), and a second Read instruction reads out the new data. In the slow-memory case, the $\overline{BUSY}$ line holds the processor in a Wait state until conversion is complete. ▶

* Use the reply card for technical data.

LOW-COST RESOLVER-TO-DIGITAL CONVERTER
Hybrid 12-Bit 2S20 Tracks at Rates up to 6,000 RPM
## Ratiometric Technique is Amplitude-Insensitive

The 2S20* is a 12-bit resolver-to-digital converter in a 32-pin dual-in-line (0.9″) package. It converts the output of a brushless resolver to a 12-bit parallel digital word representing the resolver's shaft angle. With a resolver and an ac source, the combination constitutes a high-reliability, low-cost absolute shaft encoder. Due to the use of compact, application-specific integrated circuitry, the 2S20's cost is quite low, $69 in 100s.

Specified to operate at temperatures from 0°C to +70°C, the 2S20 is ideal for angular-measurement applications in robotics, machine-tool control, factory automation, and industrial control.

It will operate with signal and reference frequencies from 1kHz to 10kHz, with signal inputs of 2.5V rms and reference inputs from 2.5V to 10V rms. The 2S20's accuracy at 25°C is to within ±11 arc-minutes (i.e., less than 2½LSB), with a tempco of 0.12 arc-min/°C. 25°C accuracy is maintained for variations of ±10% in voltage and frequency and 5% power-supply.

Microprocessor-compatible, the 2S20 interfaces its 12-bit parallel output via a set of 3-state latches. Tracking continuously, the conversion loop's operation is unaffected by data transfer. ▶
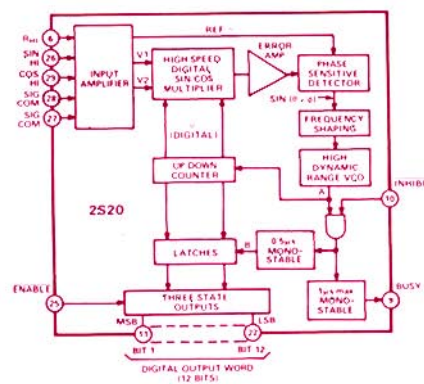
8-BIT RASTER DACS FOR −55°C TO +125°C
New Options in the HDG Series Offer Improvements in:
## Linearity Tempco, PSRR, Dissipation, Supply Current

The 8-bit HDG* Series of hybrid DACs for intensity control in raster displays first appeared in these pages in 1981 (*Analog Dialogue* 15-2, pages 3-6), to join the 4- and 6-bit members of the family. They have since become a standard in the industry and have been widely imitated.

They offer complete composite controls, including 256 levels of gray scale, self-contained digitally controlled sync and blanking, a reference white control input to ensure compatibility with EIA standards, and 10% bright capability—accompanied by 8-ns settling time. The reference is internal, only a single −5.2-volt power supply is needed, and all devices are monotonic over temperature.

Now, a new generation of plug-compatible optional members of the HDG family are available from Analog Devices, including a set of hitherto unavailable −55°C to +125°C units (SD and SDB suffixes). Performance is better in a number of important respects, internal parts count is smaller for improved reliability, and—perhaps equally important—prices are lower, starting at $39 in 100s for 8 bits (HDG-0805BW).

Performance improvements include a 30 ppm/°C max nonlinearity tempco, 35% to 75% less dissipation, 0.005%/% power-supply sensitivity, and considerably lower Strobe input loading. ▶
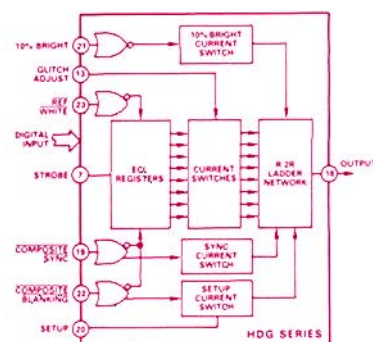
THERMOCOUPLE AMPLIFIERS IN CERDIP
AD594 & AD595 Provide Cold-Junction Compensation
Need No Trimming for J- and K-Type Thermocouples
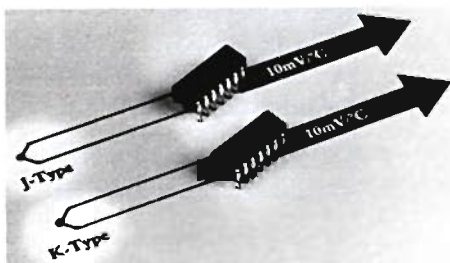
The popular AD594* monolithic IC amplifier for J-type thermocouples (first introduced in these pages in volume 16, no. 3) and the AD595* for type K (17-3), are now available in cerdip at substantially lower cost.

The devices amplify low-level thermocouple signals and provide reference-junction compensation at ambient temperatures from 0°C to 50°C, compactly and accurately, replacing everything from ice buckets to expensive, space-consuming hand-trimmed circuit kludges in custom designs.

In both devices, an instrumentation amplifier, an on-chip temperature sensor, and an open-thermocouple alarm circuit are combined in a single 14-pin cerdip package. The AD594Q produces an output scaled to 10 mV/°C from a J-type thermocouple input, and the AD595Q does the same for Type K.

The devices can be recalibrated for other thermocouple types by the addition of external resistors. They can also be used as setpoint on-off controllers or stand-alone 10 mV/°C temperature transducers, by external pin-strapping.

A single +5-volt supply will suffice when the devices are used in measurement of temperatures above 0°C (dissipation is only 1 mW maximum); but dual supplies of up to ±30 volts can be used for wider temperature ranges.

Accuracies are to within 3°C (AQ grade) and 1°C (CQ). Prices (100s) are only $6.00 (AQ grades) and $10.85 (CQ). ▶

LOW-COST PRECISION BIFET OP AMPS
AD611 Available in Hermetic Metal and Cerdip Packages
Maximum Drift, Bias Current: 10 μV/°C, 50pA (AD611K)

The AD611* is a monolithic precision BiFET operational amplifier combining high performance, low price, and a choice of performance and package options.

Available in two grades (K/J) for operation from 0°C to +70°C, it has low offset voltage (0.5/2.0mV max) and drift (10/20μV/°C max), and 8V/μs minimum slewing rate. Because of its low offset and drift, reasonably fast large-signal settling time (3μs) and well-behaved response, it is a near-ideal choice for use as an inverting amplifier with current-switching CMOS d/a converters.

The figures show its typical large- and small-signal responses as output amplifier for an AD7533 4-quadrant multiplying DAC (15 pF feedback capacitors).

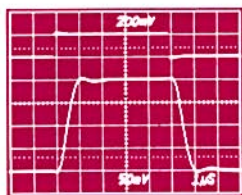Both performance grades are available in a choice of hermetic 8-pin packages: metal

*Use the reply card for technical data.
‡ See Page 24.

can (H) or cerdip (Q). Screening to the Analog Devices enhanced-reliability PLUS program† for monolithic ICs is available for a small premium. Prices (100s) for J,K,J/+, K/+ are: $1.00,$1.95,$1.35,$2.45, using either package. ▶
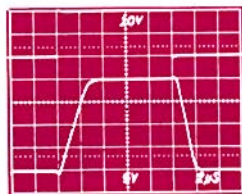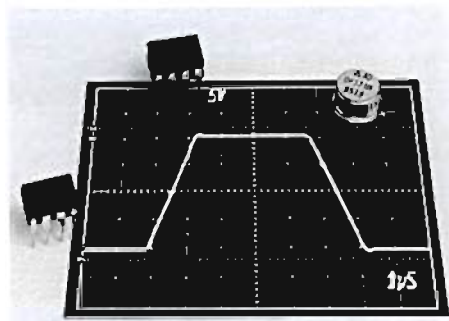

Large Signal Response

Small Signal Response

AD OP-37 OP AMP
ADI Performance & Quality
With Existing 2nd Sources

The newest member of the AD OP-07 and AD OP-27 family of precision bipolar op amps is the AD OP-37*, a high-performance monolithic operational amplifier manufactured with bipolar IC technology. It features a minimum slewing rate of 11 V/μs and gain-bandwidth of 45MHz, to accompany its excellent dc characteristics: maximum offset voltage and drift of 25 μV and 0.6μV/°C (A and E grades), and maximum peak-to-peak noise of 0.18μV at low frequency (A/B/F/E, 0.1Hz to 10Hz).

The OP-37's high gain-bandwidth product and ultra-low input voltage noise allow it to excel in applications requiring accurate amplification of very low level, high-speed signals. These features, in conjunction with minimum common-mode rejection (CMR) of 114dB (E/A) and open-loop gain of 10^6, well suit the AD OP-37 to amplifying low-level signals in instrumentation applications.

Six grades guarantee performance over two temperature ranges. From −25°C to +85°C, the G/F/E grades specify maximum offset voltage and drift of 100/60/25 μV and 1.8/1.3/0.6μV/°C. From −55°C to +125°C, the same specifications are maintained by the C/B/A grades. Other specifications include minimum CMR of 100/106/114dB for G,C/F,B/E,A grades—and maximum input voltage noise spectral density of 4.5 and 3.8nV/√Hz @ 1kHz for G/C and F/E/B/A grades, respectively.

The AD OP-37 is available in an 8-pin plastic mini-DIP, an 8-pin cerdip, or a TO-99 hermetically sealed metal can. Price (100s) ranges from $3.30 (AD OP-37GN) to $20.70 (AD OP-37AH/883B). ▶

16-BIT HYBRID ADC
Fast: 17-µs max Conversion Time
Hermetic Welded Metal Package
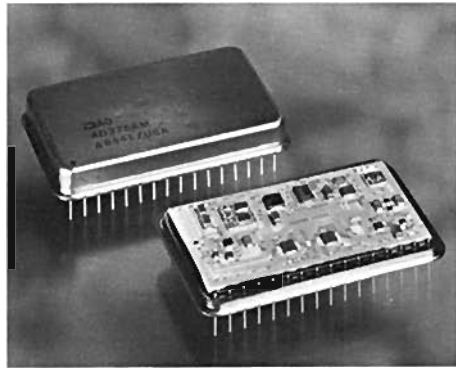
The AD376* is a 16-bit hybrid a/d converter in a hermetically sealed metal case. It performs a complete 16-bit conversion in 17 microseconds; and it guarantees no missing codes over the entire specified temperature range (for 14-bit resolution).

Applications for the AD376 include precision measurement for medical and analytical instrumentation, industrial robots, automatic test equipment (ATE), multi-channel data-acquisition systems, and servo-control systems. The AD376 is also useful for applications involving wide dynamic range.

The ADC376—which employs proprietary IC chips—tends to have lower noise, improved no-missing-codes performance, and higher predicted reliability through lower chip count than other leading 16-bit hybrid ADCs that are pin-compatible with it. This permits performance in existing applications to be more easily upgraded.

The AD376 is completely self-contained, with its own internal reference and clock for performing successive-approximation conversions. Where microseconds must be saved, it can be short-cycled for 15-µs 14-bit conversions.

Available in two 0°-70°C grades (K/J), the AD376 has linearity to within ±0.003/0.006% of full-scale range. It accepts unipolar (0 to +5,10,20V) and bipolar (±2.5, ±5, ±10V) input signals. Specified operation is with ±15-volt and +5-volt power supplies, with typical power consumption of 1.1W. Prices in 100s start at $189. ▶

*For technical data, use the reply card.

DIGITAL-TO-RESOLVER/SYNCHRO X'FORMERS
Low-Profile 0.4"H STM1680/1683 for Reference and Output
47-440-Hz STM1660/1663 Extend Operation to Low Frequency

The transformers described here are designed for use with hybrid digital-to-resolver converters, like the 14/16-bit DRC1745/1746,* introduced in these pages (vol. 16, no. 3). The transformers provide electrical isolation and easy conversion of the resolver output of these devices to synchro format.

They are used in pairs: the STM1680/1683 offer a lower profile to permit standard board spacing in card cages for systems using reference frequencies from 360Hz to 2.6kHz; and the 1-inch high STM1660/1663 for the first time offer 50/60-Hz (actually 47-440Hz) capability for the DRC1745/1746.

The STM1680 and STM1660 input transformers serve to isolate the converters (1000V dc) from the ac reference source, and to transform from 11.8-, 26-, or 115-volt primary to 3.4V rms recommended for the DRC1745/1746 inputs—at the appropriate frequency ranges. The STM1683 and 1663 provide Scott-T output transformation from 6.8-volt two-phase resolver format to 11.8-, 26-, or 90V rms three-phase (to ground) synchro format.

The output transformers can handle 0.1 volt-ampere with ±1 (maximum) arc-min of error, increasing to only ±3.0 arc-min at outputs as large as 2.2 volt-amperes, with a maximum temperature coefficient of 0.02 arc-min/°C. The transformers are rated for operation at temperatures from −55°C to +125°C. ▶
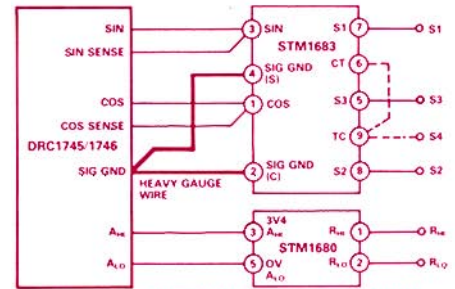
NOTE: FOR SYNCHRO OUTPUT "CT" MUST BE CONNECTED TO "TC". FOR RESOLVER OUTPUT "TC" IS S4 (NO LINK)

ANALOG DEVICES *PLUS* PROGRAM
Environmental Screening: Hi-Rel for Non-Military Parts

Analog Devices "PLUS" products are standard devices (commercial and industrial grades, plastic or ceramic packaging) with enhanced reliability—available at a *small* premium and designated by the suffix "/+". They are subjected to a stringent screening process, developed from proven MIL-STD-883 test methods. Our experience in building products on MIL-M-38510 lines, guarantees the highest standards of workmanship.

The standardized PLUS process flow offers important advantages to users with demanding application environments: lead times are minimized, and delivery is often off-the-shelf; there are no minimum-order requirements; reliability is enhanced; and high value is added at low cost.

The PLUS program embraces more than 74 popular product families—including op amps, d/a and a/d converters, voltage references, temperature transducers, instrumentation amplifiers, VFCs, analog and digital signal-processing components, CMOS switches, and sample/holds. Use the reply card for information on PLUS. ▶
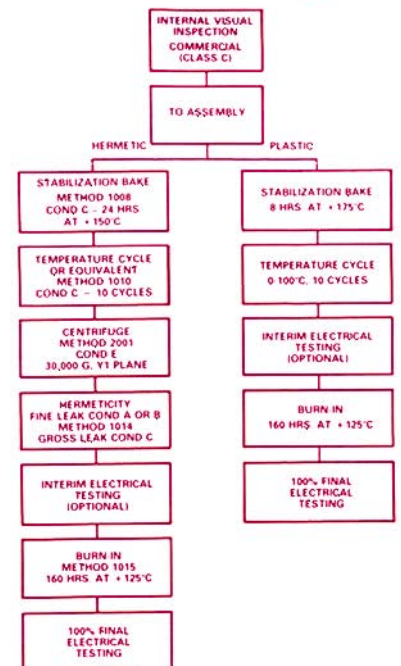
Paul Klonowski (page 10) is a Product Marketing Engineer in the Converter Group at Analog Devices Semiconductor (ADS), Wilmington, Mass. He was graduated from the University of Cincinnati in 1984 with a BSEE. Before joining Marketing, he was an Applications Engineer with ADI's Components Applications Group.

Dick Meaney (page 15) is a Senior Design Engineer at Analog Devices, BV, in Limerick, Ireland. He was graduated from the National Institute of Higher Education, in Limerick, with a B.Sc. in Electronic Systems in 1979, and joined Analog Devices the same year. Prior to his work on the AD7820, he designed the AD7240 CMOS DAC. He is a squash player and enjoys music.

John Mills (page 18) is Product Marketing Manager for Board Interface Products in ADI's Industrial Automation Division. He earned his BSEE degree at Northeastern University. John first joined Analog Devices as an Application Engineer, then became a regional Sales Manager for Datel-Intersil and subsequently rejoined ADI as a Senior Marketing Engineer. He enjoys softball, golf, cross-country skiing—and is a racquetball enthusiast.

Steve Sherman (page 3) is a Design Engineer at ADS, where he has designed op amps, computing circuits (e.g., the AD538), and software-programmable gain amplifiers. He was born in Woonsocket, RI, earned a BSEE at the University of Rhode Island and an MSEE at Case Western Reserve University. Before joining Analog Devices, he designed custom digital ICs for mainframe computers at Burroughs (San Diego) and developed IC fabrication processes for high-speed bipolar circuits at Digital Equipment Corporation.

Bill Windsor (page 8) is a Marketing Specialist in the Analog Devices Digital Signal Processing Division. Before joining ADI, he worked at Honeywell's Small Systems and Terminals Division, designing custom minicomputer hardware. Bill holds a BSEE degree from M.I.T., and an MBA from the Harvard Business School. His spare-time activities include running, backpacking, and squash. ▶

ADI Division Fellow Named
Peter Holloway

Peter Holloway has been named a Division Fellow, in recognition of his many significant contributions to the establishment of Analog Devices as the leader in integrated-circuit data conversion.

Born in Stoneham, Massachusetts, Peter received his engineering education at Northeastern University, began work as a robotics design engineer in M.I.T.'s Artificial Intelligence Laboratory in 1968, and—in 1971—founded Compumod, a modular switching power supply company. He joined Analog Devices in 1974 as an IC design engineer and became engineering manager in 1979. In 1983, he launched an internal semi-custom venture, as Director of Linear Signal Processing.

During the past ten years, Peter has been responsible for the design of some of our most significant—and successful—linear bipolar ICs, including the AD561 10-bit current-output d/a converter, the AD558 8-bit DACPORT™, and the AD574 12-bit a/d converter. He has also been involved with the AD565 (and related DACs), the AD571 ADC, and the soon-to-be released 16-bit BiMOS AD569 (his paper on this won a "best paper" award at the 1984 IEEE International Solid-State Circuits Conference).

As Converter Engineering Manager, Peter has demonstrated technical leadership in assembling a team of design engineers whose most important product developments have manifested an average compound business growth rate of 60% *per year* for the past 6 years.

He has also shown strategic ability: to foresee new technological and product challenges for Analog Devices, to gain support for proposed solutions, and to exercise entrepreneurial talents—bringing together talented people to turn dreams into reality.

His influence has extended well beyond product designs—into process development, design-tool development, and proposed solutions to the transcendent problems of design lead time.

Peter is known and respected in the industry, and he has received both formal and informal recognition of his accomplishments. He has presented and published 7 papers at the ISSCC and in the *IEEE Journal of Solid-State Circuits*, and has served both as an ISSCC Program Committee member and as a JSSC Guest Editor. He currently holds five patents in the field of monolithic data conversion.

Division Fellows—one of the company's highest levels of technical advancement—are recognized for their innovativeness and outstanding technical contributions to Analog Devices, for acting as mentors to young technologists, for having demonstrated leadership of outstanding technical groups or in generating new business opportunities, and for having developed valuable industry and academic relationships for the company.

Peter's combined technical abilities, vision, influence, and accomplishments have solidly qualified him for this appointment. He is our sixth Division Fellow, joining the select company of A. Paul Brokaw and Barrie Gilbert (1979), Jack Memishian (1980), Mike Timko (1982), and Lew Counts (1984). ▶

Worth Reading

ANALOG-DIGITAL CONVERSION HANDBOOK

3rd Edition

By the Engineering Staff of Analog Devices, Inc., edited by Daniel H. Sheingold. Published by Prentice-Hall, Inc., $32.95.* The third edition of a classic in the field, this profusely illustrated book has more than 700 pages, including an Index, a Bibliography, and much new material. Seven of its 22 chapters are totally new.

Here are the Contents in Brief:

NEW PUBLICATIONS AVAILABLE FREE FROM ANALOG DEVICES

Application Briefs

"Exploring the AD667 12-Bit Analog Output Port," by John Croteau (8 pages). Description and applications of a complete-on-a-chip double-buffered 12-bit d/a converter. Includes suggestions for interfacing the device to both microprocessors and analog systems, plus information about output settling, grounding rules, operation as an analog I/O port—with examples of 68000 and IBM PC interfacing.

"Circuit Applications of the AD7226 Quad CMOS DAC," by Mike Byrne (6 pages). Some uses of the AD7226 in dc-type, or voltage-setting, applications; these uses benefit from the inherent DAC-to-DAC matching, or from the space that the device saves

(on-chip latches and output-voltage buffer amplifiers), plus the advantages of single-supply operation. Applications include: programmable offset adjust, set-point controller, self-programmable reference, threshold testing. Additional topics (covered in greater depth than in the data sheet) include V_{ss} generation and 5-volt single-supply operation.

"3-Phase Sine-Wave Generation Using the AD7226 Quad DAC," by Mike Byrne (4 pages). Discusses the use of the AD7226 in waveform generation—specifically, how to generate three-phase sine waves, which can be used in driving small three-phase motors. The AD7226 is a quad 8-bit CMOS DAC, packaged in a 20-pin DIP.

Article Reprint

Gilbert, Barrie, "A Remarkable Monolithic Microsystem Generates Trigonometric Functions." *Industrial Electronics Equipment Design* (McGraw-Hill), September, 1984. About the AD639 Trig function generator—see also *Analog Dialogue* 18-3, pp. 12-14.

Brochure

A Family of System Building Blocks for Automation Management and Control (16 pages). MACSYM workstations, MACSYM and µMAC Measurement-and-Control Interface Units (dumb and programmable), McComm Measurement-and-Control Communications, applications software, signal conditioners, and Real-Time Interface boards.

MCDigest

The Measurement and Control Digest, published by Analog Devices, Inc. Volume 4, Number 4, September, 1985. Features: MAS/Lotus file compatibility; PIO01 Pulse Input/Output card; Three- and Four-Wire RTDs; QMX01H Module for the µMAC-5000; MACSYM user featured in trade magazine; Direct color hardcopy; DPULSE: Pulse output for µMAC boards; Interruptible WAIT statement for µMAC-5000; Applications software sources. Customer training. ▶

REFERENCES FOR PRECISION CALORIMETER (pp. 20-21)
(Only the last item (*) is available from Analog Devices.)

Almond, P.R., "Dose and Energy Calibration for Electron Beams," *Physics in Medicine and Biology* 12, 17, 1967.

Basic Concepts of Thermistors for Thermometry, Yellow Springs OH: Yellow Springs Instrument Company.

Domen, S.R., "Absorbed Dose Water Calorimeter," *Medical Physics* 7, 157 (1980).

——, "Heat-Loss Compensated Calorimeter," *Nature* 222, No. 5198, 1061 (June, 1969).

Handbook of Chemistry and Physics, Cleveland: Chemical Rubber Publishing Co., 1982.

Laughlin, J.S. and S. Genna, in *Radiation Dosimetry*, ed. F.H. Attix and W.C. Roesch, Vol. II, 411-15 (New York: Academic Press), 1966.

Pruitt, J., S.R. Domen, and R. Loevinger, "The Graphite Calorimeter as a Standard of Absorbed Dose for Cobalt-60 Gamma Radiation," *Res., National Bureau of Standards* (U.S.) 86 (5), 495-502 (September-October, 1981).

*Sheingold, D. H., ed., *Transducer Interfacing Handbook*, Norwood MA: Analog Devices, Inc. ($14.50) ▶

*Use the book order card that comes with this issue or phone (617)-461-3392, to order your copy postpaid from Analog Devices. We accept VISA.

IN THE LAST ISSUE (Volume 18, Number 3, 1984) -- 28 pages):

IVS-100: THE EYE™ -- An Intelligent Vision System for Industrial Image Analysis
IVS-100 HARDWARE: Sophisticated Hardware for the Rapid Execution of Machine-Vision Programs
IVS-100 SOFTWARE: A Comprehensive Machine-Vision Library Facilitates Applications Programming
IVS-100 APPLICATIONS: Opportunities for Machine Vision in the Electronics Industry Are Especially Plentiful and Promising.
Monolithic Analog Trigonometric Function Generator (AD639)
Monolithic Sample-Hold is Complete, Fast, Accurate (AD585)
Resolver/Digital Converter with Accurate Tachometric Output (1S14/24/44/64/74 series)
Fast 1.5-Micron Multiplier and Multiplier/Accumulators (ADSP1016A/1008A/1010A)
Precision Demo Units Simplify Analog IC Evaluations
Eight New Plugin Signal-Conditioning Modules in 3B Series
New-Product Briefs:
    8-Bit CMOS DAC with Buffered Voltage Output and Double-Buffered Digital Input (AD7224)
    4-Channel 12-Bit CMOS A/D Converter, No Missing Codes Over Temperature (AD7582)
    Two 12-Bit DACs in 0.3" 20-Pin Package (AD7549, see also p. 7, the current issue)
    Monolithic 8-Bit Raster-Display DAC (AD9700)
    3 Complete New 14-, 15-, 16-Bit Sampling A/D Converters (DAS1157, DAS1158, DAS1159)
    10-Bit, 20-MHz A/D Converter, with On-Board Track/Hold, Complete on a Single Card (CAV-1020)
    Resolver/Synchro-to-Digital Converters - 12-14-16 bits (SDC/RDC1767/1768/1711)
    Hybrid Inductosyn Preamplifier - Matched Pair of High-Gain Amplifiers (IPA1764)
    LVDT/Digital Converter - 11-bit resolution, first in the industry (2S20)
    Faster Tester - Benchtop Component Test System (LTS-2020)
    MACSYM 250 (Interface Cards, Number Crunching, 512K RAM) and MACSYM 260 (Ruggedized Stand-Alone Controller)
    Dual-Loop Controller Card (PID01) and Serial Interface Card (DSI101) for MACSYMs
Worth Reading: Free New Publications from Analog Devices
Editor's Notes, Authors, Potpourri, Advertisement: "At 1 MHz Only One V/F Converter Guarantees This [0.1%] Linearity."
(AD650 V/F Converter.)

PRODUCT NOTES . . . The 1S20/40/60/61 line of hybrid resolver/digital converters now includes the 1S10 - a 10-bit version that can track at up to 40,800 rpm (for motor drives and Inductosyns), and a set of wide-temperature-range (mil temp) options (-55°C to +125°C) in hermetic metal cans. A new data sheet for the series is available . . . °C/°F selection in temperature meters AD2050, AD2051, AD2060, and AD2060 can be remotely set by a contact closure. Set switch behind front panel lens to °C; then logic zero or ground at pin 22 of rear-panel edge connector will change mode to °F . . . Optional versions of the 3B34 RTD Input Module for 3B signal conditioning systems are now available to handle inputs from 10-ohm copper RTDs and 120-ohm nickel RTDs. The 3B34 can be ordered calibrated to 0.1% for standard ranges, or user configured ranges can be obtined with the AC1310 custom ranging card) . . . The MACSYM 200 Measurement-and-Control Interface Unit can be used with MACSYM 121 or 150 Workstations, or with an IBM Personal Computer equipped with an ADI Compatibility Kit. A data sheet is available . . . The AD625 is the industry's first precision instrumentation amplifier to be available in plastic, featuring 0.002% nonlinearity, 115 dB CMR, 4 nV/root-Hz @ 1 kHz, and 1 uV/°C input drift; user-furnished resistors provide flexible gain setting (software-programmable, when used with CMOS switching -- and an inexpensive MUX can be used because force-sense capability removes the on-resistance of the MUX from the signal path) . . . The article, "Another Lamp Failure Blinds GOES-5," in Aviation Week and Space Technology, August 6, 1984, chronicles the misfortunes of the fifth Geostationary Operational Environmental Satellite, when yet another expensive lamp used in an optical encoder burns out. Some synchro and resolver people we know suggest that such problems can be avoided when brushless resolvers and tracking converters are used in remote applications where reliable position measurement is an absolute must.

QUALIFIED PRODUCTS . . . At least 17 Analog Devices product families have versions with JAN part numbers (JM38510/...) for military contracts. They include ADCs, DACs, voltage references, instrumentation amplifiers, op amps, V/F converters, and analog multipliers. See page 33 of the 1985 Military Products Databook, or consult the nearest Analog Devices sales engineer . . . DAC87 is available from Analog Devices, in both monolithic and hybrid form, to DESC drawings 8300301JA and 8300201JC, respectively . . . The 1S10/20/40/60/61 family of resolver-to-digital converters and the DRC1745 digital-to-resolver coverter have passed nuclear radiation hardness tests for neutron bombardment, dose rate, and total dose. For details, consult your ADI sales engineer . . . The 3B Series of Modular Signal Conditioners have won Factory Mutual approval for use in Class I (nonincendive), Division 2, Groups A, B, C, and D locations, and are thus available for use where the system installation requires Factory Mutual qualification.

ERRATA AND DATA NOTICES . . . Erratum: Analog Dialogue 18-1, page 6, Figure 4; in table at left, probability corresponding to p-p/rms = 6 is 0.0027 . . . Revised recommended external R-C values for the AD7571's external clock: R = 56 k, C = 150 pF . . . Models 52J/52K, new drift specs: +5/+3 uV/°C max . . . To avoid retriggering before conversion is completed, for ADC1143, AND the Status output with a 1 us (min) positive Convert Start pulse; for DAS1157/1158/1159, invert EOC and AND it with a convert pulse (5 us min for SHA plus ADC, 100 ns min for ADC only) and apply to Trigger input . . . 1984 DATABOOK, Volume I, page 9-318 (HDS and HDH TTL device specs), package options for all six types should read: HY24G for "M" and "MB" grades, HY24E for commercial grades . . . The most current data sheet for HAS-1409 has extensive changes (including a new option available), supersedes all previous versions; its date (vertical between upper punch holes, page 6) is 9/84.

NEW PATENTS ISSUED . . . 4,475,103 (Adrian P. Brokaw and Barrie Gilbert), Integrated-Circuit Thermocouple Signal Conditioner . . . 4,475,169 (Barrie Gilbert), High-Accuracy Sine-Function Generator . . . 4,476,538 (Barrie Gilbert), Trigonometric Function Generator . . . 4,481,708 (Delip. R. Bokil and Tanjore R. Narasimhan), Reduced Internal Temperature Technique for Hermetic Sealing of Enclosures . . . 4,484,149 (Peter R. Holloway), Single-Supply IC Digital-to-Analog Converter for Use with Microprocessors . . . 4,485,372 (Peter R. Holloway), Two-Stage A-to-D Converter . . . 4,491,825 (Michael G. Tuthill), High-Resolution Digital-to-Analog Converter . . . Re. 31,850 (James J. Pastoriza), Solid-State Digital-to-Analog Converter.

The new AD667.
So advanced, there's
nothing left to add.

Analog's fully evolved 12-bit DAC combines everything you need for direct microprocessor-to-analog interfacing. And it does it in a single chip. This means a functionally complete solution to your design problems in a single package. At a singularly attractive price.

The AD667 includes our patented, current-switched DAC (the world's fastest). An ion-implanted Buried Zener Reference to insure low-drift performance. A double-buffered input latch that easily interfaces with virtually any 4-, 8- or 16-bit microprocessor. And our most recent addition, a high-speed—3µsec—op amp for direct buffered voltage output.

Integrating all of these functions on one chip eliminates the need to research, error-budget, characterize and select external components. So while saving valuable board space and design time, you get the added benefit of monolithic construction—improved system reliability!
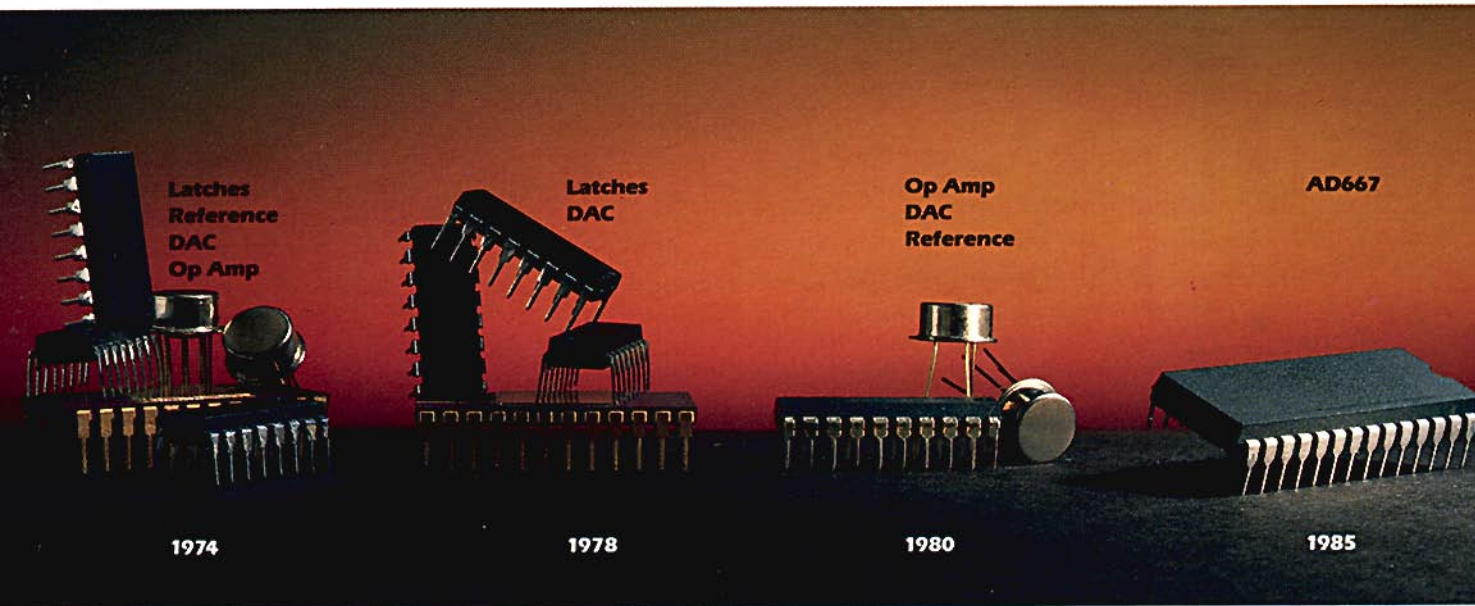
Singularly attractive
price: $9.90.

The whole now costs less than the sum of its parts, with pricing for the AD667 starting at $9.90 in thousands. So, evolution means increased economies, as well as increased functionality.

And you have choices, too. The AD667 is available in 28-pin plastic and ceramic DIPs or leadless chip carriers (LCC) for surface mounting. Alternatives that mean packaging flexibility.

Analog's evolutionary AD667. The monolithic 12-bit DAC that makes external components extinct.

For more information and the full specifications on this advanced new DAC, call Applications Engineering at (617) 935-5565, ext. 2628 or 2629, or write Analog Devices, P.O. Box 280, Norwood, MA 02062.

▶ ANALOG DEVICES

Latches
Reference
DAC
Op Amp

Latches
DAC

Op Amp
DAC
Reference

AD667

1974   1978   1980   1985

Evolution of the total 12-bit DAC.