analog dialogue

A forum for the exchange of circuits and systems for measurement and control

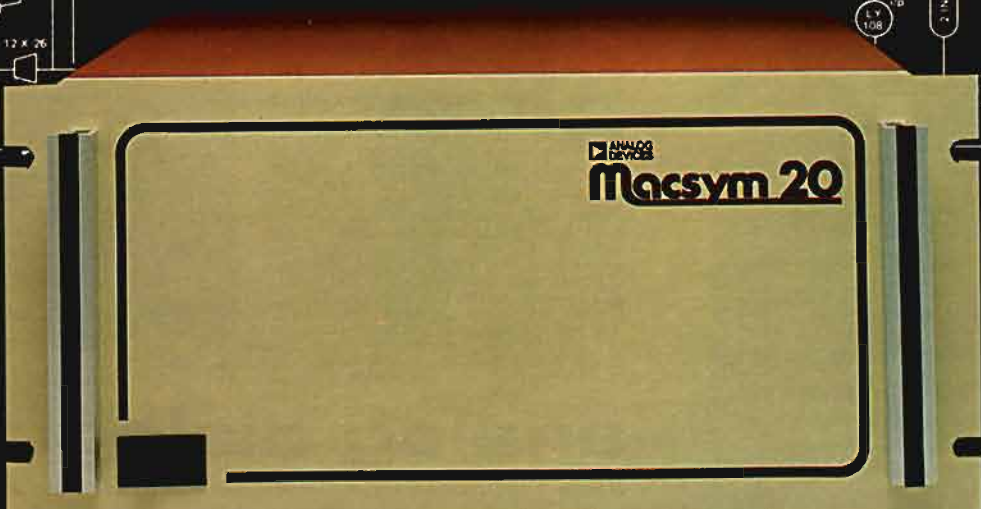
MACSYM 20
LOW-COST PROGRAMMABLE MEASUREMENT & CONTROL SYSTEM (Page 3)

Wideband, Linear, Low-Drift Isolator (Page 8)

CMOS DACs in the Voltage-Switching Mode (Page 16)

Complete Contents on Page 3

COURTESY OF TPC TRAINING SYSTEMS



Volume 14, No. 1, 1980

ANALOG DEVICES

Editor's Notes

FELLOWS

From its inception, this Journal has jealously guarded its nature as a *technical* offering of Analog Devices. The emphasis has always been on the ways our technologies and the resulting products provide benefits to engineers and scientists working in the arena broadly described as "measurement and control." Our ability to achieve the exciting new technical and product developments about which we write is, of course, directly related to the quality of our technical staff. As we grow larger, perhaps the most important challenge before us is to grow a technical staff of the same quality as we have had in the past. To do this, our goal must be to maintain an environment at Analog Devices where talented engineers can continue their career development as individual contributors and at the same time enjoy the material and psychological benefits that are commonly believed to be in the province of managers.

As a major stride towards this goal, Analog Devices has recently started to implement a "parallel career ladder" program, to provide increasing opportunities and benefits for those who show themselves as capable of extraordinary technical contributions to our Company. At the top of the ladder are a limited number of places reserved for "fellows": those outstanding technical contributors who also contribute to policy making and can serve as "mentors" for their bright but less-experienced colleagues. As our President, Ray Stata, has noted:

> What I think is very important is to clarify the role model for Division and Corporate Fellows. In particular we have characterized this role in terms of mentor, entrepreneur, consultant, writer, and organizational bridge—beyond the obvious role of inventor. And, in the case of Corporate Fellow, we go on to characterize the roles of strategist, sponsor, catalyst, and ambassador.
>
> What has been missed by dual ladders in the past is the importance of the psychological goodies that come from participation in the Corporate power structure. That is, how does one actually influence the policies and direction of the Company? Engineers, like everyone else, don't want just money; they want influence over corporate affairs. The opportunity to influence the important decisions of the firm is a subtle distinction between our Parallel Ladder program and other programs which have failed in their purpose.

Our search committee has identified the first of these leaders and teachers to be found in our midst, and they are publicly honored elsewhere in this issue. The technical quality of what we publish has always depended on the intellectual and personal qualities of people such as these, our first Divisional Fellows. Congratulations (and thanks!) Paul Brokaw and Barrie Gilbert.

Dan Sheingold

▶▶▶

THE AUTHORS

Russ VerNooy (page 3) is Systems Marketing Engineer for our Measurement and Control Products Division. Russ has a BSEE from Southern Illinois University, where he was a teaching assistant, and he is a member of TBII. He is widely travelled and has performed classified electronics work in the U.S. Air Force.

Dennis Lonigro (page 3) is a Senior Staff Engineer with ADI's Measurement and Control Products Division, with principal responsibilities in MACSYM 20 and board-level RTI products. Earlier, Dennis designed converter modules for the Modular Instrumentation Division. Before joining Analog, he worked for Raytheon (MSD), where he obtained his first patent while working on rf hybrid circuits. He has a B.S.E.E. from the Polytechnic Institute of Brooklyn.

Frank Goodenough (pages 8, 10) Technical Promotion Manager at Analog Devices, is best-known for his contributions in V-f-V converter applications at Teledyne Philbrick. In a multi-faceted career, he has designed everything from anchors and antennas to amplifiers at Brown & Root, Lockheed, Westinghouse, etc. His present activities include technical training, trade shows, editing, and writing.

Dr. Malcolm "Steve" Stephenson (page 16) is Senior Applications Engineer at ADBV. Previously, he lectured at Trinity College (Dublin) for a number of years, and he consulted on ultrasonics and basic intrumentation. He was graduated from the University of Surrey (England), where he also took postgraduate work towards his doctorate.

analog dialogue

Route 1 Industrial Park, P.O. Box 280, Norwood, Mass. 02062

Published by Analog Devices, Inc., and available at no charge to engineers and scientists who use or think about I.C. or discrete analog, conversion, data handling and display circuits. Correspondence is welcome and should be addressed to Editor, *Analog Dialogue*, P.O. Box 280, Norwood, Massachusetts, U.S.A. 02062. Analog Devices, Inc., has representatives and sales offices throughout the world. For information regarding our products and their applications, you are invited to use the enclosed Business Reply card, write to the above address, or phone 617-329-4700, TWX 710-394-6577 or 710-336-0562, Telex 924 491, or cable ANALOG NORWOODMASS.

MACSYM 20

Low-Cost Programmable Measurement And Control SYsteM

Versatile, Easy-to-Use Hardware and Software

by Russ VerNooy and Dennis Lonigro

WHAT IS MACSYM 20?

MACSYM 20* is a low-cost programmable measurement-and-control system which can function as either a complete stand-alone system or as an intelligent front end for a host computer. It provides complete signal conditioning, with direct connection to a wide variety of sensors and control elements, in both industrial and laboratory applications. Besides communicating with a host computer, it can display a formatted output on a printer or CRT via its RS232C serial I/O ports or an IEEE-488 bus interface.

As the block diagram (Figure 1) shows, MACSYM 20 consists of the following: A microcomputer, using an 8-bit Z80 processor, with 16K (expandable to 48K) bytes of random-access read-write memory (RAM). Room for 16K bytes of electronically programmable read-only memory (EPROM). An ADIO (Analog-Digital Input/Output)controller and bus, with a flexible 12-bit a/d conversion system, real-time clock, and all necessary logic to support a wide variety of signal-conditioning cards. Slots for up to 16 I/O cards, and optional serial I/O or IEEE communication ports. MACSYM 20's base price is $3,250.

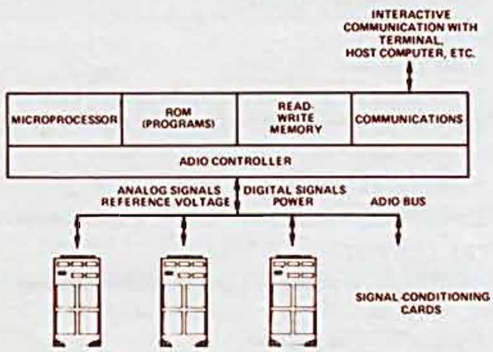
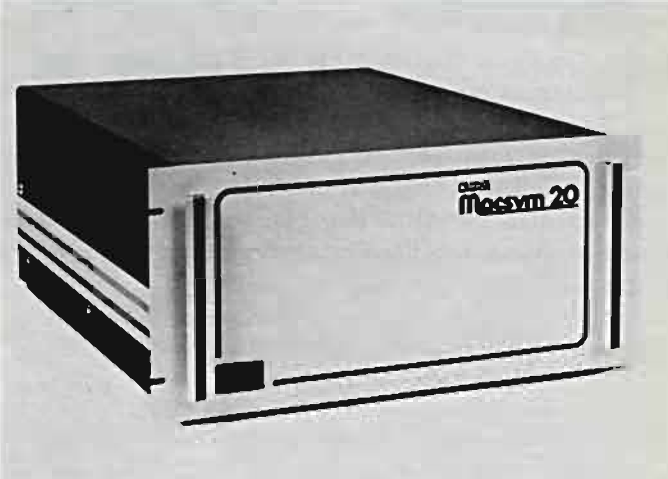


Figure 1. Block diagram of MACSYM 20.

MACSYM 20 can be programmed by the use of a powerful *command set*, which permits the user to define the application tasks by means of easy-to-learn high-level command statements, communicated in ASCII. These commands can be chained together, stored in memory, and later called and executed by simple alphanumeric characters. The system software significantly reduces the communications load between the host computer and MACSYM 20. The low cost of MACSYM 20, combined with its software flexibility, makes it an attractive replacement for data loggers and microcomputer board-level systems.

For stand-alone measurement and control applications, command-set sequences developed and stored in MACSYM 20's RAM can be burned into EPROM using special commands and the MACSYM EPROM Programmer, a device that connects to MACSYM 20 via one of its RS-232 interfaces, just like a peripheral printer or CRT. The stored command sequences are not lost if the power is interrupted.

*For further information, use the reply card.



I/O CARDS FOR REAL-WORLD INTERFACING

Nearly two dozen types of analog and digital interfacing and signal-conditioning cards are available, and more are under development. Signal-conditioning cards permit direct field-wiring hookup of industrial and laboratory sensors to MACSYM 20. The wide range of functions available includes CMOS multiplexers, digital input and output, analog output (either voltage or 4-to-20mA current-loop), thermocouple inputs with cold-junction compensation, low-level signal isolation, etc. A number of available cards are listed in Table 1. Sensors are connected via a ribbon cable or optional screw-termination panel.

(continued on the next page)

IN THIS ISSUE

Volume 14, Number 1, 1980, 20 Pages

The 16 card slots share MACSYM 20's ADIO controller and bus, which contain all the necessary data-acquisition components and interface circuitry. Because the greatest possible amount of common functional circuitry is on the ADIO controller board, including the conversion circuitry and interface logic, the cost of the individual cards is kept to a minimum. The cards may be used in any combination and/or permutation, since the slots are wired identically.

Figure 2, a block diagram of the 4-channel isolated thermocouple interface card, is a typical example of an analog input card. It has fixed gain, cold-junction compensation (for the thermocouple type specified), filtering, and isolation to 1kV ac for the individual channels; a high-level multiplexed output is presented to the ADIO bus. Either upscale or downscale thermocouple-break indication is provided; the output of the card may be offset by ±25% of the span.

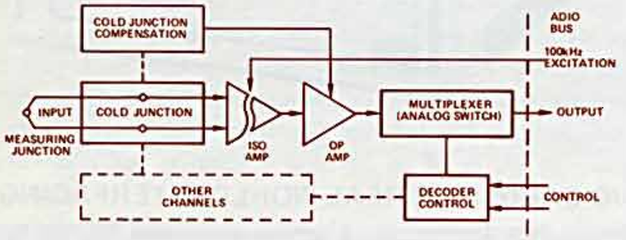


Figure 2. Block diagram of isolated-thermocouple card.

It is easy to use the card: it is hooked up by inserting it into any available slot and attaching the thermocouple wires directly to the barrier-terminal strip on the near edge of the card. Addressing the cards is equally simple, using the command-set's standard analog-input statement: AIN(slot, channel, gain), e.g., AIN(5,3,1). When this statement is executed, the on-card multiplexer will select the channel; the ADIO multiplexer will select the slot, the ADIO's programmable-gain amplifier will be set to the programmed gain value, and an a/d conversion will take place.

THE MACHINERY OF MACSYM 20

As Figure 1 shows, the ADIO Controller interfaces between the microcomputer bus and the ADIO bus. It provides power to the cards, addresses them, and furnished any logic signals that they require. Figure 3 is a functional block diagram of MACSYM 20.

Besides reducing the cost of the cards by centralizing common functions, the ADIO-bus scheme also keeps noisy digital signals

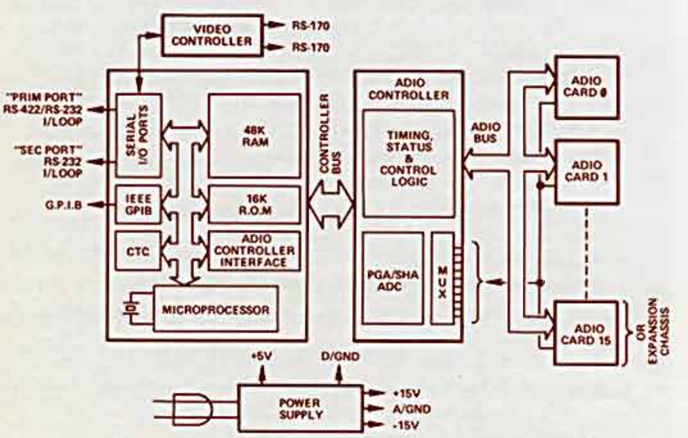


Figure 3. MACSYM 20 functional block diagram.

TABLE 1
TYPICAL SIGNAL-CONDITIONING CARDS

THERMOCOUPLE (nonisolated):
- Four channels
- Types J, K, T, E, R, S
- Common-mode rejection 120dB at ±10V
- Nonlinearity 0.01% of full-scale range
- DC protection ±90V

THERMOCOUPLE (isolated)
- Four channels
- Types J, K, T, E, R, S
- Isolation breakdown voltage 1kV ac
- Nonlinearity 0.05% of full-scale range (10-bit)

ANALOG OUTPUT
- Four channels
- Output ±10V, 0 to +10V, or 4-20mA
- Nonlinearity 0.05% of full-scale range (10-bit)
- Protected to 24V ac

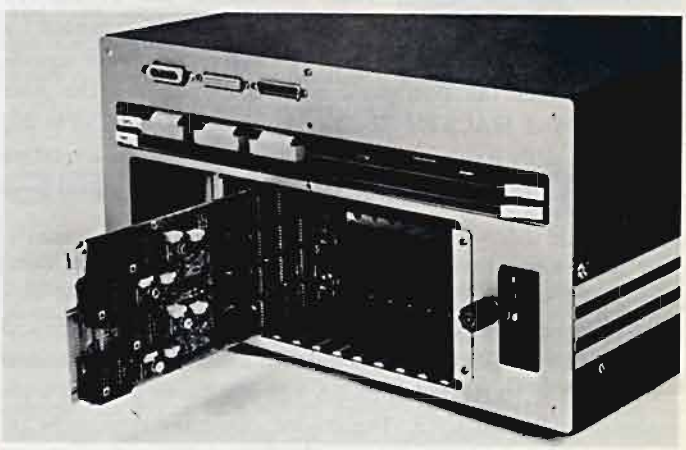
CMOS MULTIPLEXER
- 32 single-ended or 16 differential channels
- ±10mV to ±10V input range on any channel
- Nonlinearity 0.01% of full-scale range (12-bit)

PACER CLOCK
- 10MHz crystal time base
- Intervals 20μs to 12 hours
- Externally triggered user input
- Clock frequency 100kHz

STRAIN-GAGE
- Four channels
- Nonlinearity 0.01% of full-scale range (12-bit)
- Excitation 5V to 10V (voltage) or 0.1mA to 10mA (current)
- Protection 115V ac
- Bridge completion for 2, 3, 4, or 6-wire connection

DIGITAL OUTPUT
- 16 discrete, isolated, TTL-compatible open-collector outputs
- Output 1.5V at 100mA
- Protection 30V to ground, 500V common-mode

DIGITAL INPUT
- 16 discrete isolated TTL-compatible inputs
- Isolation 500V



Analog Devices MACSYM 20 will accept any combination of up to 16 signal conditioning cards through its backplane.

away from the analog signals, reducing undesirable coupling and improving overall analog I/O performance. All digital logic elements on the ADIO cards are low-power CMOS, for reduced power dissipation and improved noise margins. The ADIO controller contains a central a/d converter, programmable-gain amplifier, and sample-hold amplifier, along with all the digital logic to drive the ADIO signal-conditioning cards.

As noted earlier, the processor board uses the Z80 microprocessor. The 64K memory space is divided between a maximum of 48K of dynamic read-write memory, for data buffering and program downloading (i.e., loading of programs that are not in ROM) and 16K of EPROM for non-volatile program storage. Real-time clocks are provided to permit accurately timed measurements. The single board also contains all communication-support, controller-interface logic, and configuration hardware, resulting in reduced cost and improved reliabiliy.

COMMUNICATIONS

As noted earlier, MACSYM 20 can communicate with minicomputers, terminals, and programmable calculators via RS232C, RS422, 20-mA current loop, or IEEE-488 interfaces. Remote operation over telephone lines is possible by combining the RS232 I/O feature with a MODEM. This means that the MACSYM 20 is suitable for operations both near to and far from the host processor, as well as in distributed measurement-and-control applications.

MACSYM 20's powerful yet concise command set simplifies communications with a host system. Only a few ASCII characters are needed to execute a command sequence—or even a chain of commands.

Figure 4a shows in block form a system in which a MACSYM 2 is the host, linked to four MACSYM 20's. In Figure 4b, a MACSYM 20 is interfaced to a programmable calculator, along with other instruments, via the GPIB bus. The broad flexibility created by the wide array of communication interfaces makes it possible to use the MACSYM 20 with practically any host system, near or far.

(continued on next page)

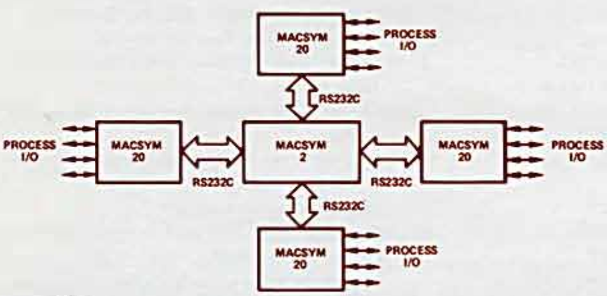


Figure 4a. MACSYM 2 as host minicomputer to four MACSYM 20's.

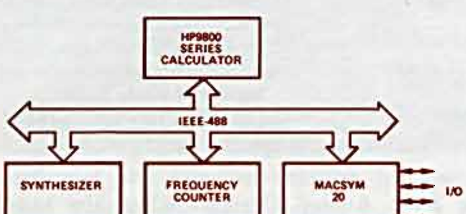


Figure 4b. MACSYM 20 on an IEEE-488 bus, in an instrumentation-system application with a programmable calculator as host.

HISTORICAL NOTE
MACSYM 2 AND MACSYM 20

A year ago,* our readers were introduced to the MACSYM 2 Measurement And Control SYsteM, a complete minicomputer-based stand-alone system that brings together a high-speed 16-bit processor, a console terminal with interactive display and full ASCII keyboard, mass storage, a family of analog and digital input/output cards, and powerful software employing a superset of the high-level BASIC programming language.

To review briefly, it was designed for applications involving signal conditioning, data acquisition, storage, computation, and display. It can deal with analog and digital inputs and outputs in multi-task modes, programmed in BASIC by users who need not be computer experts. Typical inputs might include thermocouples, strain gages, RTDs, switch closures; typical outputs might include 4-to-20mA control signals, switch drives, or ASCII data.

MACSYM 2 was human-engineered for laboratory experimenters, control-system designers, and other engineers, scientists, and technicians, whose principal interest is in applying computer intelligence to obtain desired system results with a simple, cost-effective data-handling system designed to be as transparent as possible.

The worldwide response exceeded even the least-conservative of our expectations. From the U.S. to Japan and West Germany, from refiners to automotive manufacturers and winemakers, the interest grew, and MACSYM 2 is being used in a wide range of applications, from pressure-vessel monitoring and control to environmental test of agricultural equipment to solar-energy monitoring systems.

Not the least of its virtues are its flexibility, computing power, multitasking capability, and comprehensive family of analog and digital real-world interfacing cards. And its low price: less than $10,000, ready for operation.

At the time MACSYM 2 was introduced, we recognized that a large number of potential users would prefer a system that would retain the MACSYM 2's real-world interface features (including the machine-independent ADIO card set), easy programmability, and flexible communications capability, but at a lower cost. This recognition led to the development of MACSYM 20.

*ANALOG DIALOGUE 13-1. Available upon request; use the reply card.

SOFTWARE

The MACSYM 20 *command set*, stored in EPROM, offers users a simple way to define their application tasks, using concise and easily understood English commands for analog and digital I/O, timekeeping, data storage and manipulation, limit checking and alarm monitoring, and data transmission.

Commands can be used singly, chained together, or even nested in multiple loops. The user can define and store in the system up to 286 variables and buffer thousands of readings in read-write memory. Standard arithmetic operators, such as +, −, *, /, and relational operators, such as <, =, >, <=, >=, <>, are available for data manipulation, limit-checking, and conditional functions.

As noted earlier, the command for identifying and converting an analog input is AIN (slot, channel, gain), the command to convert a digital quantity to analog and route it to a given output channel is AOT (slot, channel). The command to print data is PNT, and TAB(X) moves the print carriage so that headings, columns, and other tabular functions can be performed. A scaled print command (SPNT) allows the user to print out decimal numbers scaled in engineering units; for example, a scan of analog inputs from thermocouples could be printed in columns of °F and °C. Other features of the MACSYM 20 command-set include free use of parentheses, the ability to string together conditional and logical statements, masking of digital inputs, free insertion of WAIT statements, read and set elapsed time commands, and a trigger command.

For example, the command line

1: DOT(2, 1, 1):=1 WAIT(100) PNT(AIN(4, 3, 0))

combines the following operations: Command 1 is: set the digital output of Slot 2, Channel 1 to logic "1", wait 1 second and then sample the analog input of Slot 4, Channel 3, at unity gain ($G = 2^0$), and transmit this information to the host computer.

Another example, that shows conditional decision-making, is

2: AIN(4, 3, 0) > B [AOT(2, 2):=C #3]

Command 2 is: the analog input at Slot 4, Channel 3, is converted to digital and compared to the value of variable B. If the analog value is greater than B, the operation enclosed in brackets is executed. If the analog value is equal to or less than B, the command line is terminated and no action is taken. The operation enclosed in brackets is: set the analog output at Slot 2, Channel 2 to the value of the variable C, and then branch to command line 3.

Table 2 briefly summarizes the command-set characteristics.* The command set is not intended to replace programming languages; it is intended to simplify the programming of a user's application. A simple application remains simple; e.g., to measure the analog signal of Channel 15 on the card in Slot 8, gain of one, as command line 5, just write: 5: PNT (AIN (8, 15, 0)). Once the operation is defined and stored as command sequence five, it can be executed by merely transmitting a few ASCII characters (#5) from a terminal or a host computer. In this way, the command set eases the programming burden and reduces dependence on the host system.

Command-set sequences can be burned into EPROM for nonvolatile program storage, using an EPROM Programmer,† available from Analog Devices. When the MACSYM 20 is turned on, it will immediately start executing these ROM-based routines. MACSYM 20's low-cost program-development capability is unique among systems designed for the class of applications that MACSYM 20 services.

*For a complete summary of the command set, use the reply card.
†Use the reply card for information.

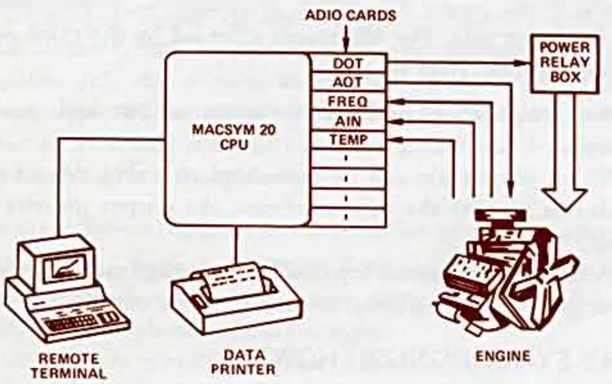
TABLE 2
ABBREVIATED SUMMARY OF COMMAND SET

ANALOG AND DIGITAL INPUT/OUTPUT	
Analog Input	AIN (Slot, Channel, Gain)
Analog Output	AOT (Slot, Channel)
Digital Input	DIN (Slot, First Bit, Last Bit)
Digital Output	DOT (Slot, First Bit, Last Bit)
Frequency Input	FIN (Slot, Channel, Time Base)
High-Speed Analog Input:	SCAN (Slot, First Channel, Last Channel, Gain, Starting Buffer Location)
	COLLECT (Slot, Channel, Gain, No. of Readings, Time, Starting Buffer Location)
TIMING AND SYNCHRONIZATION	
Wait T	Halt Program for 10•T ms Interval
RE (H,M,S)	Read Elapsed Time (Hours, Minutes, Seconds)
SET (H,M,S)	Set Elapsed Time (Hours, Minutes, Seconds)
ONT (S,B,P)	On Event, Trigger (Slot, Bit, Polarity)
ONB (S,B,P,D, #)	On Interrupt Branch (Slot, Bit, Polarity, Debounce, New Command Line)
DATA STORAGE AND VARIABLES	
A0 to Z9 and A-Z	286 Variables (see Assignment Operator) for Storage of Data, Used as Indexes or as Parameters in Commands for Setting Slot, Channel, Gain, Time, etc.
BUF (exp)	Buffer for Temporary Storage of Readings or Values at the location defined by the expression (exp).
OPERATORS	
Assignment	:= Follows Variable Symbol (see above) Example, .A: = 5 Set Variable A equal to 5
Arithmetic	+, −, /, •, or //
Boolean	AND, OR, XOR, COM
Relational	=, >, <, >=, <=, <>
PROGRAMMING	
. (received)	Prompt: MAC 20 Active and Awaiting Commands
⮧ (carriage return)	Carriage Return after Command-Line Sequence Causes Immediate Execution
0: to 9:	Ten 256-Word Program-Storage Areas
0:	256-Word Command Buffer
1: to 9:	Saved Command-Sequence Buffers to be Used as Programs or Routines
#6	Execute Command Sequence Previously Stored in Sequence Buffer Number 6
OUTPUT	
'TEXT'	Any String of ASCII Characters Enclosed in Single Quotes Will Be Transmitted as a Message from the MAC 20
RDXO N	Output Radix (Binary, Octal, Decimal, Hex)
RDXI N	Input Radix
OUT (N)	Output Directed to Primary or Secondary Ports
TAB (exp)	TAB right the Number of Spaces Defined by the Expression
CR	Output a Carriage Return
SP	Output a Space
FF	Output a Form Feed
PNT (exp)	Output the Value of the Variable or Expression in the Current Radix
PUTB (exp)	Output 8-Bit Binary Byte (non-ASCII)
PUTW (exp)	Output 16-Bit Binary Word (non-ASCII)
SPNT	Scaled Print of a Rational Number for Decimal Output in Engineering Values
TBUF (L,M,R)	High-Speed Output from Buffer at (Location, Number of Words, Radix)
List (#N)	List Command Line Specified by N

AN APPLICATION EXAMPLE

A user could find MACSYM 20 useful in automating test cells and dynamometers for testing engines. Tests are performed more efficiently, and serialized test results can be shipped with the engine and copies retained by the manufacturer as warranty records.

Figure 5 shows some of the functions that are performed by MACSYM 20, interfaced with the test cell by five cards (one MACSYM 20 handles three independent test cells, using only 15 of its card slots). The tests are performed over the engine's entire performance envelope in real time; if problems occur, there is automatic branching to a diagnostic testing mode. If the diagnostic measurements show that engine failure is imminent, several high-speed data scans are made during the automatic emergency shutdown, to allow a detailed post-mortem examination to be performed.



(ONE OF 3 TEST CELLS (5 CARDS)

CARD	FUNCTIONS
DOT (DIGITAL OUTPUT)	STARTER ON/OFF BATTERY POWER ON/OFF FUEL PUMP POWER ON/OFF
FREQ (FREQUENCY COUNTER)	RPM FROM TACH FUEL FLOW RATE FROM TACH
AOT (ANALOG OUTPUT)	CHOKE ADJUST IDLE ADJUST AIR/FUEL RATIO ADJUST FUEL FLOW ADJUST (THROTTLE)
AIN (ANALOG INPUT)	AMBIENT AIR & WATER TEMPS STARTER CURRENT COMPRESSION VACUUM EXHAUST PRESSURE NO + NO_2 + CO READINGS TORQUE LOAD
THERMOCOUPLE (T.C.) TEMP	EXHAUST TEMP WATER TEMP OIL TEMP HEAD TEMP

Figure 5. MACSYM 20 in dynamometer applications.

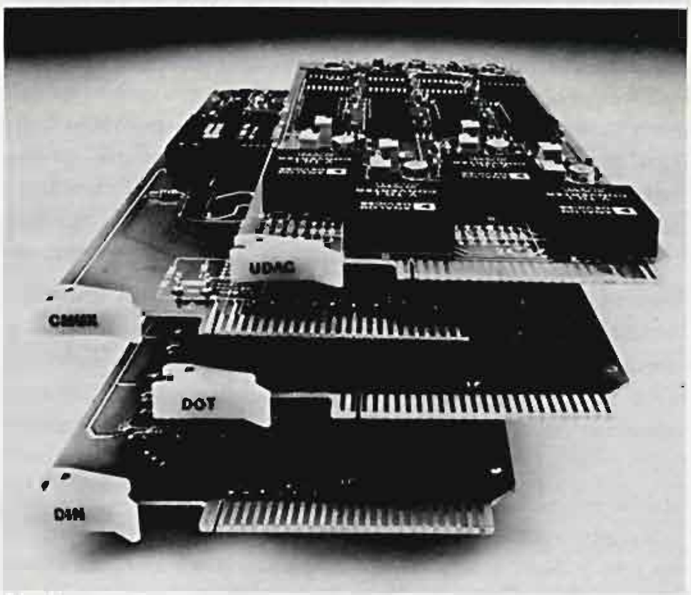
Local printouts of English-language messages are provided for production and test workers, as an informative readout of the engine's performance. MACSYM 20 also provides test and certification data for engines that pass the tests. All test results are printed in formatted columns in engineering units with labels such as: gallons/hour, RPM, foot-lb load, °C or °F, psi, and other units.

This test program, written in the MACSYM 20 command set, in combination with the integral signal conditioning, provides an effective and low-cost solution for engine-performance testing. This is one of the many possible application areas where MACSYM 20 can make a valuable contribution.

▶▶▶

SPECIFICATIONS OF MACSYM 20

CENTRAL-PROCESSOR UNIT	
Architecture	Z80 Microprocessor
Clock Speed	2.5MHz
Memory	16K Bytes to 48K Bytes (Dynamic RAM) 16K Bytes EPROM
COMMUNICATION INTERFACES	
Dual RS-232C Ports	Dual 25-Pin D-Type Connector- EIA (DTE and DCE)
Interface Compatibility	RS-232C, 20mA Current Loop, RS422, Modem
Baud Rates	110 Baud to 9.6k Baud, Switch-Selectable
IEEE-488-1975	Talker, Listener
RS-170	Dual Video Output
ADIO CONTROLLER	
Overall System Accuracy ±0.025% of Full-Scale Range	
A/D Section	
Type of Converter	12-Bit Successive Approximation
Nonlinearity	±1/2LSB max
Gain Drift	±15ppm/°C
Conversion Time	25 microseconds
Range	±10 volts
Software-Programmable-Gain Amplifier	
Gains	1, 2, 4, 8V/V (Additional Gain on Cards)
Gain Drift	±25ppm/°C
Offset Drift	±30μV/°C
Sample-Hold Amplifier	
Aperture Time	90ns max
Aperture Jitter	20ns max
PHYSICAL	
I/O Slots	16, with provision for expansion to 256 total in 16 chassis.
Size	8 3/4" X 19" X 20 3/4" 0.222m X 0.483m X 0.553m
Weight	34 lbs, 14.4kg
Operating Temperature Range	0 to 50°C
Humidity	Up to 80%, Noncondensing
Input Power	120V ac ±10%, 240V ac ±10%, 50/60Hz
Power Consumption	Less than 200 watts with full complement of I/O Cards



Signal conditioning cards permit direct field wiring hookup of industrial and laboratory sensors and transducers to MACSYM 20.

THE NEW GENERATION OF ISOLATION AMPLIFIERS

What Can You do with a Wideband, Ultralinear Low-Drift, 3-Port Synchronizable Isolation Amplifier?

by Frank Goodenough

*An isolation amplifier (or isolator) has an input circuit that is galvanically isolated from the power supply and the output circuit. The power supply and the output may also be isolated from one another, in varying degrees. Isolators are intended for applications which need: safe, accurate measurement of voltage and current at frequencies from dc to the audio range in the presence of high common-mode voltage (to thousands of volts) with good common-mode rejection; line-receiving of signals transmitted at high impedance in noisy environments; and/or safety in general-purpose measurements where dc and line-frequency leakage must be maintained at levels well below certain mandated minima. Principal applications occur in electrical environments of the kind associated with medical equipment, power plants, automatic test equipment, and industrial process-control systems.**

WHAT IS MODEL 289?

Model 289 is a three-port synchronizable isolator, with low output impedance and functionally usable gains up to 100V/V. It is capable of handling low-frequency signals with 12-bit accuracy, with linearity to within 0.012%, gain stability of 0.005%/°C, and input offset drift of 15μV/°C. Dynamically, it has small-signal bandwidth of 20kHz, full-power bandwidth of 5kHz, and settling time of 200μs to within 0.1%. And this performance is available in a small, 1.5" × 2" × 0.75" (38.1 × 51 × 19.1mm^3), package at low cost, $59 in small quantity (J version).

WHAT DOES THREE-PORT ISOLATION MEAN?

Figure 1 is a greatly simplified diagram of the 289, showing its external connections. It is divided into input, output, and power sections, separated from each other by isolation barriers. DC current cannot cross these barriers. As with all Analog Devices isolators currently available, energy and signals are transferred across the barrier by inductive coupling, using a high-frequency carrier and transformers.

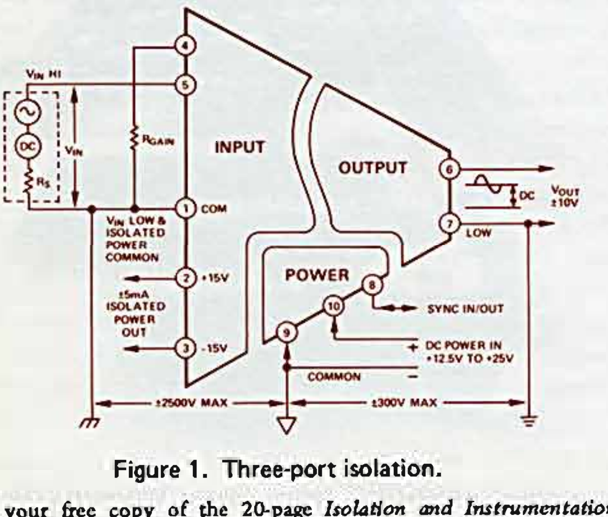


Figure 1. Three-port isolation.

*For your free copy of the 20-page *Isolation and Instrumentation Amplifier Designer's Guide*, and for information on any of the Analog Devices products mentioned here, use the reply card.

The barrier between the input section and the output and power sections can withstand ±2500 volts applied between any pins of the input section and any pins elsewhere on the device. In addition, ±300V can be applied between any pins of the output section and any pins of the power section without damage.

What does this mean to the user? As with any 2- or 3-port isolator, a fault or large common-mode voltage on the input side of the barrier cannot hurt signals, people, or equipment on the output or the power sides; conversely, a fault or CMV on the output or the power side cannot cause harm to similar entities on the input side. The advantages afforded by the third port are more subtle. Here are a few:

- No ground-loop problems between output and power ground.
- Either output pin can be connected to either side of the load; this permits the user to choose the output polarity or phase.
- A fault on the power input will not damage users or equipment (people or computers) connected to the output.

WHY SYNCHRONIZE? HOW?

If two or more carrier-coupled isolators are located in close proximity, small amounts of carrier crossfeed can, in some cases, cause low-frequency or dc-offset errors due to the generation of difference (beat) frequencies. Of course, shielding and good wiring practice help, but where high resolution is important, synchronization of all the oscillators may be the most practical solution.

Among the synchronizable isolators that Analog Devices manufactures, there are several approaches to synchronization. In the approach used for Model 289, no external oscillator is required. The synchronization terminals provided are "soft"; hence, they can be simply connected together, and the devices will agree upon a stable common frequency.

HOW DOES THE ISOLATOR WORK?

Figure 2 is a simplified view of the inner workings of Model 289. Two transformers straddle the isolation barriers between the three sections. DC power (25mA at 14.4V to 25V), connected to pins 9 and 10, is applied to a regulator which drives the 100kHz synchronizable power oscillator, which in turn drives winding *a* of power transformer T2. Isolated ac power is induced into windings b, c, d, and e. The output of winding *b* is rectified and filtered to furnish power to input amplifier A1 and, via terminals 2 and 3, to external circuitry (such as low-level preamplifiers) needing isolated power; up to 5mA at ±15V is available.

The input signal is applied between pins 5 and 1 (isolated common) to follower-connected op amp, A1. The user connects gain resistor, R_G, externally to set the gain. Gain values up to 1000V/V can be set; but specified performance is avail-

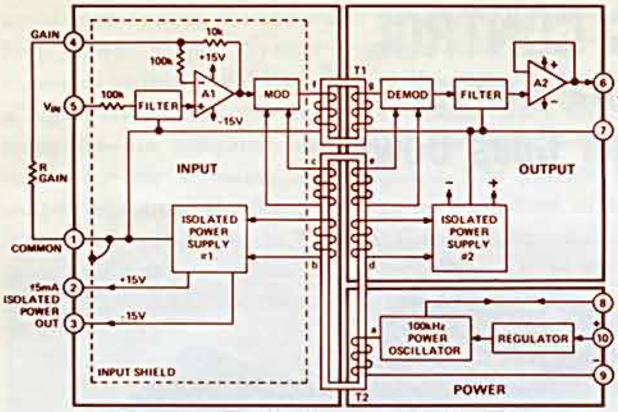


Figure 2. Block diagram of model 289.

able only for gains to 100. 100kΩ resistors protect the input from differential voltages as high as 230V rms. A1's output is chopped into winding *f*, and the resulting waveform is coupled to the output section via winding *g*, synchronously demodulated, filtered, and buffered by follower-connected output amplifier A2. A2 receives its isolated power from isolated power supply #2, which in turn is excited by winding *d*. The isolated ±10V output appears between pins 6 and 7 and may be connected for either polarity.

The input power regulator serves a number of useful purposes:

- Acting as a filter, it minimizes both conduction of electromagnetic interference to the power source and the effect of input-power ripple on the output signal.
- Since it is current-limited, indefinite shorting of the floating power will not destroy the 289.
- A short-circuit-type failure of the 289 will not pull down or blow the fuse of the input power source.

APPLICATIONS

Figure 3 shows a *portmanteau* application that demonstrates ways in which the extended bandwidth and three-port isolation of Model 289 can be useful in a single test setup. It represents a hypothetical test facility for large electrical machinery. The environment is alive with electrical and mechanical noise of all types and probably is not very clean. High voltage, transient and continuous, abounds. The system of Figure 3 shows a few of the measurements that might be made for which an isolator with Model 289's speed and accuracy would be a natural choice.

Temperature. (1) An essential test is to determine the hot-spot temperatures at various points inside the machine, since these affect the machine's life and a variety of design parameters, such as insulation, size, cooling, lubrication, and cost. As Figure 3 shows, AD590F current-output temperature sensors are indicated. They are a logical choice because of their small size, low cost, fast response, and easy signal conditioning, including multiplexing.* Since they are *current* sources, with current in microamperes numerically equal to absolute temperature (K), no errors are caused by line drops, contact resistance, or contact potentials at terminals, switches, or slip rings.

The CMOS multiplexer and its sequencing circuitry, as well as the AD590s, are excited by the isolated front-end power; the output current from the selected device flows through a resistor

*Useful information about such applications can be found in the AD590 data sheet (Figs. 17–19) and ANALOG DIALOGUE 12-2 (page 9, Fig. 5).

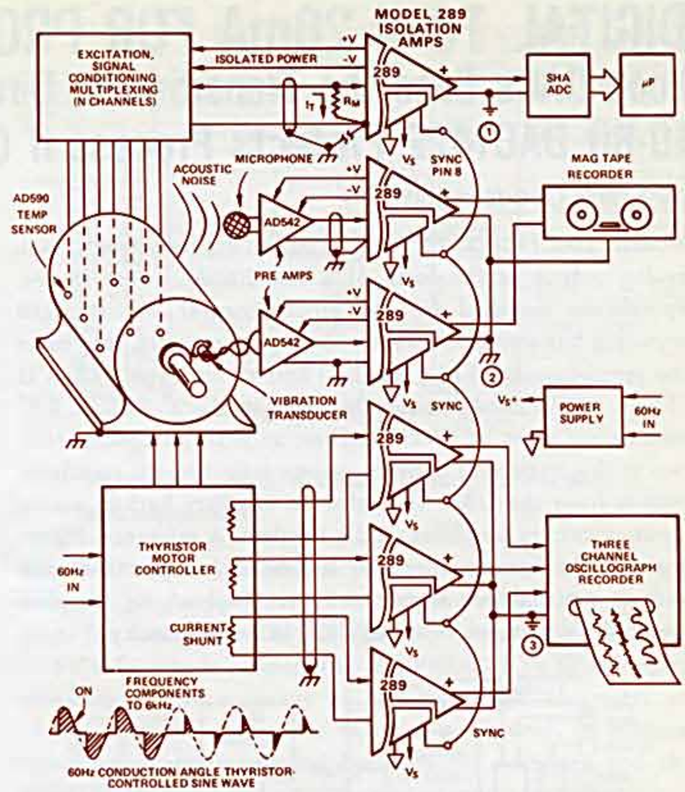


Figure 3. Test system illustrating possible applications for 3-port isolators.

at the 289's input, which measures the voltage, proportional to current, directly. Because of its 5kHz large-signal bandwidth and settling time of 200μs, the 289 can follow a rapid sequence of measurements, even at 500Hz. The 289 isolates the 590's (and any potentials between the test machine and the instrumentation panel) from the data-acquisition system to which they are connected. The three-port isolation permits a choice of output polarity, converting K to °C by adding voltage in series, and elimination of common-mode errors between the 289 output and the input of the data-acquisition system.

Noise and Vibration. (2) The audio-band response of the 289 permits isolation of acoustic noise measurements (symbolized by the microphone), lamination noise, and detection of noise due to arcing, corona discharge, etc. Vibration pickups may be used to detect problems with bearings, mountings, etc.; they can be installed in locations thought to be susceptible in large machines. In each case, the ±15V floating power from the 289 can power a preamplifier (such as the AD542 FET-input op amp) or other signal-conditioning circuits.

Electrical Instrumentation. (3) Isolation amplifiers can be used to monitor electrical waveforms, such as current, when sensed by resistive shunts at high common-mode voltage. For accurate observation of electrical noise or thyristor waveforms, with frequency components up to and beyond 10kHz, the wide bandwidth of the 289 is especially useful.

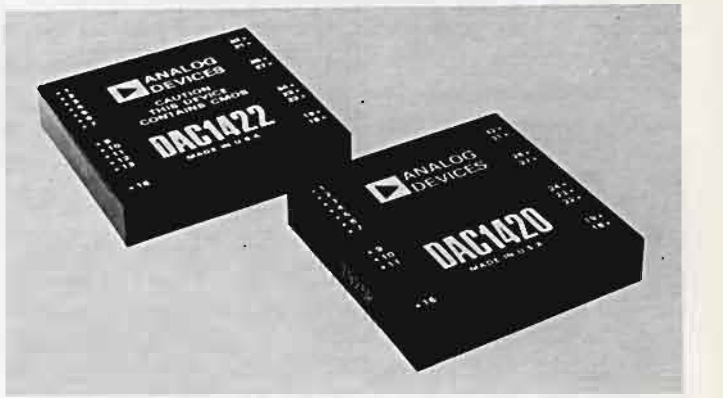
The measurements discussed above are just a few for which isolation would be useful in the testing of large electrical machines. And electrical-machine testing is a small subset of the application potential of the versatile synchronizable three-port Model 289 isolator.

▶▶▶

DIGITAL TO 4-20mA FOR PROCESS CONTROL
Loop DACs Ease the Transition to Direct Digital Control
10-Bit DAC1422 Protects Process if Computer Goes Down

by Frank Goodenough

Models DAC1420/1422* are 8/10-bit d/a converters with analog output in the form of a 4-to-20mA current source. Specifically designed for the process-control industry, and requiring but a single +10V to +36V power supply, they meet the requirements of ISA standard S50.1[1] for Type 3 Class U (3-wire non-isolated) output. Included in the 2" X 2" X 0.4" module are a set of CMOS latches, an 8/10-bit CMOS DAC, two analog-to-current converters—one reflecting the translated output from the DAC, the other an auxiliary backup analog input—a current amplifier, and a regulator & reference. Figure 1 shows the basic connections and operation of the devices with an external loop supply and a remote load, R_L, supplied via a twisted pair. Prices are $89/$99 in small quantity.



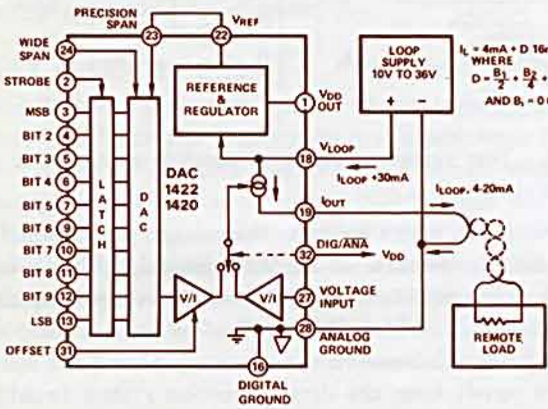


Figure 1. Block diagram of the DAC1422 in a simple application.

THE TRANSITION TO DIGITAL CONTROL

Many is the engineer who has been handed a problem in these terms, "Upgrade that old design, but don't change anything." Today it is a daily occurrence in the process-control industry. There are hundreds of thousands of electrical analog control loops running process plants throughout the World. For each loop, there is a controller driving currents of 4-to-20mA from a control panel through hundreds or thousands of feet of twisted pair to operate an actuator (valve, heater, power controller, motor, etc.) The magnitude of the analog signal is determined by a function of the difference between a set-point voltage and the results of a measurement of the quantity or quantities being controlled, also communicated by return 4-to-20mA signals.[2]

For at least the past twenty years, the process industries—both equipment manufacturers and users—have been seeking to bring the digital computer into the process plant. For many reasons (most of them beyond the scope of this article), progress has been slow. One of the important considerations in the past has been the need to implement digital operation in one fell swoop, rather than a bit at a time (no pun intended). In building a new plant, a new computer that would make all the decisions would be installed, but the cost and time involved in debugging the startup operation could wipe out many of the savings that were the purpose of going digital in the first place. In converting an existing plant to digital control, a large computer would be installed, with the analog loops left in place for backup. But the transition would still be precipitous and the problems costly.

Today, with the availability of distributed processing in the form of minicomputers and microcomputers, and the pressures caused by the increasing costs (economic and environmental) of *not* going digital, the outlook is more optimistic. It is now possible to convert to digital control, installing micro- or minicomputers to control one section of the process at a time. The incoming analog process data can be converted to digital in a variety of data-acquisition systems, set-points can be provided by the computer, and the required outputs to the actuators can be computed. All that is needed is a device to convert the parallel digital output from the computer to a 4-to-20mA control signal, so that the existing control wiring and controller/actuator can still be used. It would be helpful if, during the transition to computer operation, the existing analog controllers could still be used for backup, i.e., the line-driving DAC could respond to either analog or digital signals.

It is for applications of this kind that the DAC1420/1422 have been designed, as the first of a family of loop DACs. When these compact modules receive a parallel digital word and a strobe pulse, the output is a 4-to-20mA signal with a span directly proportional to that word, i.e., all-*zeros* produces 4mA of output current, all-*ones* produces 19.98mA, and intermediate codes produce proportional outputs. Alternatively, the output can respond to an analog voltage input. The mode is selected by a digitally operated switch.

DIGITAL CONTROL

The principal application for these loop DACs is in *direct digital control of analog process loops*. Figure 2 is a functional block diagram of a typical system containing several loop DACS. It consists of a computer, a set of loop DAC's, a data-

*For technical data, use the reply card.

[1] *Compatibility of Analog Signals for Electronic Industrial Process Instruments.*

[2] See also "V/I converters for process control", ANALOG DIALOGUE 13-2.

acquisition system, the controlled process, and an independent loop power supply. System setpoints defining the desired values of process variables—whether determined manually, by a higher-level host computer, or by computation within the computer—are compared with the process inputs; and output values for the actuators are computed. The parallel digital output bus from the computer can be connected to all the loop DACs. The data in each DAC is then updated, either sequentially or at random, by a strobe signal from the computer, addressed to the desired DAC.

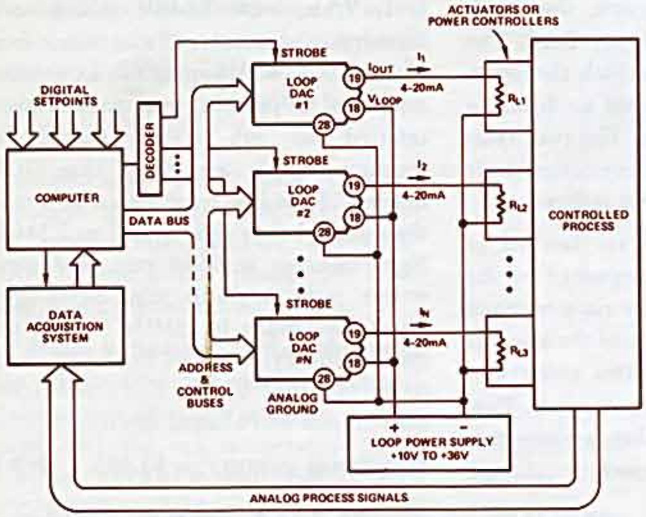


Figure 2. Typical application of loop DAC's.

The 4-to-20mA output of each DAC is a direct function of the 8 or 10 bit word which has been latched into its input register. Each current output is transmitted to its remote actuator/controller and develops a voltage across its load resistance. The return current may be over a common line, as shown in Figure 2, or over a set of individual twisted pairs with the common connection at the loop supply. As noted earlier, the three-terminal output structure of the DAC conforms to ISA S50.1, Type 3, Class U.

HOW LOOP DACS WORK

Figure 3 is a more-detailed version of Figure 1, showing some of the options available to the user in applying the DAC1420/1422. The basic digital-to-analog conversion is performed by a circuit employing an Analog Devices CMOS integrated-circuit multiplying DAC. Its output is a voltage, which is converted to a 4-to-20mA output current by a V-to-I converter circuit not different in philosophy from that in Figure 31, page 29, of the *Application Guide to CMOS Multiplying D/A converters.**

An important feature of the loop DAC is the self-contained input latch, which permits many DACs to operate from a single parallel bus. The analog output of the DAC changes when a new digital word is latched; i.e., the latch is strobed by a rising-edge signal to latch the digital data appearing on the bus. The DAC output current in this case, is shown driving a pair of external loads in series (RL_1 and RL_2). The maximum allowable value of the total load resistance is determined by the ratio of the compliance voltage, $V_{LOOP}-6V$, and full-scale output, 20mA. With V_{LOOP} at 36V, the maximum load resistance is 30V/20mA = 1.5kΩ. Since the DAC draws an additional 30mA of operating power from the loop supply, the supply should be rated at 50mA per DAC.

*Available free upon request. Use the reply card for your copy.

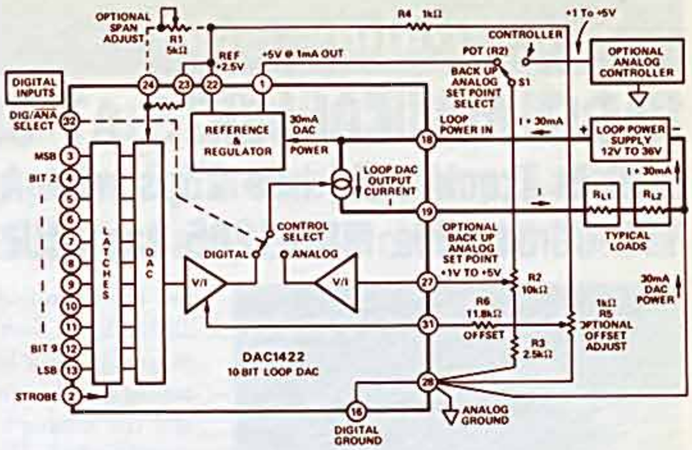


Figure 3. Loop DAC block diagram: connections and adjustments.

The DAC requires no digital power; it takes all of its power from the loop supply. It can furnish an output of 5V at up to 1mA for low-power CMOS logic. To operate the DAC, the +2.5V reference is jumpered to the PRECISION SPAN input, providing a span accuracy of 16mA ± 0.2%. If greater accuracy, or a different value of span, is required, an external resistor may be connected between the reference and the WIDE SPAN input, for a ±10% range of span adjustment.

The DAC1422's output offset (actually the 4mA output setting) is factory-trimmed to within ±0.2% of full scale (2LSB). If greater precision is required, the resistor network, R4, R5, R6, is connected between the reference and the OFFSET terminal. Because of interaction between SPAN and OFFSET, both adjustments should be repeated so as to converge on an accurate setting.

A key feature of the loop DAC is the ability to revert automatically to a backup analog input (1 to 5V, or 250Ω load on the output of a 4-to-20mA analog controller) if the computer crashes or loses power, since loop power can be supplied independently. A solid-state analog switch, its position controlled by the logic level on DIG/$\overline{ANA}$ (logic 1 for digital), connects either the DAC output or the backup input to the controlled current source.

This feature is versatile. With the computer's power bus connected to DIG/$\overline{ANA}$, it will automatically switch to analog if the computer dies, and the separately powered DAC's output will stay alive even though the computer loses power. Or DIG/$\overline{ANA}$ can be connected to a digital command output which restores analog if the computer is performing anomalously.

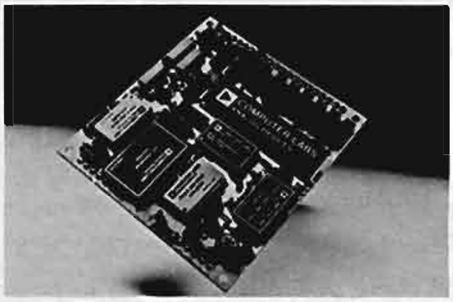
The backup analog input can come from the fixed +5V output and a resistor network, or it can be connected to a backup analog controller, as noted above (S1 to right); this backup might be the original equipment in a system being changed over to digital control.

With monotonic operation over the complete 0° to 70°C temperature range, these versatile loop DAC's can provide cost-effective design in the conversion from an all-analog to a digital system, or in the design of a new system totally under digital control.

▶▶▶

12-BIT ADC CONVERTS AT 5MHz

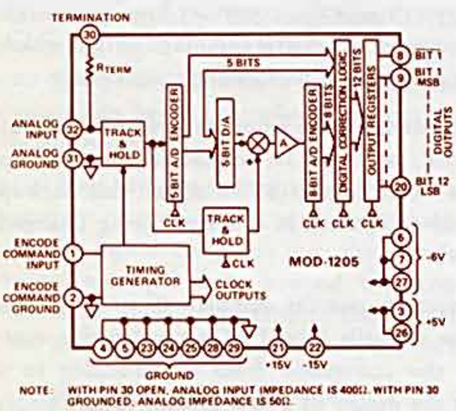
Built-In Track/Hold has 25ps max Aperture Uncertainty
TTL-Compatible MOD-1205 has SNR > 66dB, NPR > 56dB



Model MOD-1205* is a very high speed a/d converter capable of digitizing video input signals to 12-bit accuracy at random or periodic word rates from dc through 5MHz. It is constructed on a single 27-square-inch circuit card intended for mounting on a system mother board. Included in the MOD-1205 are the sample/track-hold amplifier, encoder, timing circuits, and output latches, for a true, simultaneous, all-parallel digital output. Also included are gain and offset adjustments, so that *no* external parts are required.

It is designed for applications involving accurate resolution of wideband signals or analog information multiplexed at high data rates. Typical applications include radar digitizing, digital communications, real-time spectrum analysis, and signature analysis.

Conversion is performed by a digitally corrected subranging (DCS) technique, which is illustrated schematically in the block diagram of the MOD-1205. The five most-significant bits are converted to digital by a *flash* conversion, then back to analog by a high-accuracy DAC. The analog signal is compared with the input, and the residue is converted to digital in an 8-bit *flash* conversion. The two bytes are combined in digital correction logic and latched into the output register.



MOD-1205 block diagram

*For technical data, use the reply card.

New conversion results are latched at rates up to 5MHz, as determined by the *encode* command; but the time required for a complete conversion of the input at a given point in time is two conversion periods plus 275 ± 25 nanoseconds. That is, for every data point that is converted, there are three in the pipeline.

The MOD-1205's conversion relationship is 1mV/bit, with 2.048V at full scale. Conversion is guaranteed monotonic from 0°C to 70°C, with 5ppm/°C max nonlinearity and 50ppm/°C max gain tempco, referred to full scale. Dynamically, spurious signals are more than 70dB below F.S. at low frequencies, and more than 65dB below F.S. from 1 to 2.5MHz. Signal-to-noise is 66dB min, and Noise power ratio is 56dB min. Small-signal input bandwidth is 15MHz (–3dB), permitting the dynamics of the input circuit to be governed by the characteristics of the external anti-aliasing filter.

Price (small quantity) is $3,495. ▶▶▶

FAST-SETTLING ECL DACs

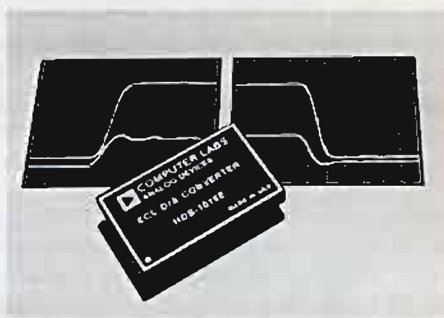
HDS-E Family: 8 Bits in 10ns, 10 Bits in 15ns
Drive 75Ω Cable *sans* External Amplifiers

The HDS-0810E and HDS-1015E* are fast-settling 8- and 10-bit d/a converters designed to be compatible with standard emitter-coupled logic (ECL). These compact hybrid circuits are complete, with high-precision monolithic voltage references, active-laser-trimmed resistor networks, 75Ω output impedance, and 27mA I_{OUT}, to permit 75Ω cable to be driven to 1 volt without external driver amplifiers.

Typical applications for fast-settling d/a converters include raster-scan and vector-graphic displays, TV video reconstruction, digital VCO's, high-frequency waveform generators, and measuring instruments. Having low glitch energy (200pVs), fast settling time (10ns and 15ns), and update rates to 100MHz, they are ideally suited for use in cathode-ray-tube displays.

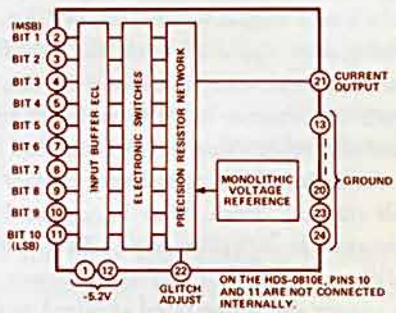
The HDS-E series DACs are monotonic over the full operating temperature range and require just a single supply (–5.2V) for operation. Packaged in an industry-standard-size 24-pin double-width dual in-line case, the HDS-E Series DAC's are

*For technical data, use the reply card.



available in either ceramic-glass cases (0° to 70°C) or hermetically sealed metal cases (–55°C to +125°C).

Small quantity prices: HDS-0810E, $129/$198 (glass/metal); HDS-1015E, $149/$229. ▶▶▶



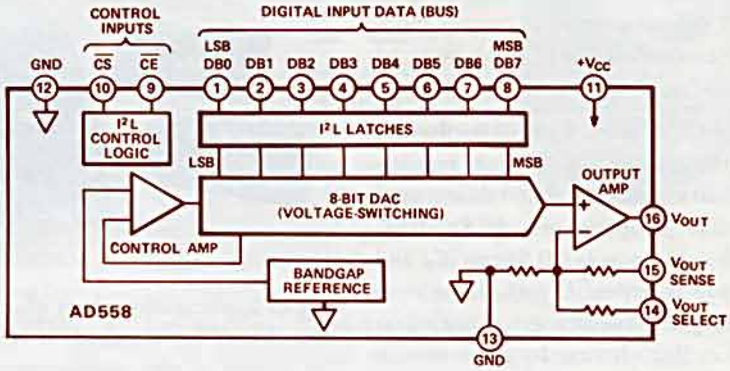
Block diagram

8-BIT LOW-COST µP-COMPATIBLE IC DAC

AD558 Is Really Complete: Reference, Op Amp, Latches, Pre-Trimmed, Single-Supply, Fast, Low-Power, 16-Pin DIP

The AD558* is a complete voltage-output 8-bit digital-to-analog converter on a single monolithic chip, housed in either a plastic or a hermetically sealed ceramic 16-pin dual in-line package—or available in die form.

It contains a precision voltage reference, an output amplifier, a latching register with *nor*'d CHIP SELECT and CHIP ENABLE inputs, for efficient µP interfacing, and a precision DAC circuit.

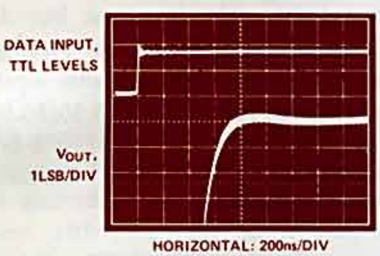


The device is laser-trimmed at the wafer stage, eliminating any need for external adjustments; calibration accuracy is guaranteed over the full temperature range to within ±1LSB at full scale or zero (AD558K/T), and all versions are monotonic over temperature.

Truly microprocessor-compatible, the 8-bit AD558 will run from the same single supply used by the host µP, at any voltage from +4.5V to 16.5V, with a choice of two output ranges: 0 to 2.56V (10mV/bit) and 0 to 10V (39.1mV/bit, for $V_{CC} \geq 11.4V$).

The AD558's low dissipation (75mW) is useful in battery-powered and portable operation, and the wide range of V_{CC} permits automotive and computer-mainframe-powered applications. Settling time to full scale is typically 0.8µs to within 1/2LSB (2.56V range).

And its price is low: from $5.95 (100+, AD558JN).



AD558 settling characteristic detail
0V to 2.56V output range full-scale step.

KEYS TO THE AD558

The block diagram shows the elements of the AD558, which is a triumph of circuit design, processing, and trimming technology, much of it covered by ADI patents.

First, its design is fully integrated, rather than a collection of stock circuits. This means a small chip (hence better yield and lower cost), low dissipation (hence better performance over temperature, and a wider range of applications), and a compact pinout (only 16 pins, hence improved reliability and a smaller footprint).

Second, the use of proven Analog Devices I^2L, bandgap reference, and thin-film-on-silicon technologies provide these important benefits: I^2L (integrated injection logic) permits efficient use of a single chip for digital and high-performance analog circuitry; bandgap reference provides tracking reference voltage with low tempcos, excellent long-term stability, and low-V_{CC} operation; and thin-film-on-silicon permits stable, linear, trimmable resistors to be fabricated for high-accuracy conversion.

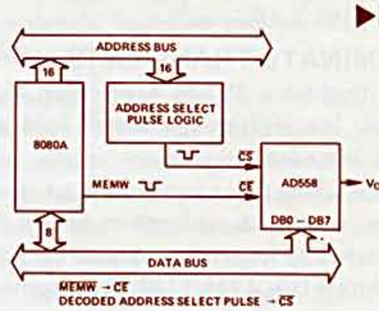
Finally, the device is automatically laser-trimmed at the wafer stage. This proven Analog Devices technology results in converters that are fully calibrated—ending rejections in expensive packages and requiring no user trims, even when bought as chips—and monotonic over the entire operating temperature range.

EASY TO INTERFACE

The AD558's low-current logic inputs, set for TTL threshold voltage, can be operated by TTL or low-voltage CMOS over the entire operating V_{CC} range. The 100-µA maximum current minimizes bus loading.

The AD558's input latches simplify interfacing to 8- and 16-bit data buses. The latches are controlled by $\overline{CS}$ and $\overline{CE}$ inputs (as mentioned earlier), internally *nor*'d so that the latches transmit input data to the DAC section only when $\overline{CS}$ and $\overline{CE}$ are both at logic zero. When either of the control inputs goes to logic 1, the input data is latched into the registers and held until both are again returned to zero. If the application does not involve control of inputs from a common data bus, both control inputs can be tied to 0 for transparency.

The AD558 acts like a "write only" location in memory. It can double up with a ROM slot, with no interaction; or, if doubled up with read-write memory, the memory will retain the word written into the DAC and can read it back without disturbing the DAC. Connections to an 8080A µP are shown in the figure. ▶▶▶



8080A/AD558 interface

*Use the reply card for technical data.

HIGH-RESOLUTION DACS & DEGLITCHER

18/16-Bit DACs Perform Well With Temperature
Deglitcher Virtually Eliminates Transients

The DAC1137/1136L* are complete self-contained voltage-or-current-output modular d/a converters with resolutions of 18/16 bits.

The *DAC1137* offers 18 bits of resolution, 16 bits of accuracy, and excellent temperature stability. Its integral and differential nonlinearity tempcos are ±0.5ppm/°C max; offset tempco is ±0.5ppm/°C, and gain tempco is 5ppm/°C max. Long-term offset and gain stability are specified at ±8ppm for 1000 hours. Its price is only $460 (1-9).

The *DAC1136L* is a new addition to the proven and popular DAC1136 family. The DAC1136L is characterized by 16-bit resolution, 16-bit accuracy, and enhanced temperature stability. Its integral and differential nonlinearity tempcos are 1.5ppm/°C max, its offset tempco is ±0.5ppm/°C, and gain tempco is ±8 ppm/°C max. It is priced at just $320 (1-9).

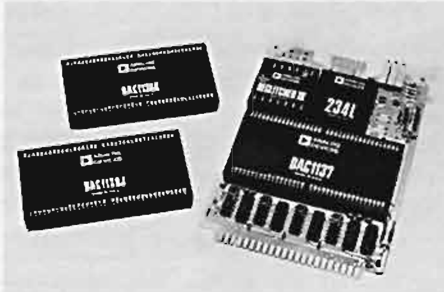
APPLICATIONS

The DAC1137 and DAC1136L are designed for applications in high-resolution cathode-ray-tube displays, automatic test equipment, analytic intruments, high-resolution servocontrol systems, and other applications where dynamic range and stability are required with high speed and low cost. Settling times to ±1/2LSB at 16 bits are 8μs in the current mode for both devices.

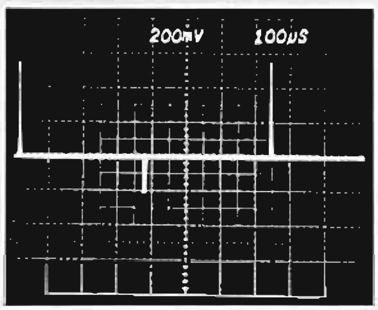
Outputs are 0 to +5V, 0 to +10V, ±5V, ±10V, or -2mA to 0mA. Digital inputs are TTL-compatible, in 2's-complement binary coding. Power required is at ±15V and +5V; package size is 2" X 4" X 0.4" (51 X 102 X 10.2mm^3).

ELIMINATE TRANSIENTS

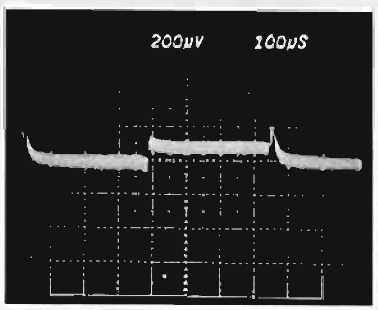
The Deglitcher IV* is a precision high-speed, low-feedthrough sample-hold circuit intended to remove spikes – due to switching-time asymmetry as some codes switch on and others switch off ("glitches")—from the output of high-resolution DAC1136/1137/1138/ converters in applications where glitch-free code transitions are required. It is provided as an option on the card-mounted assembly that is available for these converters.



The Deglitcher IV uses a proprietary sampling technique to anesthetize the DAC's output amplifier during the critical period immediately following a code change. The Before-and-After oscilloscope responses show the output of a DAC1136 when dithered up and down through the major carry between codes 1000000000000000 and 0111111111111111. The glitches can be seen to be virtually eliminated, allowing the 152μV 1-LSB step to be clearly seen (note the 1000:1 scale change). ▶▶▶



DAC1136; major-carry dither without deglitcher IV (BW = 1MHz)

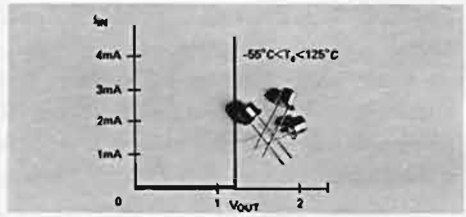


Same major-carry dither with deglitcher IV (BW = 1MHz)

*For technical data, use the reply card.

1.2V REFERENCE

2-Terminal AD589: Stable, Low-Power



The AD589* is a two-terminal low-cost temperature-compensated bandgap voltage reference which provides a fixed 1.23V output voltage for input currents between 50μA and 5mA, with 5mV max regulation and max tempcos as low as 10ppm/°C ("M"). With 0.6Ω output impedance and dissipation as low as 60μW, it is a superior replacement for other 1.2V references and an excellent choice for portable applications. Prices start at $1.20 in 100's (AD589JH). ▶▶▶

*Use the reply card for technical data.

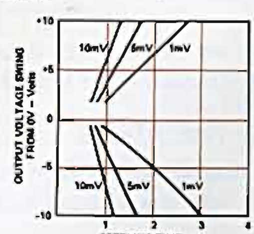
FAST FET OP AMP

High-Speed AD544 Has Low Drift & Noise

The AD544 is a TRI-FET op amp,* designed for applications requiring fast, accurate performance. It combines warmed-up bias current of 25pA max, offset voltage of 0.5mV max, and 5μV/°C max drift (AD544L) with 8V/μs min slewing rate and 3μs settling time to within 0.01%.

Combined with its high gain (50,000 min), low quiescent current drain (2.5mA max), and 2μV p-p noise (0.1 to 10Hz), these characteristics make it a best buy for applications in DACs, audio preamps, front-end buffers, and portable equipment. Price in 100s: $2.50/$3.50/$6.50/$11.50 (J/K/L/S). ▶▶▶

*Trimmed-offset, ion-implanted monolithic FET-input op amp. Use the reply card for technical data.



AD544 Settling time vs. output swing.

ANALOG DEVICES NAMES DIVISION FELLOWS

A. Paul Brokaw

Before being named a Division Fellow, A. Paul Brokaw was Director of Product Planning at Analog Devices Semiconductor (ADS); he continues as a member of the Analog Devices General Technical Committee for 1979-80. His face should be familiar to long-time readers of *Analog Dialogue*, since he has authored or co-authored several articles that have appeared here in recent year; also, in the brief time we have reported on new patents in "Potpourri", his name has appeared twice, adding to his collection of more than a dozen existing patents (there yet more pending).

Since joining ADS in 1971, Paul has contributed significantly (in varying degrees) to the design of many of our important amplifier, converter, and multiplier products. He designed the AD580 2.5V precision voltage reference and its cousins, the 10V AD581 and the AD584 multi-reference; the completely self-contained 10-bit I^2L AD571 a/d converter; and the AD521 instrumentation amplifier. He developed the basic principle for the AD582 sample-hold, has consulted on a number of other products, and is working on some interesting new designs that are expected to surface in the near future.

Before joining Analog Devices, he was employed at Communication Technology, Inc., Arthur D. Little, Inc., Labko Scientific, Inc., and Well Surveys, Inc., and has been an independent design consultant to industrial and commercial firms. He has a B.S. in Physics from Oklahoma State University and has authored a number of technical papers, including three (one with a co-author) for the IEEE *Journal of Solid-State Circuits*.

He is married to the former Sonja Kelso, of Springfield, Missouri. They live, with their son, Steven, in Burlington, Massachusetts.

A swimmer, skier, and runner, he has performed creditably in the annual Analog Devices 5km road race.

Barrie Gilbert

Barrie Gilbert is best known among analog aficionados for the seminal "Gilbert-cell" amplifier/multiplier circuit, which is at the core of the vast majority of multiplier IC's manufactured to-day. Before becoming a Division Fellow, Barrie had been a Product Designer; he continues to operate from offices in Forest Grove, Oregon. A prolific designer and writer, with a wide range of interests, Barrie has nearly a dozen patents, innumerable publications, four "Outstanding Paper" awards from the International Solid-State Circuits Conference, and the IEEE 1970 Achievement Award (for a paper that led to the subsequent development of integrated injection logic—I^2L).

At Analog Devices, Barrie's contributions include the AD534 multiplier, the AD536 rms-to-dc converter, and the AD537 V/f converter, as well as numerous contributions in circuit design, product proposals, application ideas, and process technology.

His interests range from linear and nonlinear analog signal processing to waveform-generation and shaping to integrated devices and structures to conversion devices, instrumentation, and professional audio.

Barrie is a native of England; his vocation in electronics first surfaced when he built an oscilloscope at age 12. He earned a Higher National Certificate in Applied Physics (with honors), in 1962, from Bournemouth Municipal College. Companies that have benefited from his fecundity include Mullard, Tektronix, and Plessey. He has also taught courses in circuit design in England and Belgium, as well as lecturing in the U.S.A. He is a member of IEEE and the Audio Engineering Society.

He is married to the former Myrna Loy Lumby, of Portland, Oregon; their four children are David, Timmy, Lynn and Anne. Recreational pursuits include trail-hiking, wildlife photography, music, and woodworking.

What is a 'Division Fellow?'

The naming of these first Division Fellows is part of a newly instituted Parallel Ladder program, which was established to recognize highly competent technical individuals and provide them with long-term career growth within their technical disciplines without having to assume line management responsibilities.

While the concept of the parallel ladder is not unusual in the industry, Analog's approach is unique in that it recognizes other roles, besides invention or technical creativity, by which individuals can make an impact on the process of technical innovation. Being a mentor, entrepreneur, and consultant, as well as acting as an ambassador of the company, are a few of these other roles. The program has been broadened to include all technical professionals, including process, test, and product and design engineers.

In making the announcement of the elevation of Paul and Barrie to Division Fellow, President Ray Stata commented: "These individuals have made outstanding technical contributions to the company and have exemplified unusual talents as innovators in their fields. They have acted as mentors to talented young technologists, have demonstrated leadership in generating new business opportunities, and have developed valuable industry and academic relationships for the company."

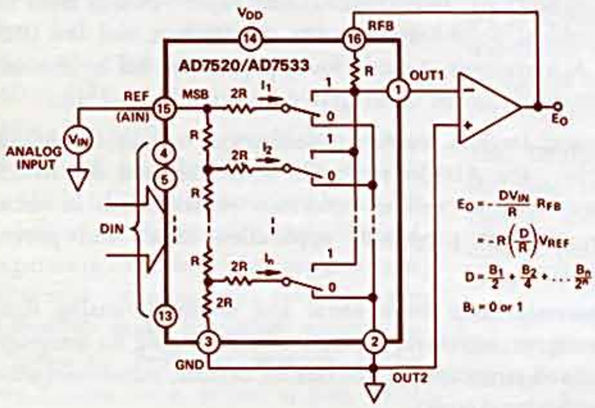
Application Note

CMOS DACs IN THE VOLTAGE-SWITCHING MODE

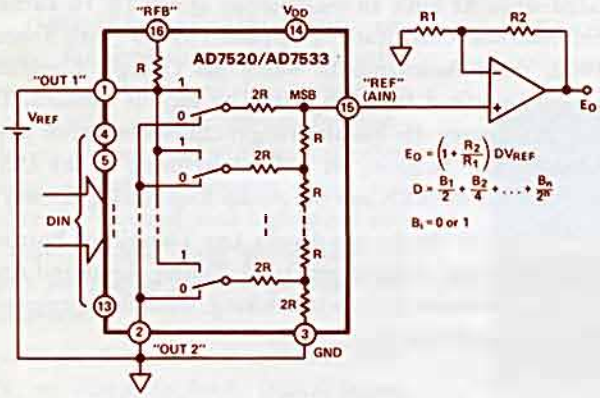
Can Work From a Single Supply, Including Output Op Amp
Have Fast Response, No Offset-Induced Nonlinearity

by Steve Stephenson

The versatile R-2R ladder attenuator can be used as either a voltage or a current source, and it may be used in either a current-steering or a voltage-switching mode.[1] Figure 1a shows the familiar connection of a CMOS d/a converter, such as the 10-bit AD7520,* in the current-steering mode; Figure 1b shows how the DAC can be connected for voltage switching by reversing the roles of the MSB node (REF/AIN) and the active switch bus (OUT 1).



(a). Current-steering mode



(b). Voltage-switching mode

Figure 1. CMOS DAC connected for different operating modes.

CURRENT STEERING

In the current-steering mode, since the OUT2 terminal is at ground potential, the operational amplifier maintains OUT 1 at the same voltage (virtual ground), and the binary-weighted currents through the 2R switch legs are independent of switch position. As commented upon in an earlier article,[2] the output capacitance and resistance (as seen by the amplifier's input) vary as functions of the input digital code. This makes the feedback-circuit's *noise gain* dependent on the code. The variation of resistance can cause the linearity to be affected if the amplifier has sufficient offset voltage. The variation of the output time-constant means that feedback compensation can, at best, only be a compromise. To ensure circuit stability for all codes, overcompensation (and consequent reduced bandwidth and increased settling time) is required.

There is also some charge injection from the gate of the switch, via the inherent capacitance between the gate and channel of the FET switch. This charge must take the lowest-impedance path to ground, in this case through the virtual ground of the amplifier. At major code-changes, output glitches may be significant.

VOLTAGE SWITCHING

In the voltage-switching mode, the constant resistance at the amplifier input eliminates the problems caused by modulation of the amplifier's offset voltage. In addition, the switch capacitance is remote from the amplifier, and the charge is shunted to the input source or to ground. Furthermore, the output capacitance of the network is considerably lower. All of this results in cleaner and faster response of the circuit to code changes.

As an additional important feature, the system's output voltage is of the same polarity as the reference voltage; as will be seen, this makes it possible to *operate the DAC and its amplifier from a single-polarity supply*. Finally, only a single amplifier is required for bipolar digital operation, using offset binary or (with the MSB complemented) 2's complement coding.

The configuration has a few minor disadvantages. Since the ON resistance of the FET switch increases the applied drain-source voltage approaches the value of the gate-drive voltage, and significant values of R_{ON} cause the division of voltage to depart from the ideal, large values of reference voltage will produce nonlinear performance.[3] However, for values of reference voltage less than +3.5V and VDD = +15V, the 10-bit DACs in the AD7500 series will retain their linearity. The 12-bit DACs will maintain 11-bit accuracy over temperature when employing a +2.5V reference (e.g., the AD580).

While the current-steering mode permits input voltages of either polarity and allows the circuit to function as a digitally controlled potentiometer (and as a four-quadrant multiplier), the voltage-switching mode permits only a single polarity of input (positive with respect to common).

[1] Examples of current steering and voltage switching may be seen in the *Analog-Digital Conversion Notes* (Analog Devices, 1977, ed by D. Sheingold, available at $5.95 postpaid), pages 116–117 and pp. 133–138.

[2] "Analog Signal-Handling for High Speed and Accuracy," by A. Paul Brokaw, *Analog Dialogue* 11-2 (1977), pages 10–16.

*Use the reply card for technical data on Analog Devices products mentioned in this article.

[3] *Application Guide to CMOS Multiplying D/A Converters*, Analog Devices, 1978

CIRCUIT POSSIBILITIES

Single Supply, Unbuffered. In Figure 2, the circuit of Figure 1b, without a buffer, is implemented with an AD584 as an adjustable reference. Settling time of better than 1μs was observed, with overall conversion linearity to 10 bits, using a 3.5V (max) reference voltage. Although the network can be loaded resistively, buffering is preferred, since the different temperature sensitivities of an external load resistance and the ladder resistance will result in a temperature-sensitive scale factor.

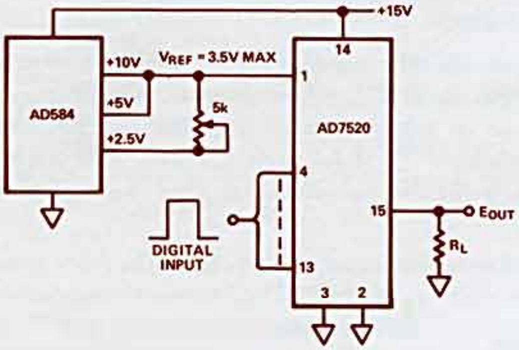


Figure 2. Single-supply DAC with AD584 reference, unbuffered output.

Single Supply, Buffered. In Figure 3, the DAC and the CMOS op amp are both powered from a single +15V supply. With this circuit, 10-bit linearity and good gain-temperature coefficient (since there are no external resistors sharing current with the ladder) were achieved over ambient temperatures up to 125°C. With a single-supply operational amplifier, offset is difficult to remove completely; therefore, some offset may have to be tolerated, usually amounting to less than one-half LSB at 3.5V reference. The observed settling time under these conditions, governed by the amplifier's performance, was found to be better than 2μs to one-half LSB.

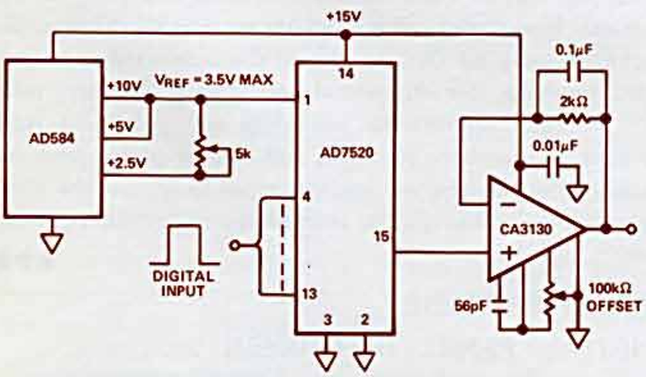


Figure 3. Single-supply DAC, buffered output.

Shorter Voltage-Settling Times. Figure 4 shows a circuit in which the voltage-switched mode is employed to obtain a *current* output, by connection of the ladder output directly to the summing point of the output amplifier. This connection provides the *fastest response* (settling time of the order of 900ns was observed): however, the gain tempco is poor, because the external feedback resistance cannot be expected to track the network's resistance variation with temperature.

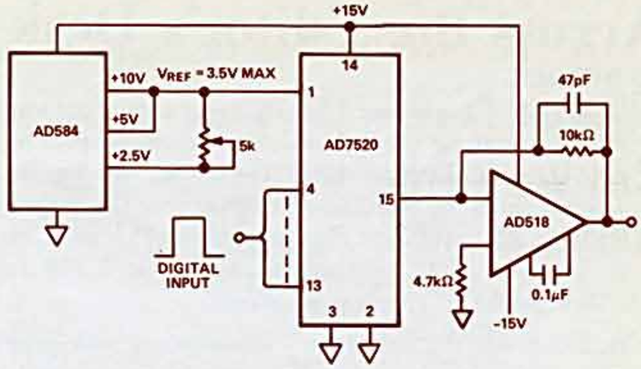
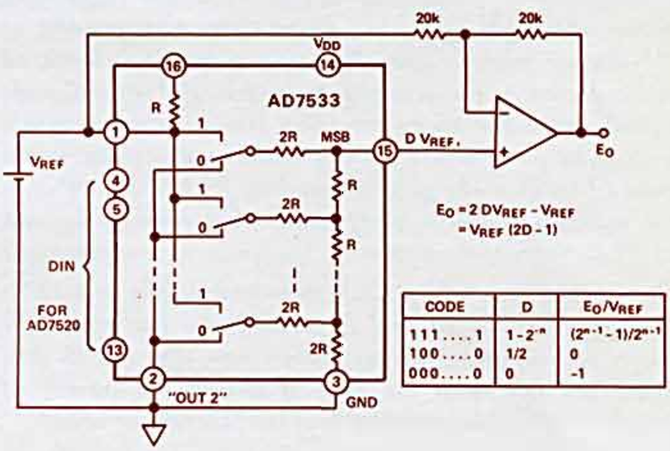


Figure 4. Increased speed DAC.

Simplified Bipolar Operation. Figure 5 shows how the voltage-switched mode simplifies the conversion of bipolar digital signals.[4] The output voltage from the ladder is applied at the amplifier's positive input, as in Figure 1b; the reference is connected to the inverting input via a resistance equal to the feedback resistance. Thus, the output of the ladder has a gain of 2, and the reference has a gain of −1; as the equation and the table show, this provides conventional offset-binary response, but *with a single amplifier*, instead of the two called for in the current-steering mode.



CODE	D	E_O/V_{REF}
111....1	$1 - 2^{-n}$	$(2^{n-1} - 1)/2^{n-1}$
100....0	1/2	0
000....0	0	−1

Figure 5. Connection for bipolar operation. If V_{REF} is provided by the 2.5V AD580, nominal output swing is ±2.5V.

SUMMARY

Using the techniques described here, Analog Devices CMOS d/a converters in the series AD7520, AD7521, AD7522, AD7523, AD7524, AD7530, AD7531, and AD7533 may all be made to operate in the voltage-switching mode with their published specified linearity. System benefits include the possibility of single-supply operation, increased speed, freedom from offset-voltage modulation, and more-economical digital bipolar operation.

▶▶▶

[4] "An Unusual Circuit Configuration Improves CMOS-MDAC Performance," by N. Sevastopoulos *et al*, *EDN* Magazine, March 5, 1979, pp. 77–82

Across the Editor's Desk

15-BIT ADC

Messrs. Mike Timko and Peter Holloway cannot get something for nothing quite as easily as claimed on page 6 of ANALOG DIALOGUE 12-3. The circuit of Figure 6 depends upon an Nx1.25-volt reference to the inverting input of the instrumentation amplifier, which must have an accuracy of 12 bits with respect to the 1.25V full-scale input for the circuit to be effective.

However, this corresponds to 15-bit accuracy with respect to the 10V reference level. For example, an error of 1 in 2^{12} in the 10V from pin 8 of the AD574 will cause a worst error of 2.4mV at the amplifier input, and 20mV, or 1 in 2^9, in the output of the DAC. The combination required, therefore, is a 12-bit resolution ADC of 12-bit accuracy, a 3-bit resolution DAC of 15-bit accuracy, and a 10V reference of 15-bit accuracy. The input-effect error of the instrumentation amplifier should be less than 0.3mV.

Yours faithfully,
Geoff. N. Payne
CSIRO Division of Materials Science
University of Melbourne, Australia

The authors reply:

It is important to note that the objective of the circuit is to obtain 15-bit resolution, i.e., digital codes corresponding to 2^{15} discrete monotonically increasing quantization levels, all codes present, with accuracy to within 2^{-12} of full scale ±1LSB. We're not asking for 15-bit resolution and accuracy with 12-bit parts, which, without statistical processing, would indeed be a little like getting something for nothing, although the accuracy is almost always better than expected because of the statistics of the divider.

Nevertheless, it is still a subtle matter to see just how 15-bit resolution is obtained, and if reader Payne has missed the point, perhaps many of our readers have also had doubts, which did not reach the stage of verbalization—merely of feeling "put on." In any event, here is a fuller explanation.

First, the method (refer to the Figure): using a successive-approximation routine, the otuput of the MUX is switched to "+5V"; the AD574 performs a conversion of $8(V_{IN} - 5V)$. For all 1's, the output of the MUX is switched to "+7.5V"; for any other code, the MUX is switched to "+2.5V." Another conversion is performed on the resulting $8(V_{IN} - 2.5V)$ or $8(V_{IN} - 7.5V)$. For all 1's, the output of the MUX is switched to either +3.75V or +8.75V—for any other code, to 1.25V or 6.25V. Another conversion is performed and, depending on whether the output is still overranged, the MUX will be either switched down or remain steady at one of the 8 levels, in 1.25V increments. A final conversion is performed, and the output will consist of the three bits that drive the MUX as the MSB's and the 12 bits from the AD574 for the lower 12 bits. [For reasons too subtle to discuss here (that do not impact this discussion), an offset is added to the AD574 output during the successive-approximation steps when it is used as a comparator.]

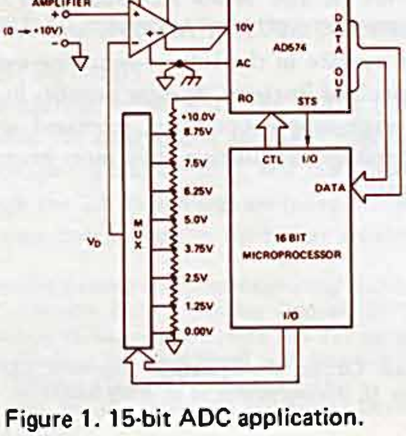


Figure 1. 15-bit ADC application.

Now, it should be noted that the resistors have all been trimmed to be within 2^{-13} of one another. Also, it is reasonable to assume an instrumentation amplifier that can safely and stably resolve 2^{-16} of full scale (153μV). Also, each voltage level from the resistive divider is fixed (but not necessarily accurate).

Please observe that no value of V_D can differ from its neighbor by more than $(V_R/8)(1 \pm 2^{-12})$, because the maximum resistance difference between adjacent resistors is $\pm 10^{-12}$, and the current is constant. Therefore, no voltage level can differ from its neighbor by more than $1.25V(1 \pm 2^{-12})$, i.e., a maximum uncertainty of 2^{-15} of the 10V full scale.

This means that, irrespective of the actual value of V_D at any level, a conversion performed at a mid-range value will not miss any codes as long as the AD574 (as specified) has no missing codes; a conversion performed at the extremity of a range will always be within 1LSB of (of 15 bits) of the value corresponding to the adjacent extremity of the neighboring range.

STATISTICAL ADC TESTING

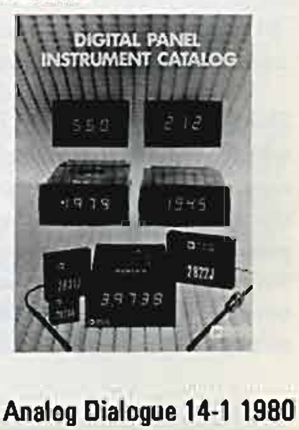
We've had an interesting communication (presumably for publication), from Jesse Lipcon, Consulting Engineer, Laboratory Data Products, at Digital Equipment Corporation, in support of Dr. D. Philip Burton's article (ANALOG DIALOGUE 13-2, page 10) on a statistical technique for measuring the differential linearity of a/d converters. Mr. Lipcon discusses the technique used by DEC to test ADC's, employed in various DEC products, for differential and integral linearity, using 800 X 4094 conversions (excluding end points), a small amount of number crunching, and two graphical presentations. Unfortunately, we have no room to reprint the letter here; but we will be glad to send a copy to anyone requesting one.

▶▶▶

NEW LITERATURE

DIGITAL PANEL INSTRUMENTS

This free, 96-page Catalog contains complete technical data on 14 DPM families, 8 temperature-measurement and signal-conditioning families (including 6-channel scanning meters), and power supplies. The introduction includes comprehensive tutorial information and a selection guide. For your copy, use the reply card.



Potpourri

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 13, No. 2, 1979) . . . *Very-High-Speed Data Acquisition* ("video" converters) . . . *Voltage-to-Current Converters for Process Control* (voltage to 4-to-20mA current loops) . . . *300kHz Conversion System* (using microcircuit track-hold and ADC) . . . *Checking Analog-to-Digital Converter Linearity* (using statistical techniques) . . . *High-Resolution Temperature-Difference Measurement* . . . and these New-Product Briefs: Single-Chip Fast 12-Bit D/A Converter (AD566); Monolithic Instrumentation Amplifier (AD521L); Three New IC Converter Families with Existing Second Sources (AD DAC-08, AD ADC80, AD DAC87); 12-Bit Data-Acquisition Modules (DAS1150, DAS1151); 14-Bit Sample-Hold (SHA1144); Two New CMOS Switches with Existing Second Sources (ADG200 and ADG201); Three New Power Supplies — DC/DC Converters (949, 951, 953); Synchro/Resolver Power Amplifier (SPA1695); S/D Converters with 3-State Latches and Continuous Tracking (SDC1725/1726); Interface Card for STD BUS Microcomputers (RTI-1225) . . . Application Brief: *Statistics Using Analog Techniques* . . . New Literature: 1979 SHORT-FORM GUIDE, COMPUTER LABS CAPABILITIES . . . "Across the Editor's Desk": *Four-Quadrant Analog Divider?* . . . Plus Authors, Potpourri, Editorial discussion of the bright future for "analog." Use the reply card for your *free* copy, or for information on any of the above items.

APPLICATION WISPS . . . If you've replaced the AD536 with the improved wider-bandwidth AD536A rms-to-dc converter and have noticed a larger offset, you may be seeing the rms value of the wideband noise from your preamp. The solution is to try a lower-noise amplifier, such as the fast AD544 TRIFET (page 14) . . . Instead of expensive high-intensity lamps for optical analyzers, perhaps consider lower-cost sources and more-sensitive electrometer-type preamps (such as AD545), preceding the 757 log-ratio module . . . Our HTS-0025 fast track-hold amplifier improves ac linearity in fast conversions, using the TRW TDC1007J ADC encoder, by about 15dB, for 5, 10, and 20MHz sine waves (write to our Computer Labs Division for information) . . . A simple way of logging temperature data from thermocouples is to use our AD2036 scanning temperature meter and a printer. An Application Note, showing the connections to a Gulton ANP-9 thermal printer, is available upon request.

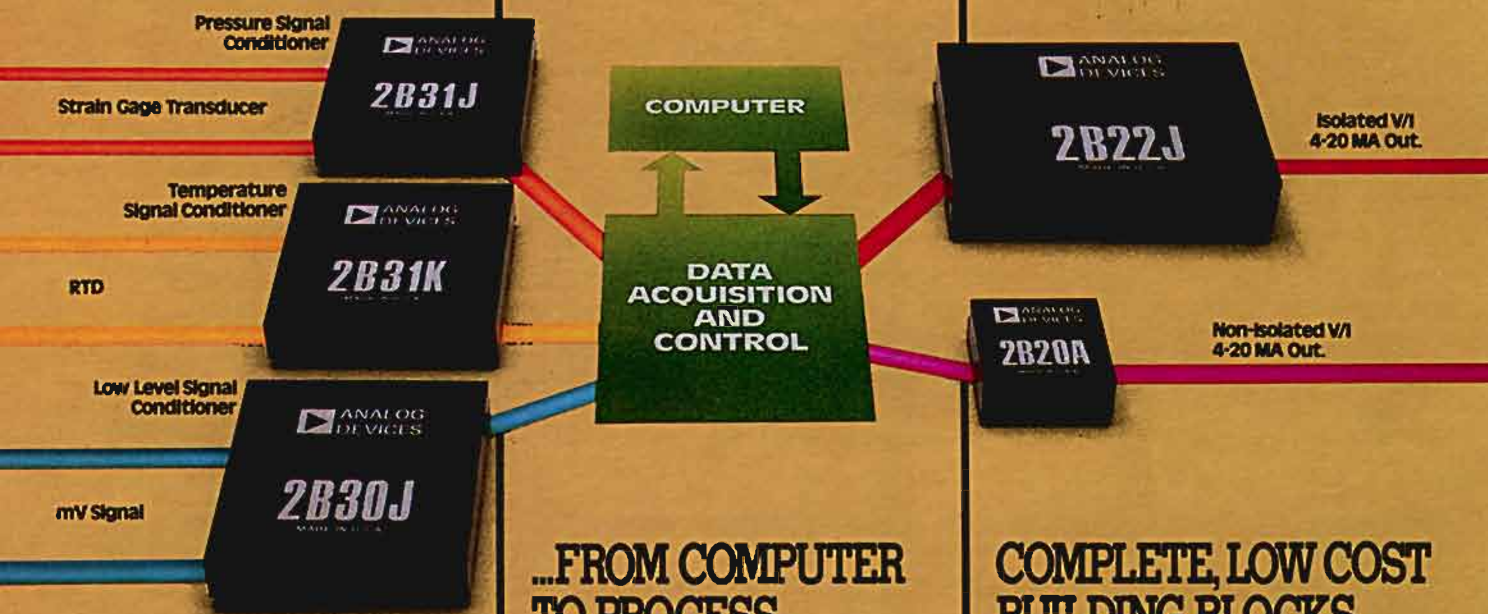
DATA-SHEET NOTES . . . The correct input range for the HAS high-speed hybrid a/d converter is 0 to +10V. (Figure 2, which shows a range of 0 to −10V, is wrong.) . . . There are errors in Table 1 of the DAS1150/51 data sheet: ADC Input-Range Connections. Until it is reprinted, an errata sheet will be furnished with the data sheet. If you already have the data sheet and would like an errata sheet (or a new data sheet, when available), use the reply card . . . On the AD537 data sheet (page 5), it would appear that the AD537 can be compensated for negative-TC capacitors; actually, the circuit shown allows compensation for a negative output-frequency tempco (which can be caused by a positive-TC capacitor) . . . On the 757 log-ratio data sheet, for the diode configuration shown in Figure 8, the device type should be 757P; if the current flows in the reverse direction, calling for reversed diodes, the "N" type is correct . . . Model 286J Isolator does not have a specified operating temperature range on its data sheet; it should be −25°C to +85°C, the same as for Model 284J . . . On the data sheet for the 2B30/31 signal conditioners, please note that the formulae for the parallel resistance values to modify the filter time constants are valid only for frequencies above 5Hz. Also, the values shown are the nearest 1%-tolerance values, not the theoretical values.

PRODUCT NOTES . . . The HDS-1250 high-speed DAC's already excellent settling time has been made all-the-more conservative in a redesign to remove a slight kink in the response. Faster than ever and cleaner! . . . The AC1580 mounting card for the SHA1144 sample-hold amplifier is more than just a mounting card. It's wired for 2 MUX's, a SHA1144, and a 14-bit ADC1130/31, and already has trim pots, power-supply bypass capacitors, and MUX channel-select logic. Plug in the suggested parts, and you have a complete 16-channel 14-bit DAS, for as little as $500 . . . When used with an external clock, the ADC1105K should have a short time-constant to slow down the clock pulse at the clock input; a series 470-Ω resistor and 100pF to ground will do it . . . The low-cost AD2026 DPM is now available for line-powered applications. Features include larger, brighter Monsanto displays (also standard in 5V-powered models), 1000V common-mode voltage, optional 10-V full-scale input range, and depth of only 2¼" behind the panel, with no mounting hardware of any kind required. Price is $54 (100's — U.S.A.) . . . The AD2040 temperature meter, for use with the AD590 absolute-temperature-to-current sensor (1K = 1μA) is also available with line power, 1000V CMV, $89, $64 in 100's.

NEW LITERATURE . . . Use the reply card for your copy of the 8-page Power-Supply Catalog, which lists dual-output supplies, triple-output supplies, logic supplies, chassis-mount types, and dc-to-dc converters . . . Our new, 120-page chip catalog, *Integrated-Circuit Chips for Precision Hybrids*, is now available for the asking.

GSA CONTRACTS . . . The most-recent GSA contracts reported are GS-00S-04972, for amplifiers, and GS-00S-04748, for modular power supplies and synchros. If you are authorized to purchase against GSA contracts, write on letterhead to the Analog Devices Sales Department for your copy of the applicable ADI price lists currently available.

BUILD STRONG SIGNALS 5 WAYS.



FROM TRANSDUCER TO COMPUTER...

Where strain gages, RTDs or low level signals measure pressure, temperature, strain, torque and force, our 2B30 and 2B31 high performance, economy Signal conditioners amplify low level signals, filter noise and excite transducer bridges. $45—100's (2B31J).

The 2B31 directly interfaces to transducers providing adjustable voltage or current excitation, programmable gain, low offset drift, 0.5uV/°C max., high CMR, 140dB @ 60Hz, and a low pass filter with 60dB/decade rolloff to eliminate line noise and aliasing errors. The 2B30 has no excitation capability. $34—100's (2B30J).

...FROM COMPUTER TO PROCESS.

Our new high performance Voltage-to-Current converters produce a standard 4 to 20mA current proportional to the voltage input. The 2B20 provides non-isolated V/I conversion with low span drift, 0.005%/°C max., over the −25°C to 85°C temperature range. It operates from a single +10V to +32V supply and provides 4 to 20mA output from a 0 to +10V input into a grounded load without any additional external components. $25 in 100's (2B20A).

The 2B22 offers 4 to 20mA output with ±1500V dc input to output isolation to eliminate ground loops and to protect against high voltage transients. It meets IEEE Std 472 for transient protection (SWC). $59 in 100's (2B22J).

COMPLETE, LOW COST BUILDING BLOCKS.

In harsh industrial environments, our new signal conditioners feature high noise rejection, filtering, input protection, and excellent temperature stability to assure measurement integrity. Economical, easy to use, they provide a pre-packaged, cost-effective analog signal handling and interface capability for a wide variety of transducers or process signals.

For complete information, call Janusz Kobel at 617/329-4700. Or, write Analog Devices, Inc., P.O. Box 280, Norwood, MA 02062.

ANALOG DEVICES

WAY OUT IN FRONT.

Analog Devices, Inc., Box 280, Norwood, MA 02062; East Coast: (617) 329-4700; Midwest: (312) 894-3300; West Coast: (213) 595-1783; Texas: (214) 231-5094; Belgium: 031/37 48 03; Denmark: (02) 845800; England: 01/94 10 46 6; France: 686-7760; Germany: 089/53 03 19; Japan: 03/26 36 82 6; Netherlands: 076/879 251; Switzerland: 022/319704; and representatives around the world.