

analog dialogue

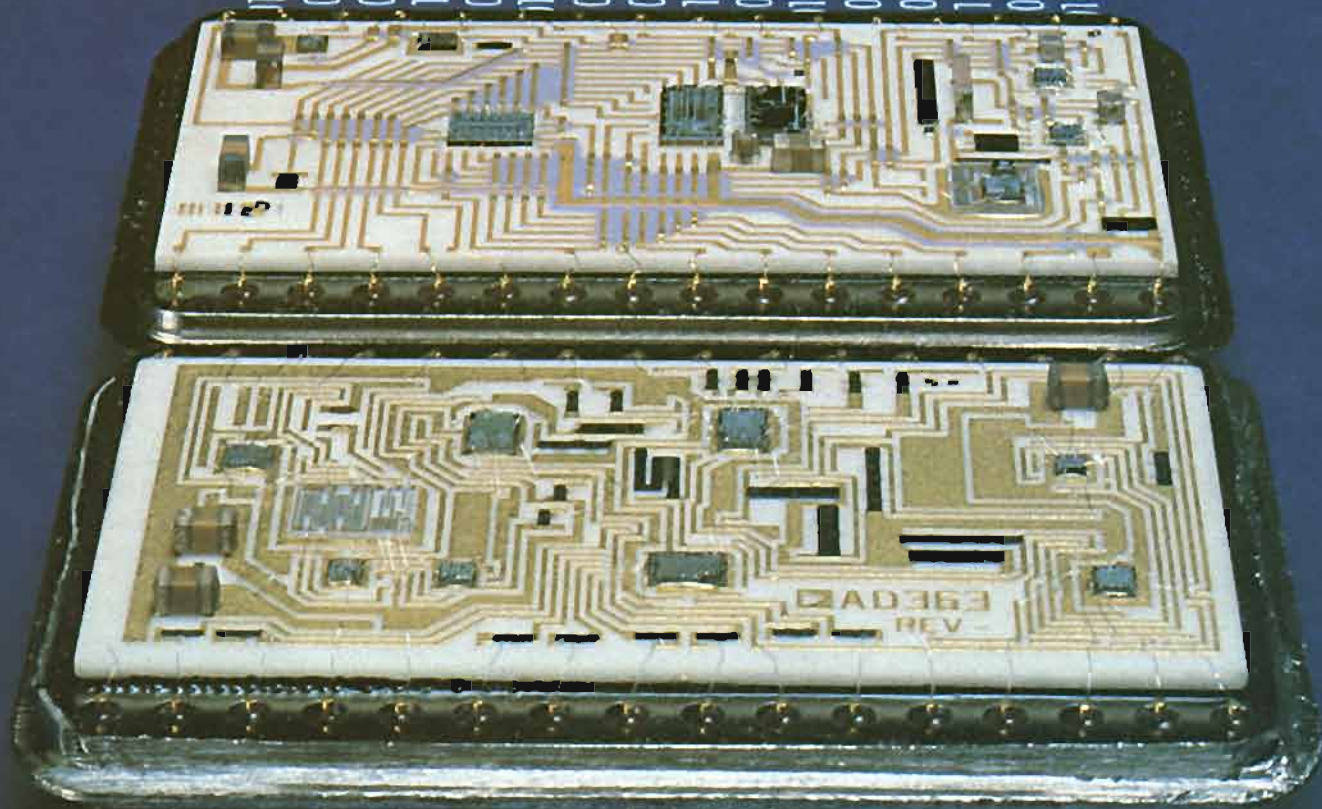
A forum for the exchange of circuit technology: Analog and Digital, Monolithic and Discrete

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Multiple-Output IC Voltage Reference

Circuit Design Ideas for IC Converters

Complete Contents on Page 3



Editor's Notes

ANALOG DIALOGUE — AN INSIDE VIEW

Perceptive readers may have noticed that we do not sport a conventional "masthead", bristling with Associate Editors, Managing Editors, Contributing Editors, and other functionaries.

Just about everyone who works on *Analog Dialogue* has deep commitments to other activities. Yet it manages to appear, from time to time, as a reasonably attractive, reasonably accurate, reasonably readable, hopefully interesting, coherent whole.

We have a mandate, a budget, and a stimulus from the highest levels of our Company to publish as frequently as feasible. We have the cooperation and interest of technical people, both inside and outside Analog Devices (as our "Authors" list will testify). While our door is in no immediate danger of being battered down by eager throngs of would-be contributors, we do seem to have a good and timely impedance-match to sources of interesting technical material.

But the real key to the *Dialogue's* appeal is the conscientious handling by our busy Graphic Services group. The best of manuscripts can be damaged in credibility by poor use of type and layout, drawings that obfuscate, typographic errors and inconsistencies, and — in sum — casual, uninterested handling. We wish publicly to acknowledge our debt to Marie Etchells, Manager of Marketing Services at Analog Devices, Cammy O'Brien, Supervisor of Graphic Services and Distribution, and the people who actually produce *Analog Dialogue*: Ernest Lehtonen, Marci Leavitt, and Dianne Nemiccolo on the boards, and Kathleen Hurd and Joan Costa at the keyboards.*



Without their creativity, thoroughness, and patient understanding, *Dialogue's* effectiveness and readership would be but a fraction of what it appears to be. Thanks, one and all!

Dan Sheingold

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*Standing: Ernie, Dianne, Kathy, Joan, Marci; Seated: Cammy, Dan, Marie.

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Alfred (Archie) Gagne (page 16) is a Member of the Technical Staff at Sanders Associates, Inc., Nashua, N.H., where he has worked for the past nineteen years. Archie is currently responsible for several programs involving special applications of noise-figure instruments to meet unique system requirements. Travel trailering in the summer and house restoration keep him occupied in his leisure time.



analog dialogue

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12-BIT IC DATA-ACQUISITION SYSTEM

Includes MUX, Sample-Hold, Analog Buffer, Complete A/D Converter
Analog Inputs May be Single-Ended, Differential, or Mixed

by Jeffrey R. Riskin

The AD363* is an 8- to 16-channel 12-bit data-acquisition system in two hermetically sealed, welded, 32-pin metal dual in-line packages (Figure 1). One package is a complete analog input system, consisting of multiplexers, differential amplifier, sample-hold, and all the logic required for channel-switching, enabling, and configuring. The other package is a complete successive-approximation 12-bit a/d converter, similar to the proven AD572*, with parallel and serial (NRZ) outputs, and sufficient reference and analog-buffer capacity for system applications.

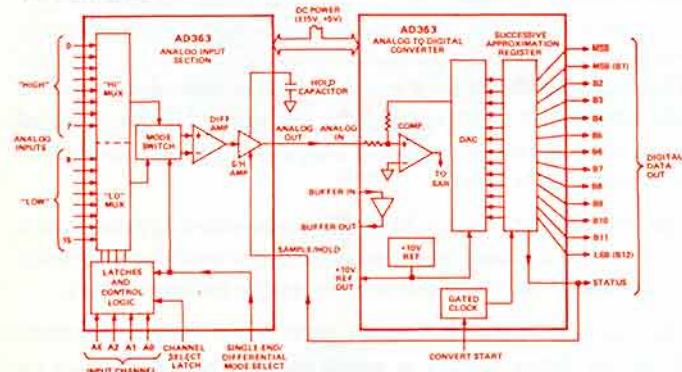
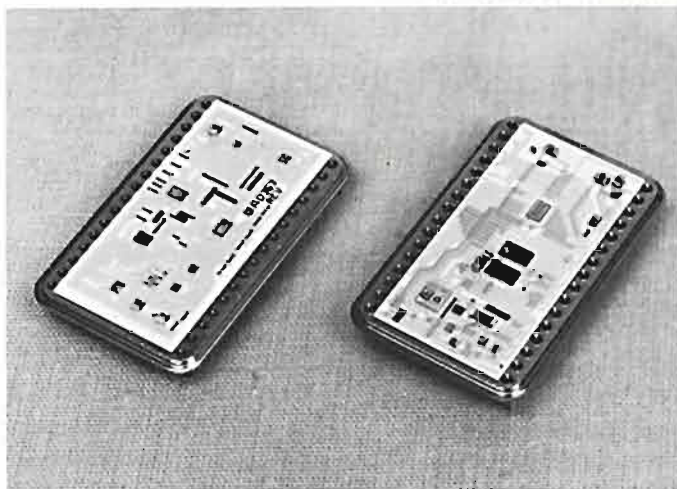


Figure 1. AD363 functional block diagram.

Conversion takes place within $25\mu\text{s max}$, and the minimum throughput rate is 25kHz for full rated accuracy. A short-cycle feature is provided to permit higher speeds at the cost of resolution. The AD363 is designed to be versatile, reliable, and low in cost. Two versions provide a choice of temperature ranges: the AD363K operates over the 0°C to $+70^{\circ}\text{C}$ range, and the AD363S operates over the -55°C to $+125^{\circ}\text{C}$ range, with no missing codes. Processing to MIL-STD-883B is available. Price of the complete AD363 in 100's is \$139.50 (K) and \$275 (S). The small-quantity price is \$195 (K) and \$395 (S).

The use of two packages has several advantages. The natural division into the two functional specialties permits each to be optimized independently. Because each package is less complex to assemble, yields are higher, unit reliability is higher, and costs are lower. More features are incorporated to permit a wider range of applicability. For example, ten single-ended and three differential input sources may be used with a single AD363, employing software-controlled mode switching.

ANALOG INPUT SECTION

Figure 2 is a block diagram of the analog input circuit. It consists of two 8-channel multiplexers, a differential unity-gain amplifier, a sample-hold, channel-address latches, and control logic. The 16 input lines can be connected to the amplifier input singly — referred to analog ground — or in differential pairs, depending on the channel chosen and the state of the MODE SELECT control input. For example, if

the channel address is 1100 (twelve), and the mode-select level is at "0", the differential amplifier will read the voltage between input 12 and analog common. For the same address, if the mode-select level is at "1", the amplifier will read the voltage between inputs 4 and 12. This useful feature permits any combination of single-ended and differential input sources involving 16 signal lines, from 8 differential up to 16 single-ended channels (Table 1), under program control.

The channel address is applied via a level-triggered register, controlled by a channel-select latch. When the latch input is at "1", the control signals feed through the register to select the chosen channel directly. When the latch is at "0", the address information is held in the register. This feature is useful

(continued on the next page)

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*For technical data, use the reply card.

The use of an external hold capacitor permits the user to make his own speed/accuracy tradeoff, by the choice of a different capacitor. Less capacitance means shorter acquisition time, but greater error. Greater capacitance means smaller errors but increased acquisition time. A polystyrene capacitor is provided with the AD363K, a Teflon capacitor with the AD363S.

The analog input section is constructed on a substrate that has thick-film resistors for non-critical applications, such as input protection and biasing. A separately mounted laser-trimmed precision-resistor network is used to establish stable gain and common-mode rejection. The metal package provides electromagnetic and electrostatic shielding and is hermetically welded, using a low-temperature process. Welding eliminates the possibility of contamination by solder particles or flux, and the low-temperature process minimizes disturbance of the resistance values during welding.

ANALOG-TO-DIGITAL CONVERTER

The design of the AD572 was described in some detail when it was introduced in these pages in *Dialogue* 11-2. Its principal feature are shown in the block diagram (Figure 3) and will be described briefly here.

The a/d converter is a 12-bit, 25µs, successive-approximation device, that includes an internal clock, a precision reference, a comparator, and an uncommitted analog buffer follower.

The +10V reference is derived from a low-tempco reference diode—its Zener voltage is amplified and buffered by an op amp, which provides up to 4mA externally, as well as serving the needs of the converter. The resistors that determine the gain of the op amp are laser-trimmed for reference accuracy to within ±5mV.

The DAC feedback weighting network, similar to the AD562's (*Analog Dialogue* 8-2), comprises a proprietary 12-bit analog current-switch chip and a silicon-chromium thin-film ladder network. The resistance ratios are actively laser-trimmed to within 0.005% of full-scale range, to insure that there will be no missing codes over the operating temperature range. Included in the design are scaling resistors to provide user-selectable analog input ranges of ±2.5V, ±5V, ±10V, 0 to +5V, and 0 to +10V.

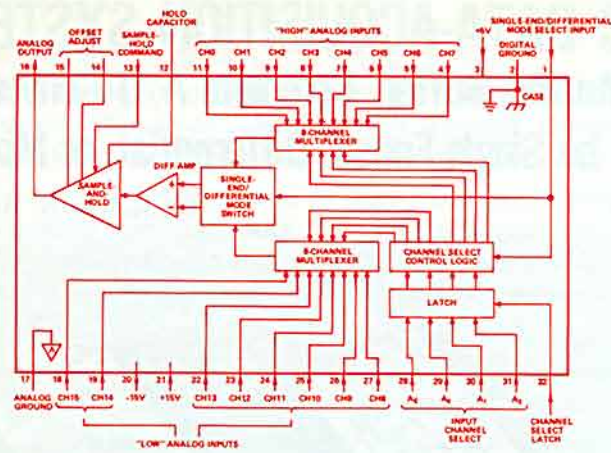


Figure 2. AD363 analog input section functional block diagram and pinout.

when input channel-address information is provided from an address, data, or control bus that may be required to service many devices, or in any situation where the user has no control of when address information may change. The latch input may also be used to control a single external flip-flop for applications where the differential/single-ended mode-select switch must be latched.

A differential amplifier buffers the multiplexer outputs, providing high input impedance in both differential and single-ended modes. The gain of the amplifier and its common-mode rejection are actively laser-trimmed to within ±0.05% and 70dB, respectively.

The monolithic sample-hold chip, which can also function as a gated op amp, serves as the output subtractor of the data amplifier. This dual function eliminates an amplifier stage, reducing power consumption, cost, complexity, and errors (due to drift and settling time). When the logic input to the sample-hold is at "0", the output is tracking the analog signal input; when the logic input is at "1", the output is in hold. When the sample-hold control input is connected to the status (or "end-of-conversion") output of the a/d converter, the input of the ADC is in hold during conversion, and in sample at all other times, tracking the analog input. The sample-hold's acquisition time to 0.01% is 15µs max, when the 0.002µF capacitor (furnished with the AD363) is used, and the aperture

ADDRESS				ON CHANNEL (Pin Number)		
AE	A2	A1	A0	Single Ended	Differential "Hi"	"Lo"
0	0	0	0	0 (11)	None	
0	0	0	1	1 (10)	None	
0	0	1	0	2 (9)	None	
0	0	1	1	3 (8)	None	
0	1	0	0	4 (7)	None	
0	1	0	1	5 (6)	None	
0	1	1	0	6 (5)	None	
0	1	1	1	7 (4)	None	
1	0	0	0	8 (27)	0 (11)	0 (27)
1	0	0	1	9 (26)	1 (10)	1 (26)
1	0	1	0	10 (25)	2 (9)	2 (25)
1	0	1	1	11 (24)	3 (8)	3 (24)
1	1	0	0	12 (23)	4 (7)	4 (23)
1	1	0	1	13 (22)	5 (6)	5 (22)
1	1	1	0	14 (19)	6 (5)	6 (19)
1	1	1	1	15 (18)	7 (4)	7 (18)

Table 1. Input channel addressing truth table.

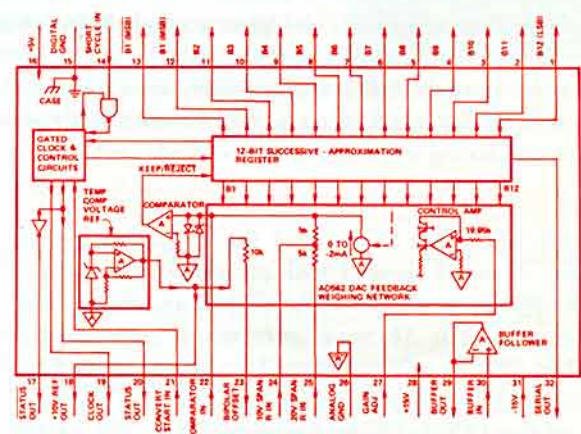


Figure 3. AD363 ADC section (AD572) functional diagram and pinout.

The digital output is positive-true binary for unipolar ranges, or two's complement or offset binary for bipolar ranges. A serial output is available, non-return-to-zero (NRZ), in synchronism with the clock output. A short-cycle capability provides increased speed for resolutions less than 12 bits. A high-impedance-input buffer amplifier, provided in the AD572, but not required in AD363 functions, is available for applications elsewhere in the system.

As in the analog-input section, thick-film resistors are used in non-critical areas, while thin-film substrates are separately mounted to ensure accurate and stable reference and DAC performance. Packaging considerations are the same as for the front end.

THE AD363 AT WORK

Figure 4 is a timing diagram for the AD363, connected as shown in Figure 1, and operating at the maximum conversion rate. The normal sequence of events is as follows:

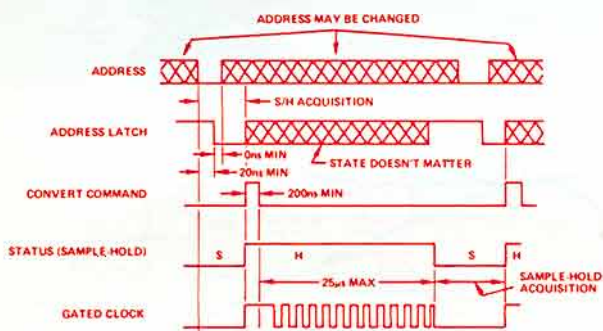


Figure 4. AD363 timing diagram.

1. The appropriate channel-select address is latched into the address register. Sufficient time is allowed to elapse for multiplexer and sample-hold settling. (Usually, channel switching is done while the previous conversion is taking place.)
2. A *convert* command is issued to the ADC; a logic "1" immediately appears on the *status* line to indicate that the converter is "busy".
3. Under control of the *status* line, the sample-hold goes into *hold* and remains in that condition while the converter is "busy".
4. The ADC goes into its conversion routine, which takes a maximum of 25µs for 12 bits. Since the sample-hold is holding the proper analog value, the address may be updated during conversion. Thus, the settling of the multiplexer, taking place during conversion, need not affect the overall throughput rate.
5. When the ADC completes the conversion, the status line returns to "0"; the sample-hold returns to *sample* and starts to track the input signal.
6. If the input signal has changed full-scale (different channels may have widely differing data), the sample-hold will require up to 15µs to acquire the next input to sufficient accuracy for 12-bit conversion. After sufficient time has elapsed, a new convert command may be issued to the ADC.

APPLICATIONS

Figure 5 is a diagram of a circuit that demonstrates the versatility provided by the AD363's "extra" features. It shows how

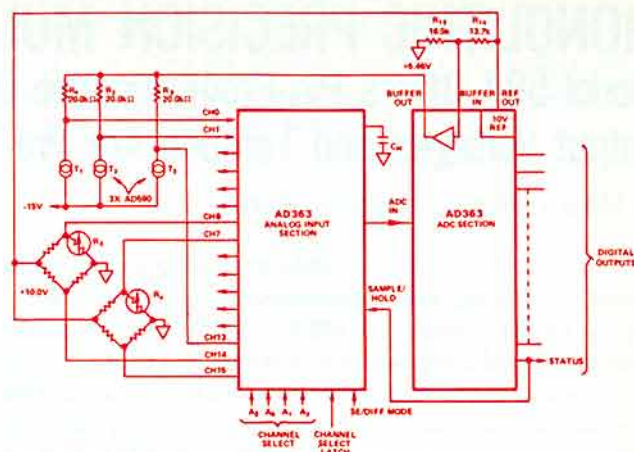


Figure 5. AD363 transducer interface application.

three single-ended temperature measurements and two differential bridge measurements might be implemented.

In this example, temperature is measured by AD590* two-terminal temperature transducers. The AD590 can be considered to be an ideal current source; its current in microamperes is numerically equal to its kelvin temperature (e.g., at +27°C, the current is 300µA). The voltage developed across each of the 20kΩ resistors is thus equal to 20mV/K. In order to translate the temperature reading from absolute to Celsius, 5.46V (=20mV x 273) is subtracted from the voltage developed across the resistors, using the reference voltage from the converter, a resistive attenuator, and the converter's buffer follower. Since this voltage is referenced to analog common, the net voltage, proportional to °C, appears between each of the resistors and analog common. These single-ended outputs are connected to channels 0, 1, and 13.

The bridge outputs (assumed to be high level, in this case), are applied differentially to lines 6-14 and 7-15 (differential channels 6 and 7). The bridges are driven from the stable, accurate 10V reference output of the ADC (which is also the reference for conversion, making the measurement ratiometric).

To read temperature, the channel mode is single-ended ("0") the appropriate channel number is selected (0, 1, 13). To read bridge output, the channel mode is "differential" ("1"), and the appropriate differential channel-number is selected (6, 7).

The a/d converter is configured (by the input jumpers) for the desired input range.

Microprocessor Interfacing: For acquisition of analog data accurately, it is almost universally recognized that the analog portion of the system is the "hard part", the digital is relatively much easier. In the case of the AD363, the digital interfacing has deliberately been left uncommitted to accommodate any conceivable digital interface, since every processor system and application has different interface requirements. Designing for one specific processor could complicate matters in other applications or if no processor is to be used. Typical system architectures for using the AD363 with microcomputers are discussed on the data sheet.



*Use the reply card to receive technical data on the AD590.

MONOLITHIC PRECISION MULTIPLE VOLTAGE REFERENCE

Model 584 Offers Pin-Programmable Choice: 10.000V, 7.500V, 5.000V, 2.500V Output Voltages and Tempco Are Pre-Trimmed, No External Components Needed

by Mike Timko and Goodloe Suttler

The AD584* is a complete eight-terminal precision voltage reference offering pin-programmable selection among four popular output voltages – 10.000V, 7.500V, 5.000V, 2.500V – without external components or trims. Other values of voltage, above, below, or between these values, can be programmed with external resistors. The input voltage may have any value from 4.5V to 40V. Like the 10-volt AD581,* the AD584 may also be configured as a current limiter or as a negative-reference 2-terminal "Zener diode".

In addition to the programmable output voltages, the AD584 offers a unique *strobe* terminal, which permits the device to be turned on or off. For example, when the AD584 is used as a power-supply reference, the supply can be switched off with a single low-power signal. In the *off* state, the normal 1mA *max* quiescent current drain of the AD584 is reduced to about 100 μ A.

The programmed output voltage is available at currents up to +10mA at 25°C, +5mA over the temperature range, and -5mA (sink current) for all temperatures up to +85°C. In addition, precision voltages at the programming pins are *simultaneously* available, and may be buffered by follower-connected op amps to supply or sink current. These voltages, too, may be adjusted by the choice of external resistors, a feature that makes the AD584 a highly flexible and useful device. For many users, it will eliminate the need for designing-in or inventorying a variety of different precision references.

The AD584 is available for either the 0°C to 70°C range (J, K, L) or the -55°C to +125°C ("military") range (S, T, U). Devices in the latter grades are available with processing to MIL-STD-883A, Level B. All grades are packaged in the hermetically sealed eight-terminal TO-99 metal can. Maximum errors range from ± 5 mV at 10V output, and ± 2.5 mV at 2.5V, for the AD584L and AD584U, to ± 30 mV at 10V and ± 7.5 mV at 2.5V, for the "J" and "S", at 25°C. Maximum tempco's range from 5ppm/°C (AD584L) and 10ppm/°C (AD584U) to 30ppm/°C ("J" and "S" versions). Prices in 100's are \$3.50/\$6.50/\$10.95, for the J/K/L and \$7.95/\$12.95/\$19.95, for the S/T/U. Single units are available for \$4.95/\$9.95/\$17.50 and \$13.50/\$19.95/\$33.00.

UNDERSTANDING AND USING THE AD584

The AD584, shown schematically in Figure 1, is a compensated bandgap reference, like the AD581 and the AD580* (described in numbers 8-2 and 9-1 of this Journal and elsewhere^{1,2}).

Figure 2, a simplified version of the schematic, shows how the output voltages are programmed. The compensated bandgap voltage (1.215V) is applied to the + input of an on-chip op amp. Feedback, provided via a tapped divider, maintains an equal voltage at the negative input. The current in the resistor

*Use the reply card for technical data.

¹"A Simple, Three-Terminal IC Bandgap Reference", by A. Paul Brokaw, *IEEE Journal of Solid-State Circuits*, SC-9, No. 6, December, 1974.

²U.S. Patent 3,887,863.

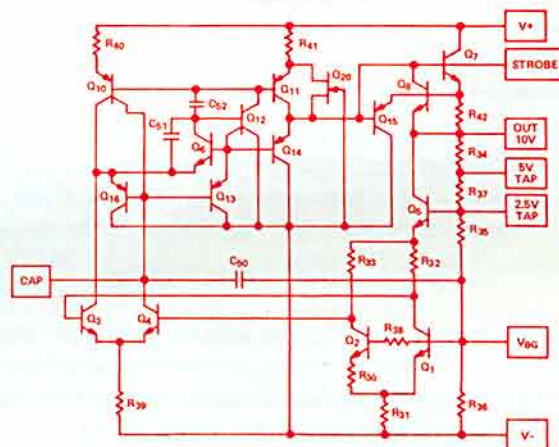
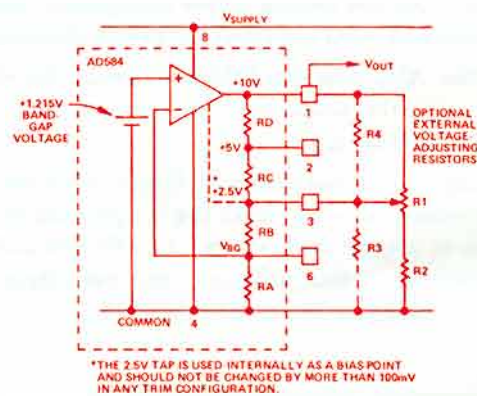


Figure 1. Schematic diagram.

string thus depends only on the bandgap voltage and R_A and is independent of the values of R_B , R_C , and R_D . The proportion that these resistances bear to R_A determines the voltages at the taps. It is not difficult to calculate that the ratio of these resistors is ideally 16.46:8.23:4.23:4; i.e., if $R_A = 4$ k Ω , $R_D = 16.46$ k Ω . The thin-film on-chip resistors are actively laser-



*THE 2.5V TAP IS USED INTERNALLY AS A BIAS POINT AND SHOULD NOT BE CHANGED BY MORE THAN 100mV IN ANY TRIM CONFIGURATION.

Figure 2. Variable output options.

trimmed during wafer-probe to set the individual voltages. The temperature coefficient is also trimmed during wafer-probe.

The output voltage, at the upper end of RD, is set to +10V, and the voltages at the taps are +5V, +2.5V, and +1.215V. Since the current in the feedback string is constant, a short circuit of one or more of the upper resistors will set the voltage between the associated pins to zero, and reduce the output voltage by the amount of voltage subtracted. For example, to obtain +7.5V, the 2.5V drop across RC is shorted out; for +5V, RD is shorted; and for +2.5V, RC and RD are shorted. The voltages at the tap points are also usable, if negligible current compared to that in the string ($\sim 300\mu\text{A}$) is drawn. The user may change the voltages by connecting external resistance across portions of the string. For example, it can be shown that two resistors ($1.029R_A$ across RA & RB, and $8.23R_A$ across RD) can be connected to produce outputs of 20V and 10V at the two uppermost taps (using adequate V+).

Internal capacitance is provided to reduce output noise. It is possible to reduce wideband output noise by adding capacitance externally between the CAP and the BG (bandgap) terminals. Figure 3 is a plot of noise with various values of capacitance.

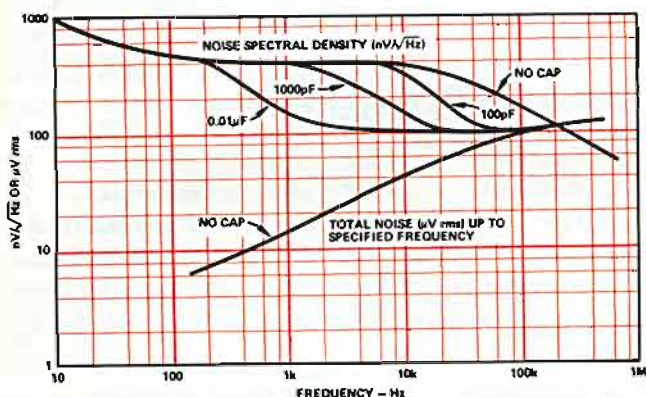


Figure 3. Spectral noise density and total rms noise vs. frequency.

APPLICATIONS

The AD584 can be used in a 2-terminal "Zener" mode to provide a precision -10V, -7.5V, or -5V reference. Figure 4 shows the VIN and VOUT terminals connected together at ground for this purpose. The AD584 common terminal is connected through a resistor to the negative supply and is used as the -5V reference terminal.

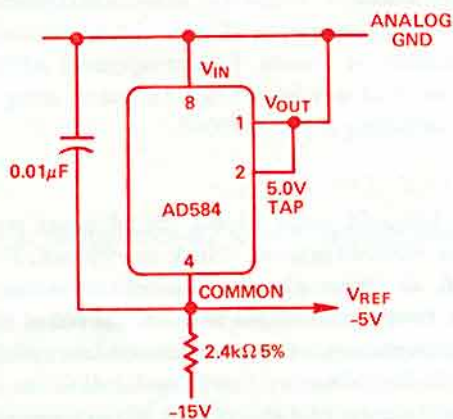


Figure 4. Two-terminal -5 volt reference.

The AD584 can be used in low-wattage battery applications to provide a 3-wire supply. Figure 5 shows an application in which the +5V pin drives the common lead of a $\pm 5\text{V}$ supply, via an op amp, while the $\pm 5\text{V}$ outputs are furnished by the high and low output leads of the AD584.

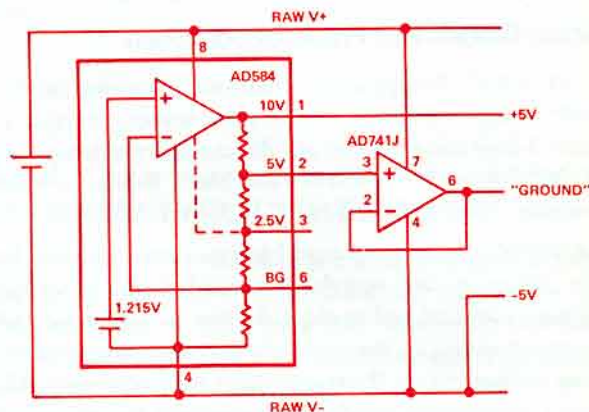


Figure 5. Dual $\pm 5\text{V}$ supply.

Figure 6 shows the AD584 in use as a precision current limiter. The limit current is equal to the quiescent current plus the load current through a resistor adjusted appropriately.

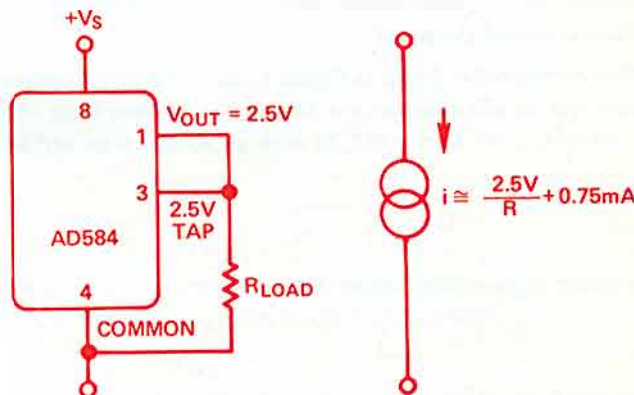


Figure 6. A two-component precision current limiter.

The AD584 can be easily connected to NPN or PNP power devices and Darlington circuits to provide much greater output-current capacity. The circuit shown in Figure 7, using a Darlington NPN, benefits uniquely from the availability of multiple output taps. The output is a precision 5V (or 2.5V) with up to 12A supplied to the load.

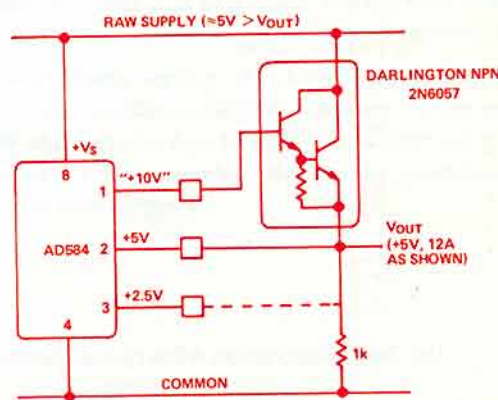


Figure 7. High current precision supply.

LOW-COST DIGITAL TEMPERATURE INDICATORS

Work Hand-in-Glove With IC Temperature Sensors, Simplify Measurement, Display, and Control of Temperature

by Steve Castelli and Frank Goodenough

The AD2040* Temperature Indicator, working with the AD590* integrated-circuit temperature sensor, provides easy, low-cost 3-digit measurement and direct display of temperatures from -55°C to $+150^{\circ}\text{C}$ (or the Fahrenheit, Kelvin, or Rankine equivalents) for as little as \$76 (1-9) for the AD2040.

The AD2040 is a low-cost digital temperature indicator, based on the successful and popular AD2026* digital panel meter. Providing excitation and readout for the AD590 temperature-to-current transducer, the AD2040 is jumper-programmed by the user to read out on the temperature scale of choice. All the precision components needed to implement the proper range are self-contained; only an external 5V power source is necessary. The device's functional characteristics are determined by the external connections to a terminal block on the rear of the AD2040. If required, the calibration adjustments are easily accessible. No hardware of any kind is needed to mount the AD2040 in its panel cutout, and it projects less than $1\frac{1}{2}''$ (38mm) behind the panel.

When connected as shown in Figure 1, the temperature-measurement system will measure and display temperature from -55°C to $+150^{\circ}\text{C}$ (-67°F to $+302^{\circ}\text{F}$) with an accuracy to within 1



(± 1 count). The AD590 can receive its excitation from the AD2040 (Figure 1a) or from an external voltage source of 4V to 30V (Figure 1b).

THE SENSOR

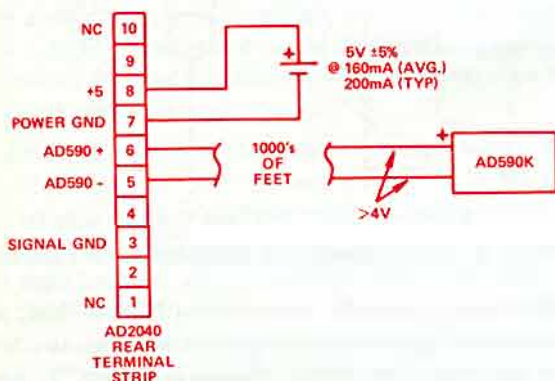
The AD590 is a laser-trimmed, high-level, 2-terminal temperature sensor. Its equivalent circuit is that of a current source, with a sensitivity of $1\mu\text{A}/\text{K}$; current in microamperes is numerically equal to absolute temperature (kelvin) over the specified range.

When connected, it requires no signal conditioning of any kind with respect to linearization, cold-junction compensation, or gain. Since the AD590 is a current source (unlike the more-familiar thermocouple or RTD), it may be located at a substantial distance from its companion AD2040 indicator (up to thousands of feet of twisted pair) with no concern for line drop, costly transmitters, or special wire. It is only necessary that at least 4V of excitation appear across the sensor itself.

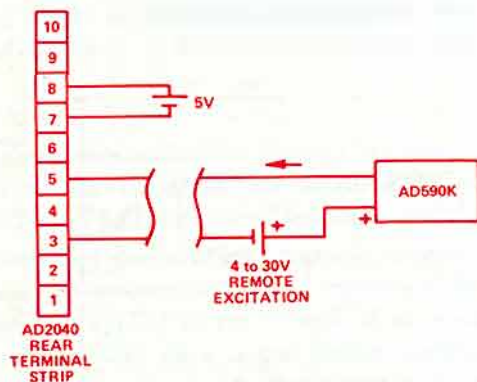
The AD590 is available in the hermetically sealed TO-52 can or in chip form, and a small, probe-mountable flatpack version will soon be available. Because it draws a maximum of $423\mu\text{A}$ full-scale, battery operation (Figure 1b) is practical. Furthermore, a number of remote, battery-operated AD590 current loops can be read out by a single indicator, using manual or automatic switching at the AD2040.

THE INDICATOR

The basic full-scale range of the digital panel meter at the heart of the AD2040 is from -99mV to $+999\text{mV}$. For use with the AD590, to obtain direct numerical temperature readout, the $1\mu\text{A}/\text{K}$ temperature signal must be converted to a $1\text{mV}/^{\circ}$ voltage representation, using precision resistance of appropriate value — $1\text{k}\Omega$ for Celsius or Kelvin, and $1.8\text{k}\Omega$ for Fahrenheit or Rankine. In order to display $^{\circ}\text{F}$ or $^{\circ}\text{C}$, an appropriate offset from the absolute range must be introduced: 273mV for $^{\circ}\text{C}$ and 492mV for $^{\circ}\text{F}$.



(a) Sensor excitation from the AD2040 meter.



(b) Sensor excitation from remote battery.

Figure 1. Basic AD2040 - AD590 connections.

*For information on these products, use the reply card.

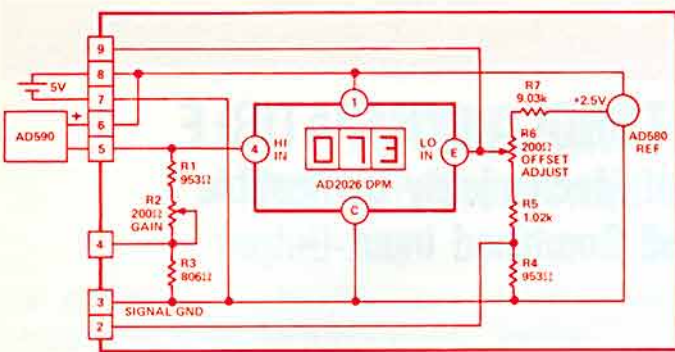


Figure 2. Connection diagram of the AD2040, showing internal connections and external connection to read Fahrenheit.

Figure 2 is a block diagram of the AD2040, showing the AD2026 DPM, the current-to-voltage conversion resistors (R1, R2, R3), the offsetting resistance network (R4, R5, R6, R7), and the connections to the terminal strip. Attenuated voltage from the AD580 2.5V reference provides the offsets for read-out on the F and C scales. Jumpers are connected by the user at the terminal strip, and the device is trimmed to read out in the appropriate units of temperature for display, according to the following scheme:

Units	Connect These Terminals Together
Celsius	2,3,4
Fahrenheit	None
Kelvin	3,4,9
Rankine	3,9

For switching among the various sets of units, for demonstrations of the various scales (with some loss of accuracy), the simple switch network of Figure 3 will do. The reader is left with the challenge of working out a circuit to switch from °F to °C, using a double-pole, single-throw (DPST) toggle switch.

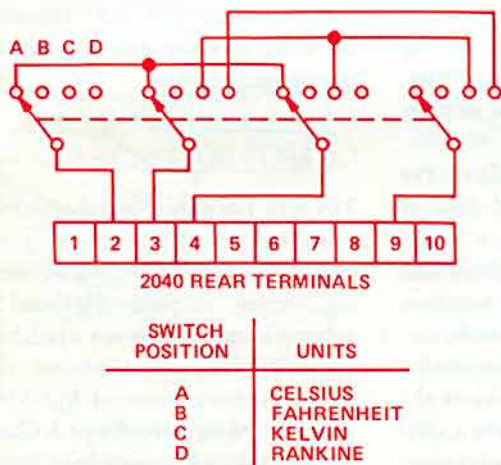


Figure 3. Switch circuitry to select units of display.

Figure 4 illustrates a field application, in which the AD2040 is powered by a 6V lantern battery, in series with a voltage-dropping diode, and turned on—when necessary—by a switch or relay. In intermittent operation, it should perform for about 20 hours. Battery-excited AD590's should operate for a month on the 9V "transistor" battery or for one year on a 6V lantern battery.

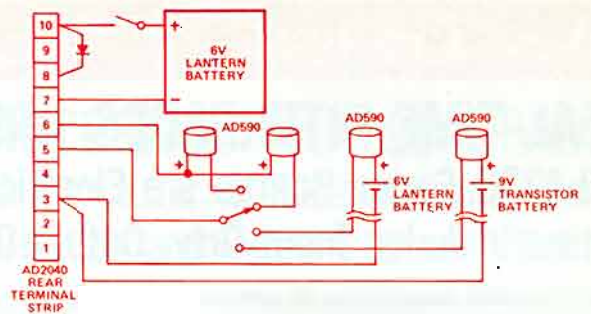


Figure 4. Typical modes of excitation for field applications, showing switch circuitry to select among sensors.

In Figure 5, an AD7501 CMOS 8-channel multiplexer (MUX) is used to provide selective excitation and readout for eight sensors, according to the binary code applied to the address lines. The 10V Zener diode reduces the drop across the AD590's from 15V to 5V to reduce self-heating. Note that the AD590 sensors are shown symbolically as current sources.

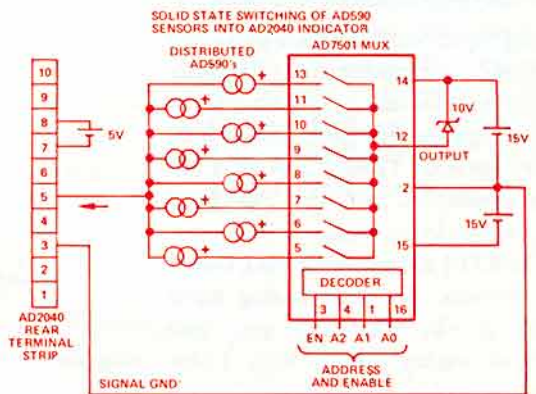


Figure 5. Selective excitation and readout among eight channels of temperature-sensing using a CMOS multiplexer.

SET-POINT MONITORING

The voltage developed at the indicator input (terminal #5) by the AD590's current can be used as an analog indication of temperature; in particular, it can be compared with set-point values to furnish high-low signals. In Figure 6, this voltage is applied to a dual comparator (CA3290E). The precision reference voltages are obtained from an AD580 2.5V reference IC, via a pair of adjustable voltage dividers.

When the voltage at terminal 5 goes higher than the "hi limit set" voltage, the output of A1 goes low and D1 is turned on. Similarly, when terminal 5 is at a lower voltage than the "lo limit set" voltage, the output of A2 goes low and turns on D2.

To set the high limit, replace the AD590 with a variable resistor. Adjust the resistance until the reading of the meter is numerically equal to the desired high-temperature set point. Adjust R1 until D1 just turns on. Repeat the procedure to adjust R2 for the lower limit. ▶▶▶

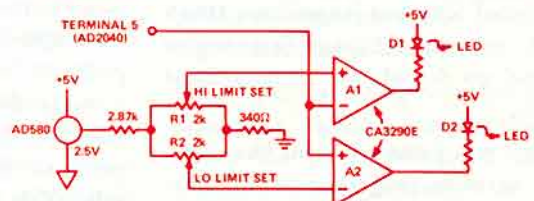


Figure 6. Limit detector and readout circuitry.

REAL-TIME INTERFACES ARE MOTOROLA-COMPATIBLE

RTI-1230 Series Boards are Electrically and Mechanically Compatible

Series Includes Input-Only, Output-Only, and Combined Input-Output

The RTI-1230* series is a set of complete, 8-bit and 12-bit analog I/O subsystems, which are electrically and mechanically compatible with the Motorola EXORciser Development System and Micromodule single-board microcomputers. The series comprises an input-only board (RTI-1230), an output-only board (RTI-1232), and a combination I/O board. Each interfaces to the μC as a block of 16 address locations (memory-managed interface).

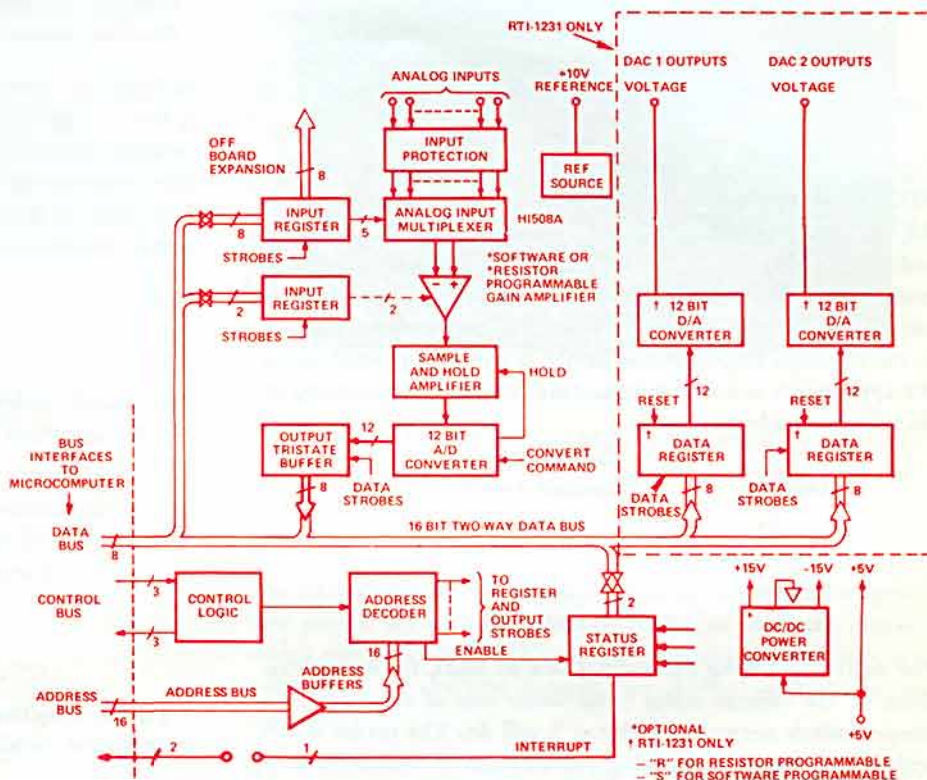
The analog-input designs include protected multiplexers, instrumentation amplifier with optional resistor-programmable or software-programmable gain, sample-and-hold amplifier, optional 12-bit, 25 μs or 8-bit, 2 μs a/d converters, and the associated digital interface logic, as shown in the diagram. The RTI-1231 combination I/O subsystems provide the same analog input functions as the RTI-1230, plus two channels of analog output with 12-bit resolution.

The RTI-1230/1231 are available with up to 32 single-ended/16 differential (protected) input channels on-board; they have the capability to handle off-board expansion to 256 channels. The MUX channel can be selected either randomly or by being incremented upon receipt of a convert command. This *auto-increment* feature allows scanning and random-channel addressing to be mixed under software control.

These input boards are available with a choice of two types of instrumentation amplifiers having 12-bit compatible common-mode specifications. *Software-programmable* gain (1-2-4-8) provides dynamic-range expansion through sub-ranging, as well as the flexibility of using different gain settings for each channel. *Resistor-programmable* gain (1 to 1000) may be used for input ranges from 10mV full-scale to $\pm 10V$ F.S. with little loss of speed and no degradation of linearity at high gain.

The input subsystems provide the user a choice between single-instruction pro-

*For technical data, use the reply card.



gramming, for software simplicity, or variations of polled-status programming for the highest data-throughput rates. The subsystem can be used in any of these three modes of operation:

- The *CPU Hold Mode* allows the user to initiate conversions and read or operate upon ADC data with a single instruction. This completely eliminates the need for interrupt service routines, resulting in minimum software overhead.
- In the *Interrupt Mode*, the setting of the end-of-conversion (EOC) bit in the status word can be made to create a CPU interrupt. The only acknowledgement required is to read the status word, which clears both the EOC bit and the associated interrupt. The result of this is efficient polling.
- In the normal *Polled Status Mode*, the CPU reads the EOC bit in the status word to determine if the ADC data is valid. This mode allows the greatest software flexibility and can be mixed with the

software-controlled EOC Interrupt Mode for truly versatile data-acquisition-system operation.

OUTPUT SUBSYSTEMS

The RTI-1232 Output Subsystem provides four channels of 12-bit analog voltage- or current output and four high-current digital logic-driver outputs. Optional 4-20mA current-loop outputs are available (Model 0A08 V/I converter modules); they meet all the requirements of ISA-S50.1 compatibility of signal for Type 3, Class L, non-isolated 4-20mA current-loop transmitters.

The four digital outputs are software-controlled open-collector drivers capable of sinking 300mA and sustaining voltages up to +30V. They can be used for on/off control of relays, solenoids, valves, etc.

RTI-1230-series prices begin at \$395 (1-9); significant OEM discounts are available.



MONOLITHIC HIGH-ACCURACY ANALOG DIVIDER

AD535K is Pretrimmed to 0.5% max Error, 10:1 Denominator Range

Use it for AGC, Ratios and Percent, Square-Rooting

The AD535* is a monolithic integrated-circuit analog divider that is dynamically laser-trimmed at the wafer stage for less than 0.5% total error for a 10:1 denominator range (AD535K) and less than 2% error over a 50:1 denominator range. With external trims, the denominator can vary through a range of 50:1 with less than 1% error. Figure 1 shows error specifications as a function of denominator, without trims, and Figure 2 shows the specifications with two or four external trims.

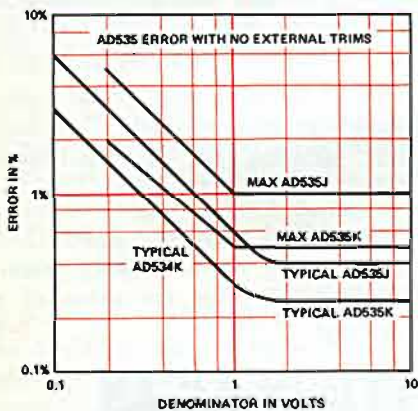


Figure 1. AD535 error with no external trims.

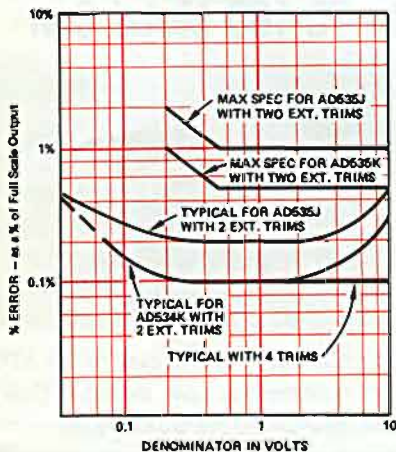


Figure 2. Errors with external trims at 25°C.

The AD535 is available hermetically sealed in the 10-pin TO-100 can and the 14-pin TO-116 DIP and is available in two 0°C to 70°C accuracy grades, AD535J/K. In the TO-100, the AD535J/K is priced at

*Use the reply card for technical data.

†See also the free *Multiplier Application Guide*; use the reply card to obtain a copy.

\$16/\$24 in 100's, and \$26/\$36 in small quantity.

The AD535 is basically similar to the AD534* multiplier, introduced in these pages in 1977 (*Analog Dialogue* 11-1)†, but, during the trimming process, its performance is optimized for division. The block diagram, similar to that of the AD534, is shown in Figure 3, in the normal divider connection.

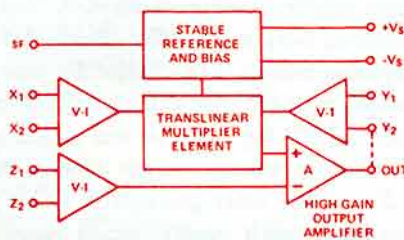


Figure 3. AD535 functional block diagram.

Since the net input to the high-gain output amplifier must be near-zero in the steady state, the AD535 enforces:

$$(X_1 - X_2)(Y_1 - Y_2) = SF(Z_1 - Z_2) \quad (1)$$

Since Y_2 is connected to the output,

$$E_o = Y_2 = Y_1 + SF \frac{Z_2 - Z_1}{X_1 - X_2} \quad (2)$$

"SF", the scale factor, is normally 10V, but it can be externally reduced to as little as 3V.

The availability of differential input terminals imparts a great deal of flexibility to the AD535. For example, $X_1 - X_2$ must be a positive voltage; however, it is easy to apply a negative voltage by simply reversing the input connections. Similarly, the sense of the output can be reversed by interchanging the "Z" input terminals. Also, a constant (or variable) can be added to the output at the Y1 terminal.

APPLICATIONS

The AD535 may be used in many of the conventional divider applications: ratio, efficiency, and $\Delta\%$ computation, square-root computation and gain measurement. It may also be used in algebraic analog computers of all types, e.g., in cathode-ray-tube pincushion-distortion correctors.

Another typical application of division is in automatic gain control. Figure 4 shows a type of AGC loop employing a divider. The ac output of the AD535 is detected (by a peak, average, or rms measuring circuit) and its dc measure is compared with a reference. The error signal is amplified by a high-gain amplifier and will tend (a) to increase the magnitude of X if V_{OUT} is too large, causing the AD535's gain to decrease, or (b) to decrease the magnitude of X if V_{OUT} is too small, causing the gain of the AD535 to increase. In the steady state, the high gain of the amplifier will cause the measure of V_{OUT} to be equal to the reference voltage. ▶▶▶

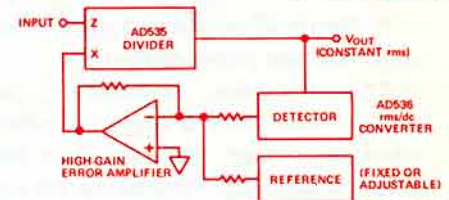
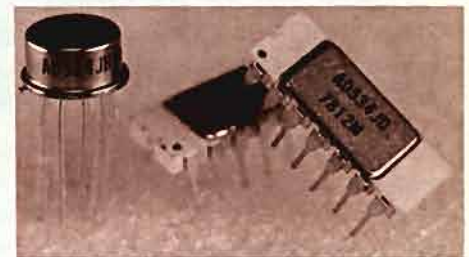


Figure 4. AGC loop.

CERDIP AD534 Multiplier Now in 14-Pin Package



Readers familiar with our AD534* multiplier in the TO-100 can may have wondered at the availability of the AD535 in both can and bug configurations. Wonder no more! The AD534, too, is now available in the 14-pin hermetically sealed ceramic side-braze, dual in-line package.

Same specs, same options, but of course somewhat higher prices for the DIP. In 100's, the AD534J/K/L/S/T are priced at \$20/\$29/\$43/\$51/\$68. ▶▶▶

*Use the reply card for the new data sheet.

WHAT'S IN A DAC80?

AD DAC80: A 3-Chip, High-Reliability, Low-Power 12-Bit DAC Voltage and Current Options, Monotonic Over Temperature

The AD DAC80* is a low-cost 12-bit integrated-circuit d/a converter in a 24-lead side-brazed ceramic dual in-line package. It is fit-, form-, and functionally compatible with other "DAC80" devices, but it is significantly better in many respects, at no increase in cost:

- Its 3-chip construction makes it the optimum choice for applications where low cost and high reliability are major considerations.
- The fully differential, non-saturating switching-cell structure provides greatly increased immunity to supply-voltage variation and reduces nonlinearities due to thermal transients as the various bits are switched.
- Nearly all critical components operate at constant power dissipation.
- A low-noise, high-stability sub-surface Zener diode is used to produce a reference voltage with excellent long-term stability, high external current capability, and temperature-cycling characteristics competitive with the best discrete Zener references.
- Reduced power requirements result in improved stability and shorter warmup time.

WHAT'S IN THE DAC80?

The AD DAC80† is a 12-bit d/a converter, consisting of matched bipolar switches, a precision resistance network, a low-drift

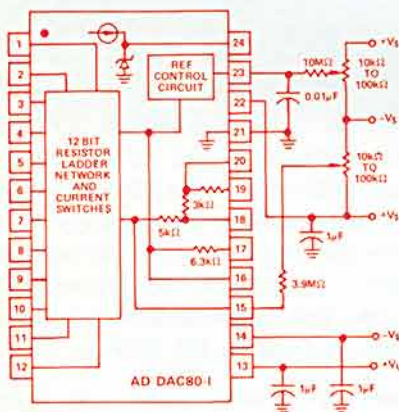
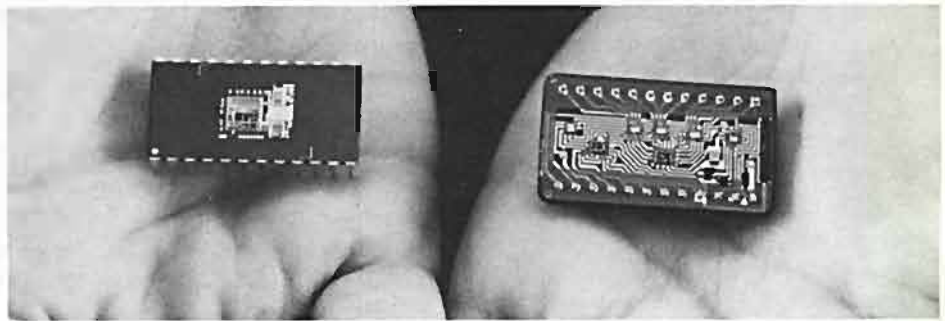


Figure 1. External adjustment and voltage supply connection diagram, current model.

*Use the reply card for data on the AD DAC80.



high-stability voltage reference, and an optional output amplifier (Figure 1 & 2). Options include TTL-compatible complementary 12-bit binary (CBI) or three-digit BCD (CCD) input codes, and a choice of current or voltage output modes. Also, "Z" models offer guaranteed 12-bit performance with supply-voltage range extended to $\pm 12V$. The AD DAC80CBI Models offer output voltage ranges of $\pm 2.5V$, $\pm 5V$, $\pm 10V$, 0 to $+5V$, or 0 to $+10V$ (voltage-output "V" models), and $\pm 1mA$ or 0 to $-2mA$ (current-output "I" models).

The AD DAC80 is recommended for all 12-bit d/a-converter applications where reliability and cost are of paramount importance. The AD DAC80 is also ideal for use in constructing a/d-conversion systems and as a building block for higher-resolution d/a systems.

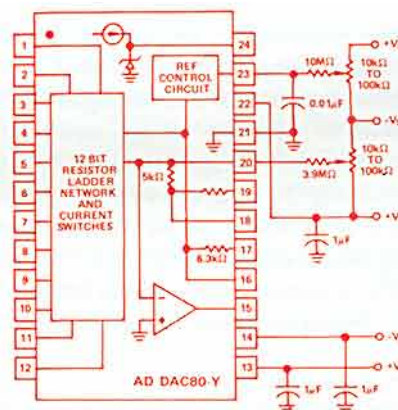


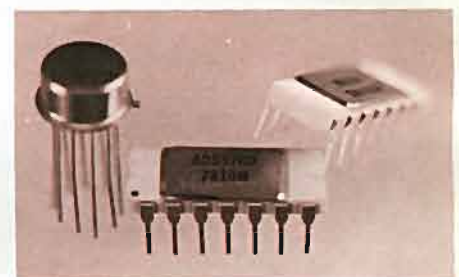
Figure 2. External adjustment and voltage supply connection diagram. Voltage model.

†Covered by patents numbered: 3,978,473, Re 28,633, 4,020,486, 3,747,088, 3,803,590, 3,961,326

Binary versions have a maximum linearity error of $1/2LSB$ max; BCD versions have a maximum linearity error of $1/4LSB$ max. Offset and gain errors are 0.15% and 0.3% of full-scale range (FSR) max, adjustable to zero externally. Total bipolar drift, including gain, offset, and linearity drifts, is $\pm 20ppm/^{\circ}C$ max.

Prices (100's) range from \$18.50/\$19.50 I/V, for the normal supply range, to \$19.50/\$20.50, for the extended supply range. ▶▶▶

VFC IN A CAN AD537 Now Available In TO-100 Metal Can



The versatile, popular, easy-to-use AD537* V/f converter is now available (less cost and space) in a 10-pin TO-100 hermetically sealed metal can, as well as in the hermetic 14-pin DIP. In the can, it has the same specs and many of the same functions, including the 1V reference and the $1mV/^{\circ}C$ temperature-sensitive voltage. Price of the AD537JH/KH/SH is \$4.95/\$7.95/\$14.95 in 100's and \$7.50/\$11.50/\$22.50, 1-24. ▶▶▶

*For technical data on the AD537, in both packages, and for a comprehensive 20-page application note, use the reply card.

CIRCUIT IDEAS FOR IC CONVERTERS

Put DAC's and V/f Converters to Work in Useful and Unusual Ways

by Walter Jung,¹ Jeff Riskin, and Lew Counts

The alert circuit designer is constantly on the lookout for new devices and new ways to use existing devices to realize needed functions more efficiently, at lower cost, or in ways not previously practical. Some recently introduced analog-digital-conversion integrated circuits fit in this class. In these pages, we offer a few circuit ideas, either for direct application, or to stimulate the Reader's thinking about related possibilities.

Included in the discussion are such devices* as the AD537 V/f converter, the AD1408, AD561, and AD7520 d/a converters, and the AD581 reference, as well as some older devices, in a variety of circuits suited for instrumentation, data-acquisition, and process-control applications. All these ideas are workable; a few of them are ready to hook up and use as they stand. The others are useful to illustrate concepts and are ripe for adaptation and further modification for specific applications.

OHMS-TO-FREQUENCY CONVERTER

Ohms-to-volts conversion is a familiar property of many digital voltmeters. However, ohms-to-frequency conversion provides added flexibility, since it facilitates remote measurements, averaged measurements, and optional a/d or f/v conversion at the destination.

In the circuit of Figure 1, the 1V reference voltage available at the AD537 is unloaded by buffer amplifier A1, which drives a reference current into the resistor under test in the feedback circuit of amplifier A2. The output voltage, proportional to resistance, develops a current at the input of the V/f converter, which generates a square wave at a frequency proportional to current, and hence to R_x . Since the reference for the measurement is the same as the reference for the conversion, ratiometric operation minimizes the effects of variation of the AD537's reference with temperature.

A counter can be used to read resistance directly. Typical laboratory counters have more than adequate resolution; models with adjustable gate time permit the decimal place to be located as appropriate for the resistance range being measured. For example, a gate time of 1s will provide a readout in Hz, and the central measurement range will provide a direct readout, $1\Omega/\text{Hz}$, or $1\text{k}\Omega/\text{kHz}$, up to the 100kHz full-scale range.

In this application, we are taking advantage of the typically wide dynamic range of V/f conversion to provide a readout of the most-frequently used resistance values on a single range. After calibration at 100kHz full-scale, with a 100k Ω standard, (R2 is adjusted), and at 100Hz low-scale, with a 100 Ω standard,

(R4 is adjusted), the linearity error will typically be no more than $\pm 0.06\%$.

R_s and R1-R2 should be stable precision types, and C_1 an NPO ceramic, for best stability and repeatability. C1 and C2 serve as noise bypasses, but C2 should have low leakage (polystyrene), since it is effectively in parallel with R_x .

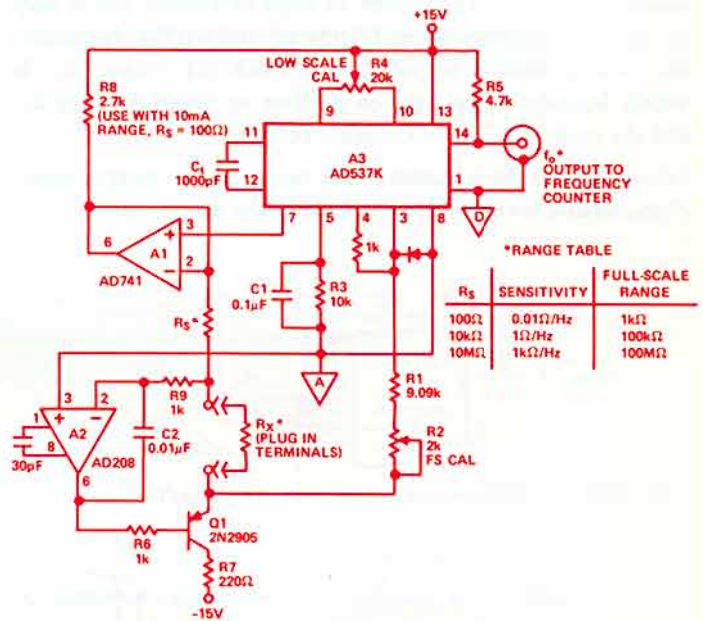


Figure 1. Ohms-to-frequency converter.

As the chart notes, two additional ranges are suggested. The 0.01 Ω/Hz range has greater resolution and accuracy, for $R_x < 1\text{k}\Omega$, with a 1k Ω (= 100kHz) full-scale limit. Resistances less than 0.1 ohm can be resolved on this scale. A pullup resistor, R8, should be used on this range, to minimize loading on A1, since R_s (= 100 Ω) will draw 10mA.

The highest scale range (1k Ω/Hz) allows resistances in the tens of megohms to be read. A low-bias-current amplifier, such as the AD208 (or the AD517, or a FET-input amplifier) should be used to minimize errors due to the flow of bias current in R_s .

ALGEBRAIC MANIPULATIONS — QUOTIENTS OF DIGITAL INPUTS

Since d/a converters multiply analog inputs by digital numbers, devices that permit a wide range of analog variation can perform a variety of algebraic manipulations involving multiplication or division of analog and digital quantities.^{2,3} An

¹This article is adapted from portions of Walter Jung's *IC Converter Cookbook*, recently published by Howard W. Sams & Co., Indianapolis, Indiana (1978).

*For data on any of the Analog Devices products mentioned here, use the reply card to obtain our comprehensive 600-page *Data Acquisition Products Catalog* or individual data sheets, at no charge.

²*Analog-Digital Conversion Notes*, D.H. Sheingold, ed., Analog Devices, Inc., Norwood MA, 02062 P.O. Box 796, \$5.95.

³"Application Ideas for Multiplying DAC's", *Analog Dialogue* 12-1, 1978.

example of the technique can be seen in Figure 2, a circuit that produces an analog quotient of two digital words, multiplied by a constant or variable reference.

In this circuit, two CMOS d/a converters are used. Converter A1 is connected in the forward path of op amp A3, producing an output, $V_1 = -B V_{REF}$, where B is the fractional binary value corresponding to the input code. Converter A2 is connected in the feedback path of op amp A4, producing an output, $V_O = -V_1/A$, where A is the fractional binary value associated with A2's input code. The overall relationship, therefore, is

$$V_O = \frac{B}{A} V_{REF} \quad (1)$$

V_{REF} may be of any value in the range $\pm 10V$, B may be any number from 0 to 1023/1024, in steps of 1/1024, and A may be any such number from 1/1024 to 1023/1024. Naturally, the ratio is limited to values for which the output, V_O , is within bounds. V_{REF} may be positive or negative, ac or dc, and the output will be of the same polarity.

Like analog division circuits, this circuit has an output error-characteristic inversely proportional to the denominator, A.

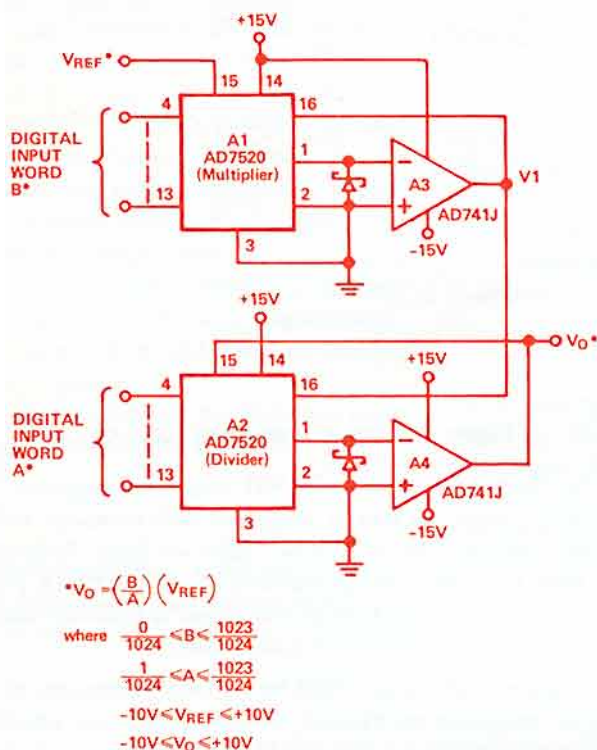


Figure 2. Algebraic manipulations — Analog quotient of two digital words.

8-BIT-PROGRAMMABLE SQUARE-WAVE OSCILLATOR

Programmability is an important new degree of freedom in analog circuit and system design. Virtually any circuit parameter can be made digitally controllable with little difficulty, using a/d and d/a conversion devices. It is important to be aware that "digitally controllable" doesn't necessarily mean that programmed circuits must interface with computers, processors, or even digital systems. In many cases, the digital input can be provided by manually operated switches, which

need not be fancy, since they need only to switch binary levels. This circuit and those that follow illustrate a variety of practical examples of programmable circuits.

Figure 3 shows an 8-bit (255-frequency) programmable oscillator with square-wave output. The circuit comprises a current-output d/a converter (AD1408 family) and a current-to-frequency converter (AD537 family). The digital input produces a linearly related current from the DAC; this current, driven directly to the input of the VFC, produces a square-wave that has a frequency proportional to the numerical value of the digital input word.

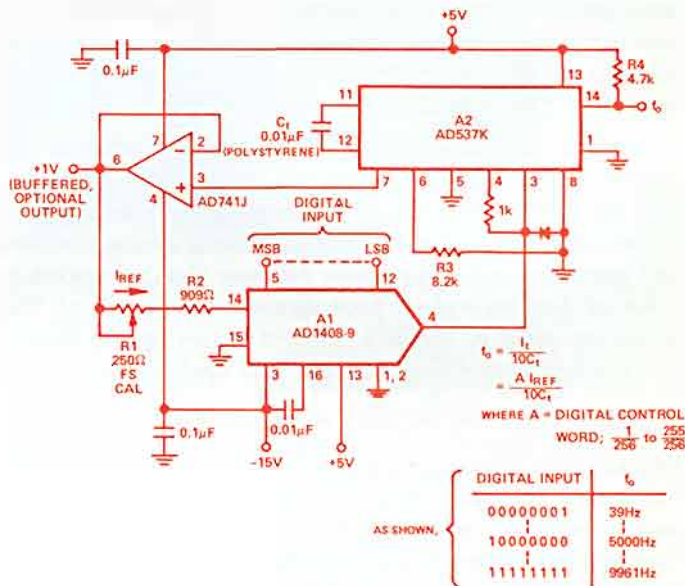


Figure 3. 8-bit programmable oscillator, square-wave output.

The AD1408-9 (9-bit-linearity) DAC is scaled for 1mA full-scale current output, to match the 1mA full-scale input of the AD537K. The 1mA reference current for the DAC is derived from the 1V reference output of the AD537, buffered by the AD741 follower-connected op amp. Since the basic reference source is common to both devices, errors due to its drift tend to cancel out.

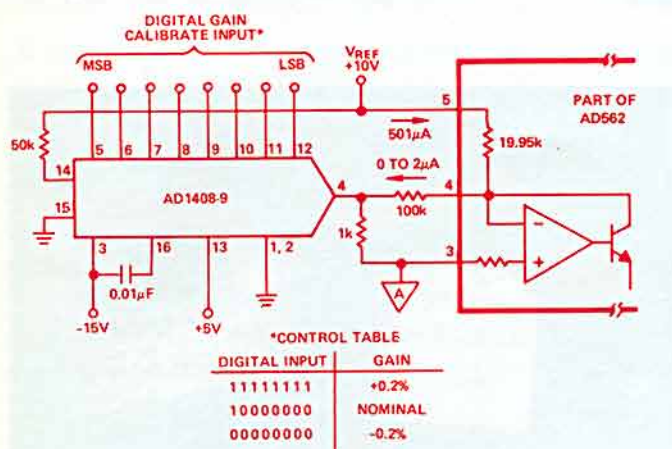
A polystyrene capacitor is used for C_T , and its tempco is compensated for by loading the AD537's V_T output with R_3^4 . R_3 can be adjusted to trim the overall system tempco. The circuit, as shown, has a nominal full-scale frequency of 10kHz (9961Hz for all-1's), with $C_T = 0.01\mu F$. Worst-case nonlinearity of the specified DAC-VFC combination is 0.16%. The output is a TTL-compatible square wave.

PROGRAMMABLE GAIN TRIMMING OR CALIBRATION

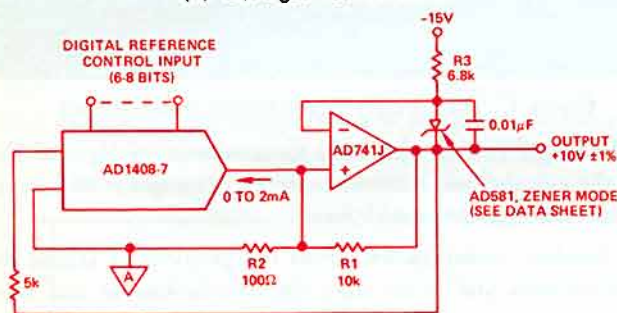
It is usual, in the design of devices such as converters or amplifiers, to concentrate design attention on linearity, since gain and offsets are considered to be reducible errors. Nevertheless, in high-precision applications, the gain must eventually be calibrated. D/A converters are improved substitutes for potentiometers, if the gain of the device-to-be-calibrated is set at a value near the nominal value, and the programmed converter provides the difference. Calibration can be performed automatically, under software control, with the required incremental value retained in a counter or latched; or it can be performed manually, using a thumbwheel switch.

⁴ AD537 data sheet, page 4.

In the circuit of Figure 4a, an AD1408-9 (256 adjustment steps) provides the incremental adjustment range for the scale factor of an AD562 12-bit DAC. When pin 5 of the AD562 is connected to a 10V reference, the gain will be 0.2% high. In this circuit, a programmable 0 to $-2\mu\text{A}$ current applied at the summing point will provide a $\pm 0.2\%$ range of gain change in 15.6ppm/LSB increments (1/16 of an LSB in the AD562).



(a) D/A gain calibration.



(b) Direct reference voltage calibration.

Figure 4. Gain calibration methods.

The performance of the components used to achieve this function is not highly critical, since their contribution to overall gain error is reduced by their small weighting. The use of this scheme with an AD562 DAC is a simple example, but it is applicable wherever automatic calibration to high absolute accuracy is required.⁵ Coarser steps (fewer bits) could have been used (6 bits of a 1408-7) if appropriate.

In Figure 4b, a related scheme is used to calibrate the output of a buffered reference circuit. The basic reference is an AD581 10V bandgap reference, connected as a 2-terminal "Zener diode", in the feedback path of an op amp. The 1% positive feedback increases the output voltage to 10.1V, and the 2mA full-scale output from the AD1408-7 DAC, flowing in the 100Ω resistor, can reduce the output voltage to about 9.9V. Thus, the adjustable range is 10V $\pm 0.1\text{V}$, in increments of about 780μV/bit, for 8-bit control.

Amplifier gain can also be trimmed by using a DAC to set incremental gain values in the neighborhood of nominal gain. A typical scheme for programming inverting-amplifier gain would employ a CMOS DAC, with its input attenuated, in shunt with the input resistor of an inverting operational amplifier.

⁵ For another example, see the AD572 12-bit ADC data sheet, Figure 11.

⁶ See the AD521 data sheet, Figure 4, page 4.

PROGRAMMED OFFSET

A programmed constant offset (or offset-zeroing voltage) can be introduced at the reference input of an instrumentation amplifier, to provide an output offset, independent of gain. Figure 5 shows how an AD521 instrumentation amplifier might operate in conjunction with an AD561 10-bit d/a converter. In this case, the nominal full-scale output range of the AD561 is $\pm 1\text{V}$, when loaded by 2.5kΩ. Larger offset ranges than $\pm 1.67\text{V}$ would be available by using a follower-with-gain between the DAC output and the amplifier's reference input, or by providing a portion of the AD521 gain via sense feedback,⁵ the offset would be amplified by the same amount. Smaller offset voltages are obtained by simply reducing R_x .

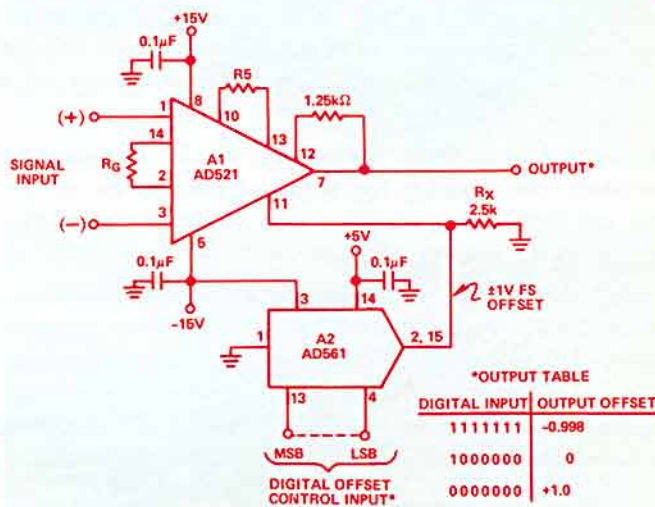


Figure 5. Programmable offset instrumentation amplifier.

4-20mA CURRENT CONTROLLER

A common requirement in industry is for transmission of analog data in the form of a 4-20mA current, to minimize the effects of ground-potential differences, series resistance, and voltage-noise pickup. 4mA corresponds to zero, 20mA to full scale.

Figure 6 shows a circuit to accomplish this with 10-bit resolution. An AD561 is used, in conjunction with an op amp and a Darlington transistor. With an all-0's digital input, the 1kΩ offset pot is adjusted for 4mA of output current. With all 1's, the scale-adjust pot is set for 20mA (or 19.98mA) of output current.

Although the load is shown here as being referred to a +15V supply, it may—in general—be returned to any positive voltage within the breakdown rating of the transistor used. The diode protects against reverse-polarity faults, the fuse against shorts.

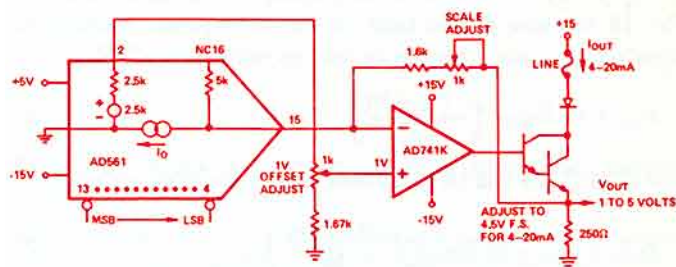


Figure 6. Process control current source.

ON-LINE NOISE-FIGURE TEST SET

Simple Analog Computer Makes Possible Compact, Portable

Noise-Figure Test Set for Military Receivers

by Alfred L. Gagne

Today's broadband electronic warfare systems, usually containing large numbers of receivers, can pose a costly checkout and maintenance load for already overburdened technicians. If system sensitivity is one of the parameters to be measured, several signal generators and other pieces of equipment are required. The procedure can be time-consuming and difficult to perform, especially under operational conditions on a moving vehicle in the field.

The typical noise-figure instrument, usually intended for laboratory use, is either too large and cumbersome, or too slow and limited in application to be an effective alternative for measuring sensitivity of systems in the field.

Sanders Associates* has developed a noise-figure test set (Model 5400B, Figure 1) to fill today's need for a compact, lightweight, and portable instrument capable of evaluating — on line — receiving systems in the 1MHz to 40GHz range. Typical measurement accuracy is to within ±1dB (including the variation of the "excess noise" source across the band).

WHAT IS NOISE FIGURE? HOW IS IT MEASURED?

In simple terms, noise figure is a logarithmic (dB) figure-of-merit for a tuned receiver or receiving system, based on the ratio of input thermal noise power (N_I) plus receiver (system) noise power — referred to the input — (N_R), to input noise. That is,

$$\begin{aligned} \text{Noise Figure} &= 10 \log_{10} (\text{Noise Factor}) \\ &= 10 \log_{10} \left(\frac{N_R + N_I}{N_I} \right) \end{aligned} \quad (1)$$

A perfect system would add zero noise ($N_R = 0$), yielding a noise factor of 1, or a noise figure of 0dB.

Noise figure is usually measured by first measuring the noise output of the system [$N_1 = (N_R + N_I)G$], then connecting a known noise source (N_T) to the input terminals, and again measuring the noise output [$N_2 = (N_R + N_I + N_T)G$], where G is the overall gain of the system.

The known noise source, in effect, increases the input noise power (or its characteristic temperature) by a known amount. The dB measure of the ratio of the noise-power increase to input noise power is known as "excess noise power", N_{ex} .

$$N_{ex} = 10 \log_{10} \left(\frac{N_T - N_I}{N_I} \right) \quad (2)$$

The noise figure can be computed from these measurement,

$$\text{N.F.} = N_{ex} - 10 \log_{10} \left(\frac{N_2 - N_1}{N_1} \right) \quad (3)$$

*Nashua, New Hampshire.



Figure 1. The Sanders model 5400B noise test set.

If the receiver is tunable, the measurement of N_1 and N_2 , and the calculations, must be repeated at a number of discrete frequencies over the tunable band.

The Sanders Model 5400B solves the problem of taking the measurements and performing the calculations in real time via an analog computer assembled from a variety of commonly available analog devices.

CIRCUIT DESCRIPTION

A simplified block diagram of the circuitry used to instrument the noise-figure equation is shown in Figure 2. The circuit pulses the noise source at a rate of approximately 8Hz. This causes the detected noise applied to the true-rms circuit to switch between N_1 (input noise + system noise) and N_2 (input noise + system noise + excess noise). The output of the rms circuit is a dc voltage proportional to $\sqrt{E_N(t)^2}$, which is a voltage measure of the average power (energy content) of its input.

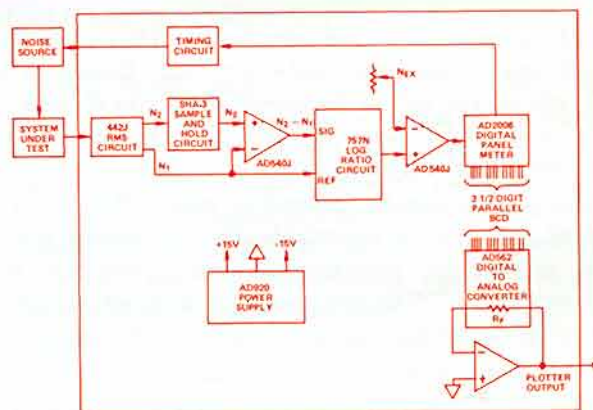


Figure 2. Block diagram of the noise test set.

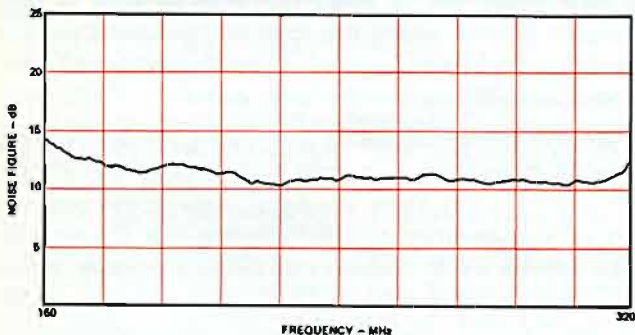
When the noise source is pulsed *on*, the rms voltage is a measure of N_2 . When the noise source is pulsed *off*, N_2 is stored in the sample-and-hold circuit, and the rms output measures N_1 . The timing circuit gates V_{N2} to a difference amplifier (using an op amp), during the time the noise source is off; the difference amplifier subtracts V_{N1} from V_{N2} . This output is applied to a log-ratio circuit, as the numerator term; V_{N1} is applied to the denominator; and the output is the log of the ratio,

$$-K \log_{10} \left(\frac{N_2 - N_1}{N_1} \right)$$

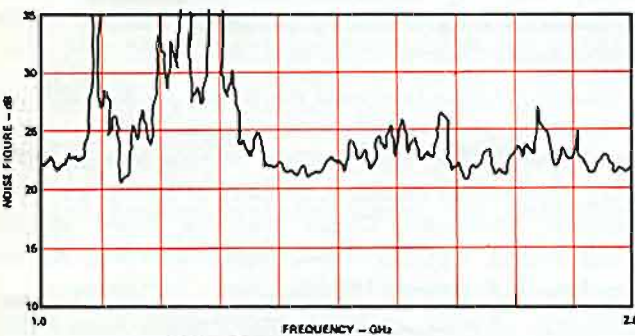
This output is applied to the non-inverting input of the final summing amplifier. A voltage proportional to $-N_{ex}$ is applied to the inverting input of the summing amplifier; it is adjusted to represent the exact value of excess noise being injected into the system under test, so that losses of devices used in connecting the noise source (relays, couplers, cable, etc.) can be taken into account in the final calculation.

The output of the final summing amplifier is of the form of equation (3), the desired solution. This dc voltage is applied to the digital panel meter on the test set, and the reading is the noise figure of the system under test.

For a plot of noise figure vs. frequency, it is necessary to obtain an analog voltage to represent the decimal number displayed by the DPM. This is obtained by connecting the BCD output of the DPM to a BCD d/a converter, consisting of a current-output DAC and an op amp. Since the DAC is updated only when the computation is complete, the plot is a continuous representation of the noise figure. Typical plots are shown in Figure 3.



(a) Well-behaved system.



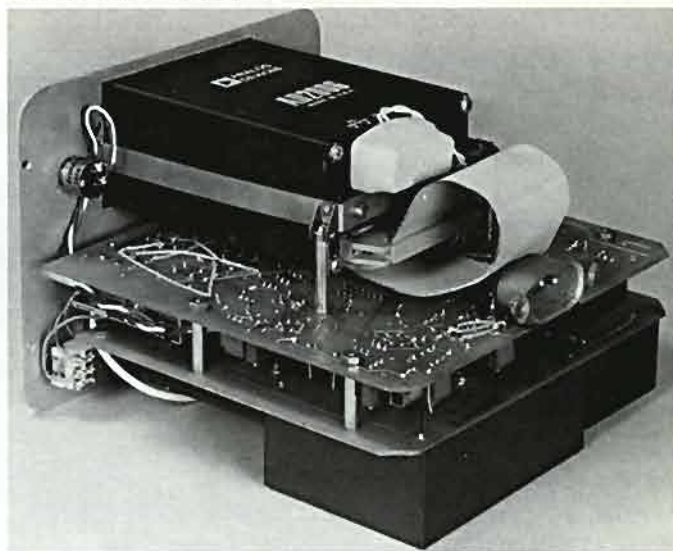
(b) Malfunctioning system.

Figure 3. Typical chart recordings.

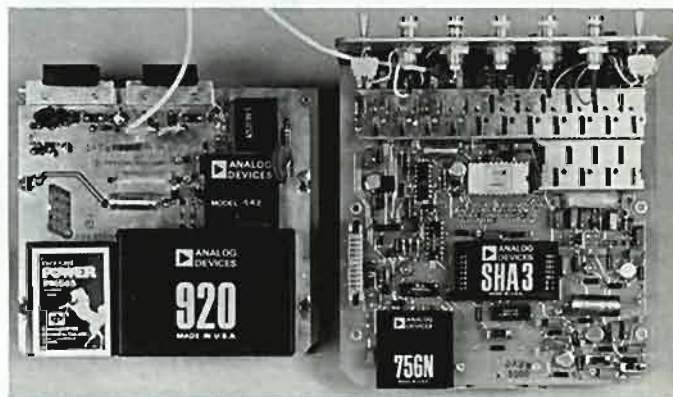
PHYSICAL DESCRIPTION

The Sanders Model 5400B is small and rugged. It was designed to withstand the harsh military field environment, yet be small and light enough to be easily stored and carried. It is 5" high, 7" wide, and 7" deep. With the cover in place, its depth is 10.5". The unit weighs 8 lb and consumes less than 20W of

power from a 115V, 50-420Hz ac source. Figure 4 shows the insides of the instrument.



(a) Rear photo of the instrument.



(b) The two operational subchassis.

Figure 4. Internal photographs.

In its standard configuration, the Model 5400B includes a 1MHz to 18GHz noise source, 10dB and 20dB attenuators, a 3mm to N adapter, a power cord, and an instruction manual. All accessories, including the instruction manual, are stored in the Test Set cover. A typical system in which it might be used is shown in the block diagram of Figure 5.

The Model 5400 is a relevant example of the kind of special-purpose-instrumentation design problem that can be solved simply and at low cost by the use of "off-the-shelf" analog components.†

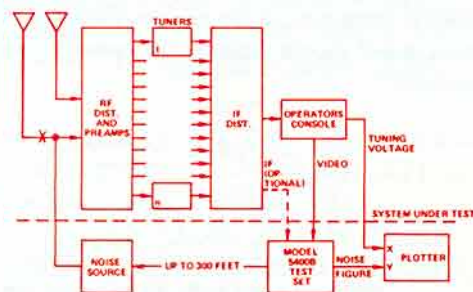


Figure 5. Block diagram of a typical application, showing multi-channel system testing.

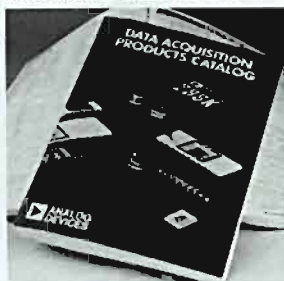
†Use the reply card for technical data on any of the Analog Devices components pictured here. If you are using our products for measurement and control in interesting ways and would like to share your ideas with our readers, we'd like to hear from you. (Ed.)

Worth Reading

NEW PUBLICATIONS FROM ANALOG DEVICES

600-PAGE DATA-ACQUISITION PRODUCTS CATALOG

If you are on our mailing list, you have already received your copy of our new data book. If not, you are invited to obtain a copy FREE, just by requesting it on the reply card. It includes tutorial material, selection guides, and more than 110 comprehensive data sheets on signal-conditioning, conversion, and computer interface IC's and modules,



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20-PAGE IC VOLTAGE-TO-FREQUENCY CONVERTER APPLICATION NOTE

The AD537 is one of the most versatile IC VFC's on the market. Its differential inputs, 1V fixed- and 1mV/K TC- references, and square-wave output, together with single-supply capability and open-collector output circuit, plus its availability in both hermetic can and hermetic ceramic

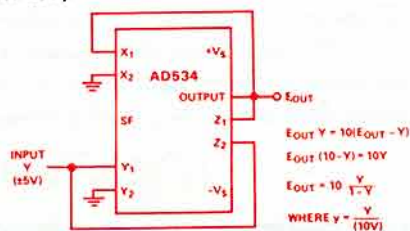


DIP packages, make it a first choice for applications in instrumentation, telemetry and communications, and specialized VFC applications. In this FREE Application Note, you will find practical down-to-earth information on the device and how to use it, and on such application areas as signal isolation, two-wire data transmission, a/d conversion, transducer interfacing, frequency-shift modulation, f/V conversion, waveform generation, long-term analog integration, analog division, and even sound-velocity measurement. Request your copy now.

ERRATUM

We made a bad goof, and, as Murphy¹ has so correctly predicted, it was detected only after it had been propagated. The Figure below is the correct version to replace:

- (1) The figure labeled "Bridge-Linearizing Function" at the top of page 8, *Analog Dialogue* 11-1, 1977, and
- (2) Figure 33, "Bridge-Linearization Circuit", on page 21 of the *Multiplier Application Guide*, 1978 (in addition, a resistor has been omitted from one of the bridges shown in the figure and "Z connections" should replace "X connections" in the preceding sentence).



Bridge-linearizing function

¹"The Contributions of Edsel Murphy to the Understanding of the Behavior of Inanimate Objects", D. L. Klipstein, *EEE*, Vol. 15, No. 8, August, 1967. See Also *Murphy's Law and Other Reasons Why Things Go Wrong*, Arthur Block, Price/Stern/Sloan Publishers, Inc., Los Angeles

The correct Figure differs from the earlier ones in that (a) the Z1 and Z2 connections are interchanged, and (b) the X1 and X2 connections are interchanged. Circuits connected as shown in the locations cited will run into limits because of positive feedback around the output amplifier of the AD534.

A somewhat similar figure appears in Figure 6 of the AD534 data sheet. It is correct, but it embodies the function, $10y/(1+y)$, instead of $10y/(1-y)$, which simply calls for the variable resistance to be in a different leg of the bridge. Also, maximum output in this connection is only $\pm 5V$.

A complete explanation of the use of feedback around a multiplier to correct for large-signal bridge nonlinearity is to be found in the *Nonlinear Circuits Handbook*².

We are indebted to Mr. Wilson Caselli, of Fycon Engineering Corporation, Charlotte, N.C., for calling the mistake to our attention; naturally, we regret any inconvenience to readers.

AFTERTHOUGHT

In Walt Jung's article, "Audio Application Ideas for CMOS DAC's", *Dialogue* 10-1 (1976), pp.16-17, two circuits were shown for digitally controlled stereo "panners" (Figs. 4 & 5). As the digital number, D, increases in relative magnitude from zero to 1, the stereo balance swings from full-on to full-off for one channel and vice versa for the other.

The approach shown manipulates the voltage input to the channels in proportion to D, and (1 - D), respectively. Unfortunately, Walt notes, the power (which relates more closely to what we hear) varies as the square of voltage. For $D = 1/2$, the total power will be down 3dB from its value at either extremity; in other words, this approach to panning produces a "hole" in the balanced condition (the apparent sound source becomes more distant as well as more central).

To preserve the overall sound level during panning (constant power), it is necessary to increase the voltage level by a factor, $(2D^2 - 2D + 1)^{-1/2}$. There are digital, analog, and combined ways of implementing or approximating this function; the choice depends on the facilities available in the overall system.

BOOKS RECEIVED

The following are among the titles received at our library recently; they are mentioned here for your information. *The books are not endorsed by and are not available from or through Analog Devices.*

Handbook of Linear Integrated Electronics for Research T.D. S. Hamilton, McGraw-Hill Book Company (UK) Limited, London, New York, 1977, 469pp. (Review of basic circuit theory, Operational amplifiers, Stability of feedback systems, Amplifiers, Oscillators, Circuit functions, Power supplies, Circuit devices, Optoelectronics, Signal detection, Applications) Heavily documented bibliography

The Design of Operational Amplifier Circuits, with Experiments, H. Berlin, E & L Instruments, Inc., Derby, Conn., 1977

The Design of Active Filters, with Experiments, Howard M. Berlin, E & L Instruments, Inc., Derby, Conn., 1977

Note: It may be of interest to our readers that the *Nonlinear Circuits Handbook* has been translated into Russian, with our permission, and is being distributed by Mir Publishers, Moscow.

²*Nonlinear Circuits Handbook*, D. H. Sheingold, Ed., Analog Devices, Inc., Box 796, Norwood MA 02062, 1974 and 1976, \$5.95, pp.90-91

An Eclectic Collection of Miscellaneous Items of Timely and
Topical Interest. Further Information on Products
Mentioned Here May Be Obtained Via the Reply Card.

IN THE LAST ISSUE (Volume 12, No. 1, 1978) . . . Monolithic μ A/K Temperature-to-Current Transducer (AD590) . . . Complete Monolithic 10-Bit A/D Converter (AD571) . . . 12-Bit CMOS Pretrimmed Multiplying D/A Converter (AD7541) . . . Real-Time Interface Boards for Texas Instruments Microcomputers (RTI-1240 Family) . . . Low-Drift Superbeta Op Amp (AD517) . . . and these New-Product Briefs: 6-Decade, Fast, Low-Cost Log-Antilog Amplifier (759); 8-Bit CMOS Multiplying DAC, Lowest Cost Ever (AD7523); 3-Digit Monolithic A/D Converter Chip (AD2020); AD1408/1508 8-Bit Super Second-Source D/A Converters; Synchronized Isolation Amplifiers and Drivers (288, 947, 948); Synchro-to-BCD Converter Family (SBCD1752/1753/1756/1757) . . . Plus an Application Note, "More Applications for Multiplying DAC's" and an Application Brief, "The Strange Case of the Large Offset" . . . and Four New Publications from Analog Devices: Analog Devices Short-Form Catalog (free); 50-page Multiplier Application Guide (free); 12-page User's Guide to Instrumentation Amplifiers (free); Microprocessor Systems Handbook, by Dr. D. P. Burton and Dr. A. L. Dexter, \$9.50, check or Master-Charge information to P.O. Box 796, Norwood MA 02062. Use the reply card for free items.

SHOWS . . . During the remainder of 1978, Analog Devices will be exhibiting in these major trade shows in the United States: WESCON (September 12-14, in Los Angeles) . . . ISA (October 16-20, in Philadelphia) . . . MIDCON (December 12-14, in Dallas) . . . If you're in the neighborhood, come in and see us.

IMPROVED SPECS . . . The Model 284J Isolation Amplifier has a number of improved specifications, effective with all units shipped after 1 August 1978, at no increase in price: Nonlinearity has been reduced to 0.05%, a 5:1 improvement; Gain Tempco has been reduced to 75ppm/ $^{\circ}$ C, a 3.3:1 improvement; Initial Output Offset has been reduced to 20mV, a 10:1 improvement; and Output Offset Tempco has been reduced to 150 μ V/ $^{\circ}$ C, a 10:1 improvement.

MTBF INFO . . . A complete electrical/thermal stress-analysis and reliability prediction (per MIL-Handbook-217B) has been performed on the 10-MHz Model 429 High-Speed Analog Multiplier. The calculated MTBF: 775,194h (more than 88 years!) If this matter is important to you, your Analog Devices sales engineer can obtain a copy of this 20-page document for your perusal.

DATA-SHEET ERRATUM . . . The drawing at the lower left-hand corner of page 2 of early AD2023 data sheets has been superseded. It is given correctly in all post-May '78 data sheets and on page 408 of the new Data-Acquisition Products Catalog.

F/V CONVERTER SETTLING TIME . . . Why is the settling-time spec for an F/V Converter always greater for decreasing frequency than for increasing frequency? The reason is that the settling-time specification consists of two components, the settling time of the filter — which doesn't change — and the period for two cycles at the new frequency (inversely proportional to frequency).

REPRINTS RECEIVED . . . Reprints are now available of the *Electronics* cover feature (April 13, 1978 issue), "I²L Puts It All Together for 10-Bit A/D Converter Chip", by A. Paul Brokaw, writing about the design philosophy of the AD571 complete monolithic 10-bit a/d converter. Use the reply card.

GSA CONTRACTS . . . Cover sheets and price lists for the following GSA Contracts are in print: GS-00S-04555 (ADC's, DAC's, and DPM's — 1 March '78 through 28 February '79); GS-00S-04748 (Power Supplies and Converters — 12 April '78 through 31 March '79); GS-00S-04972 (Amplifiers — 1 May '78 through 31 April '79); GS-00S-49216 (Multipliers — 1 June 78 through 31 May '79). If your organization is qualified to purchase on these GSA contracts, see your Analog Devices sales engineer, or write on letterhead to the Analog Devices Sales Department.

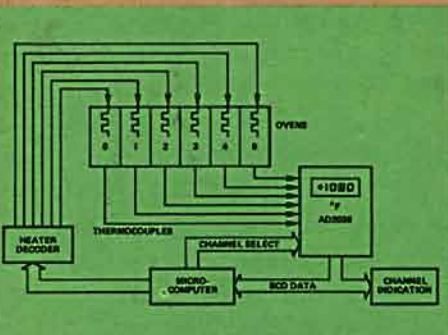
PRICE REDUCTIONS . . . Prices of the AD2023 "add-a-display" DPM-module family have been sharply reduced in quantity — to \$23 in 100's for the AD2023 and \$21 in 100's for the AD2023/B.

PUT IT TO THE TEST

THE WORLD'S LOWEST COST AUTOMATIC, SELF-CONTAINED 6 CHANNEL SCANNING DIGITAL THERMOMETER.

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Packaged in a standard DPM case, the AD2036 fits the same panel cutout. It provides continuous, automatic unattended scanning of up to six input channels. Individual channels can be addressed by means of a 3-bit-word control input for remote computer or microprocessor control.

Only \$349 in singles, less in multiples, the AD2036 monitors six thermocouples, provides switching, cold junction compensation, linearizing, conversion, 0.5" LED display, opto-isolated analog front

end, and parallel BCD output with channel identification. To get this kind of capability could cost you as much as \$1200.

\$349.

Put it to the test, yourself. For complete specs or to arrange for a 30-day evaluation unit, contact your local sales office, or Steve Castelli at (617) 329-4700. Or, write Analog Devices, Inc., P.O. Box 280, Norwood, MA 02062.

 **ANALOG DEVICES**

WAY OUT IN FRONT

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