analog dialogue

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

MACSYM II

VERSATILE MEASUREMENT AND CONTROL SYSTEM (Page 3)

Complete contents on page 3

Volume 13, No. 1, 1979

ANALOG DEVICES

Editor's Notes

DECENNIAL RETROSPECTIVE

Tempus Fugit! It's hard to believe that ten years have gone by since readers of *Analog Dialogue* were first exposed to more-youthful versions of the adjacent photograph and the first trickle of our purple prose. It's been an exciting decade at Analog Devices, watching technologies grow and advocating them to a growing readership; we wouldn't trade it for anything. At the time of the first issue (*Dialogue* 3-1), Analog Devices was principally a manufacturer of modular op amps, just embarking on a career as a manufacturer of converters-as components. Perhaps the most interesting chain of development (among many interesting chains of development) was the transformation of 12-bit a/d converters from hard-to-build modules through the various stages of downward integration to the two-chip AD574, reported on in the last issue. The 574—and the fact that IC's now comprise more than half our business—seems to answer affirmatively the question once posed: can a successful module maker make it in IC's? Perhaps the question for the next decade is: can a successful subassembly maker make it in systems? Keep your eyes on MACSYM. ▶▶▶

COMPUTER LABS – WELCOME ABOARD

If you've wished that you could read about really high-speed a/d and d/a converters for video and radar applications in these pages, you may be pleased to know that you must have done something right: your wish has come true. Recently, Computer Labs, Inc., of Greensboro, North Carolina, has been merged with Analog Devices. You will be reading about their technology and products in future issues of *Analog Dialogue*.

Computer Labs was created over a decade ago by a group of dedicated people with an outstanding product . . . a truly high-speed analog-to-digital converter. No other a/d on the market could match its speed and quality. The high-speed ADC became the cornerstone of the new company and, over the years, Computer Labs expanded its products to include a wide variety of ADC's, DAC's, analog multiplexers, computer peripherals, and associated data-acquisition equipment.

Computer Labs data converters are now in every major digital radar system in the world, and their customer list reads like a "Who's Who" of the electronics industry.

Typical conversion products include 10-bit, 5MHz a/d converters on cards, 8-bit, 20MHz ADC's and DAC's in modules, and 12-bit, 2.8μs ADC's in hybrid packages, as well as a complete line of hybrid and modular DAC's, track-and-holds, deglitchers, and fast op amps.

For a quick overview of the Computer Labs product line, request a copy of the 16-page Computer Labs *Product Guide* on the reply card (or by writing or phoning Analog Devices). We're delighted at the prospect of sharing Computer-Labs technology with our readers. ▶▶▶

MACSYM II

In this issue of *Analog Dialogue*, we introduce MACSYM II, an intelligent, programmable, stand-alone Measurement-And-Control (sub)SYsteM. MACSYM II represents the highest degree of integration of any product developed for sale to a general electronic measurement and control market by Analog Devices. (Some of the *specialized* textile quality-control systems—manufactured by our Microsensors Division—are totally integrated, from thread-handling to data-handling.) MACSYM deals with real-world analog and digital inputs and outputs, under the control of programs written by users in MACBASIC, a versatile form of BASIC specifically designed by us to make effective programming of MACSYM easy, especially for the computer novice.

Since MACSYM is unique, our treatment of it is unconventional; we have devoted most of this issue to descriptions of its salient features, in a set of articles written by the people who developed MACSYM II. Not every one of our faithful readers is likely to be a potential customer for MACSYM, but we think all will find the concept interesting. We would also like to welcome any new readers of *Analog Dialogue*, who are encountering it for the first time because of their interest in MACSYM II. We hope you will join our mailing list and will gain some insight into our broad spectrum of active electronic components and subsystems, and their applications, as a result of your future reading in *Dialogue*.

Dan Sheingold

IVAR WOLD—CREATOR OF MACSYM

Ivar Wold is Director of Measurement and Control Products at Analog Devices. MACSYM, the most ambitious system product in our 14-year history, was conceived, fostered, and brought to fruition under his leadership and guidance by an enthusiastic, closely knit team of engineers, technicians, programmers, and others, who have contributed of their considerable skills and efforts to make MACSYM II (and its MACBASIC language) a reality.

A native of Norway, Ivar spent a considerable portion of his life in England, where he obtained a B.Sc. in Aeronautics and Astronautics from the University of Southampton, with First-Class Honors. Following graduate work, during which he designed a hot-wire anemometer and time-delay correlator (and obtained the first of many patents), he has developed complex analog and digital measuring instruments and a real-time multi-terminal banking computer. At Analog Devices, he has designed circuits, ranging from IC a/d converters to panel meters, and systems, ranging from SERDEX and MACSYM II; he is currently working on MACSYM-compatible devices, subsystems, and instruments.

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MACSYM II
A Complete Measurement And Control SYsteM
Sophisticated Hardware that is Easy to Use

by Ivar Wold and Fred Pouliot

MACSYM II* is a complete stand-alone system designed for measurement and control applications. It 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 version of the high level BASIC programming language.

Designed for applications involving signal conditioning, data acquisition, storage, computation, manipulation, and display, MACSYM II 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, RTD's, switch closures; typical outputs might include 4-20mA control signals, switch drives, or ASCII data.

MACSYM II 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. MACSYM's architecture and packaging, software and documentation are specifically designed to minimize the time, effort, and experience required for system configuration, hookup, and operation in the user's real-world environment. MACSYM II programming requires neither prior software experience nor separate development systems. The unique time-saving aspects of MACSYM are described in the pages that follow.

While MACSYM II provides all the power and function traditionally associated with minicomputers in its class, it costs much less. A standard MACSYM II, ready for operation, packaged as a single compact desktop unit (rack-mountable), includes the 16-bit processor, an analog and digital I/O subsystem, real-time multitask BASIC, 64K bytes of memory, cartridge tape drive, full ASCII keyboard (upper case), operator control panel and CRT, and full documentation and system support. Its list price is only $8,990.

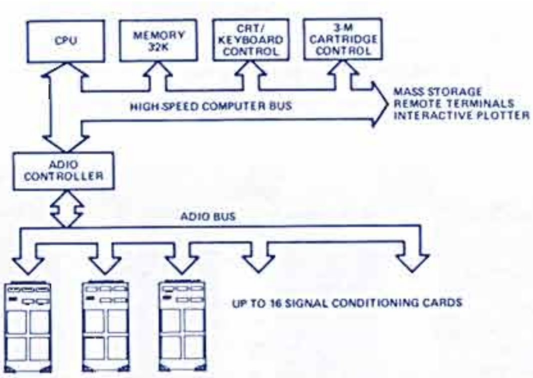

Figure 1. Block diagram of MACSYM, showing the key role of the dual bus system and ADIO Controller.

*Use the reply card for data on MACSYM II.

MACSYM II SYSTEM ORGANIZATION

Figure 1 is a simplified block diagram of MACSYM II, depicting the organization of the major components comprising the system. The *Central-Processing Unit* (CPU), described more fully on page 5, is a 16-bit high-performance unit built from microprogrammable Schottky 4-bit-slice elements and capable of addressing 64K bytes of memory. Special features of the CPU include byte-manipulation instructions and floating-point mathematics.

A key element of MACSYM II is the dual bus system. The processor communicates with memory and computer-type per-

(continued on the next page)

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ipherals via the conventional computer bus structure. However, communication with the *analog and digital I/O cards* (see page 7) is established by way of the *ADIO Controller* (page 6), an intelligent interface which provides a number of shared functions (such as a/d conversion), minimizing cost of the individual cards, and isolating the input/output bus (ADIO bus) from the noisy high-speed processor bus, permitting improved performance to be obtained with low-level analog input signals. The ADIO Controller deals with each card on the basis of its own identity; this makes it possible to utilize any assortment of cards, plugged into any permutation of the 16 sockets (Figure 2).

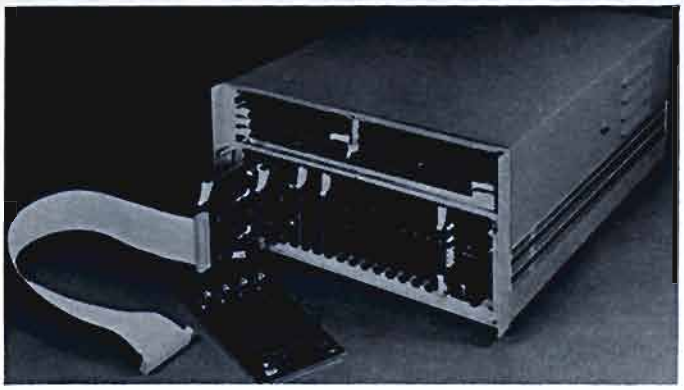

Figure 2. Any signal-conditioning card slides into any one of MACSYM's backplane slots. The cards permit direct sensor hookup to MACSYM II at low cost for a wide variety of I/O functions.

MACSYM II, as noted earlier, is an interactive stand-alone unit. This is made possible by the integral processor-controlled full-ASCII keyboard and the five-inch CRT display. The display format is keyboard-selectable as either 16 lines of 32 characters, or 16 lines of 64 characters.

MACSYM's fully buffered read/write memory is organized as 32K 16-bit words, utilizing mature, 4K dynamic MOS RAM technology for low power dissipation. There is a nickel-cadmium battery for memory backup in the event of a power failure. In addition, an automatic startup protocol provides for orderly initialization after a power failure. Mass storage of both data and program is provided by an integral data-cartridge system, which has 100K byte capacity, uses a microprogrammed controller, and requires no extra hardware. The mass-storage system performs data encoding and decoding, and it controls tape position and movement.

Some of the other salient features of MACSYM include: a real-time clock, serial communication ports, and an IEEE-488 communications interface. In addition, MACSYM has been designed to interface with a number of peripherals, which can be provided by Analog Devices. Among these peripherals are: mass-storage systems (single or dual floppy disk or 9-track magnetic tape), remote terminals, and an interactive graphics plotter.

Capabilities of the signal-conditioning card family include:

- Low-level analog in/analog out
- Direct sensor interfaces: thermocouple, strain gage, RTD, etc.
- Digital input/output
- Isolation
- Special functions

As many as 16 assorted cards may be plugged into MACSYM II's card cage; their number may be extended to 120 cards, via extension chassis. The user's external wiring can be brought to edge connectors and plugged directly into the cards. A useful alternative option is a 50-terminal screw-termination board for making direct connections to sensor wires. For larger systems, a rack-mounted screw-termination panel provides for the mounting of eight screw-termination boards (Figure 3).

MACSYM II SOFTWARE

Like MACSYM's hardware, the software has also been designed specifically for measurement and control *applications* (see page 12). An outgrowth of easy-to-use, problem-oriented BASIC, MACBASIC is a powerful tool with some interesting properties (see page 10):

1. *Integral I/O Statements.* All measurement-and-control inputs and outputs are treated as simple variables within statements; ranging and formatting are performed automatically. For example,

```
X = SQR(AIN(7,5)*1ØØ)
```

means that the voltage at Channel 5 of the Multiplexer Card plugged into Slot 7 is to be multiplied by 100, and the square root of the resulting number is to be computed. If AIN(7,5) is 5.42V, the result in response to the command,

```
      PRINT X
would be
       23.28
```

2. *Multitasking.* Multitasking in BASIC allows the user to handle simultaneous asynchronous events or operations in a simple, orderly manner. Tasks may be activated either unconditionally or on the arrival of a time of day, an external event, or the conclusion of a periodic interval. While in multitasking, the console terminal is "live"; the user can debug or exercise full control over his program in real time. To support multitasking, complete resource-allocation and intertask communication facilities are provided.

3. *Full computational repertoire.* All the computation facilities of BASIC, plus various special computations, data-storage, and data-presentation functions are available.

4. *Interactive graphics.* A full interactive graphics package supporting the interactive Tektronix 4662 Digital Plotter is available; it uses simple BASIC statements.

The BASIC Manual starts with material written specifically for the user with little or no programming experience; it enables him to manipulate real-world application data immediately. Commands and statements are introduced in logical progression; within a few pages, the user will be able to write programs in BASIC. At the end of the introductory session, the user's firm grasp of BASIC programming will have fully prepared him to comprehend and deal with the transition to MACBASIC.

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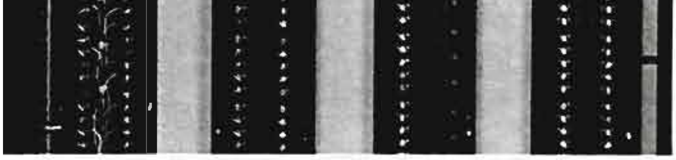

Figure 3. Screw-termination boards make connection of external I/O devices easy. MACSYM is available for table or rack mounting.

Fast, Efficient 16-Bit Central-Processing Unit

by Charles Ehlin

The MACSYM II Central Processing Unit (CPU) is a 16-bit general-purpose digital minicomputer employing Schottky TTL, integrated injection logic (I^2L), internal microprogramming, and bit-slice technology. The result is a compact, powerful, and versatile computer characterized by fast operation and low power consumption. What this means to the MACSYM user is fast execution of BASIC commands, efficient multitasking, and a wide range of mathematical and logical operations in real time, including floating-point computation and byte-manipulation instructions.

From the standpoint of the user, a processor must provide three basic facilities: first, an ALU (arithmetic and logic unit) to perform the required arithmetic and logical manipulations; second, a memory, for storage of program and data; and third, an input/output (I/O) port where various I/O devices can be connected to permit a data flow in and out of the processor.

The 16-bit ALU function is performed on MACSYM's processor board by four 4-bit ALU "slices," joined in such a way that arithmetic and logical functions are performed in a single 16-bit parallel operation. Each ALU "slice" also contains eight 4-bit registers, which are joined to form eight 16-bit registers. Four of these registers are available to the user, via the CPU's instruction set; these registers are used as the sources and destinations of data being manipulated, either as a result of an arithmetic/logical instruction to the CPU (add, subtract, etc.), or a memory-reference instruction (load/store the contents of an accumulator from/into memory). One of the remaining registers is the user's program counter, and the other three are used as scratchpad memory.

A maximum of 32K 16-bit words of read-write memory are available for the user to store programs and data. The memory is synchronously controlled by a memory-control circuit, which allows the connection of any combination of dynamic or static RAM (random-access memory) or ROM (read-only memory).

Sixty asynchronous I/O devices can be connected to the processor through the I/O control circuit. The I/O interface provides for data transfers between the processor and as many as three 16-bit registers in each I/O device. The I/O Control circuit also controls interrupts and direct memory access (DMA). In addition to the availability of I/O ports, input/output exchange with the signal-conditioning cards is memory-managed via the ADIO controller; i.e., the input or output of data via the ADIO controller is equivalent to reading from or writing to memory.

The control of these three facilities (ALU, Memory, and I/O) is accomplished by a specialized microprocessor consisting of a Microprogram Flow Sequencer, Microprogram ROM's, and a CPU Instruction Register (Figure 1). The operation to be performed by either the microsequencer, the ALU, memory control, or I/O control is directly controlled by the contents

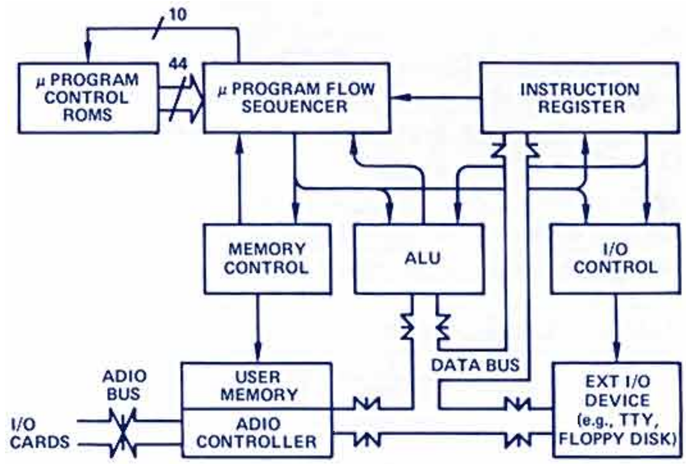

Figure 1. Block diagram of the MACSYM II central processor.

of a 44-bit output word from the microprogram ROM addressed by the microsequencer.

Some insight into the power of the processor may be gained by considering a typical sequence of events. The instruction cycle starts with a *fetch* microcycle. Under microcode control, the ALU register dedicated as the user's program counter is outputted onto the data bus, and the memory-control block is commanded to issue a *load-memory-address* pulse. This signal is used to latch the user memory-address to be accessed for the fetch for the duration of the memory access time (about 500ns). At the end of this interval, a signal is generated instructing memory to place the addressed data on the data bus.

On the next micro-instruction cycle, this data is loaded into the instruction register, and the micro-sequencer will jump to a routine which will execute the function specified by the contents of the instruction register. At this point, the microcode can manipulate data in any of the ALU registers or contents of memory, through the ALU, storing the result in the requested destination.

It is important to note that the total operation is controlled by the various parallel bytes of the *44-bit word* from the micro-instruction ROM's. A number of CPU instructions can be created, resulting in an operating system having the high execution speed that is important in a measurement and control system.

For example, a *load* or *store* byte routine written using a standard machine instruction-set has an execution time of about 40μs. When executed in microcode, these same instructions take only from 2 to 2.5μs. Speed enhancement is even more dramatic when floating-point instructions are considered. A software floating-point package can execute a floating-point multiplication in 2 to 3ms; the microcoded version of the same operation requires approximately 100 to 150μs.

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ADIO Controller & Bus Minimize Interference, Power, and Cost

by Bill Gonsalves

The MACSYM ADIO Controller provides an interface between the high-speed digital processor and the *A*nalog/*D*igital *I*nput/*O*utput bus. The ADIO Controller is implemented as a memory-mapped device that appears to the CPU as a block of memory; this permits a very flexible means of software access to the Controller.

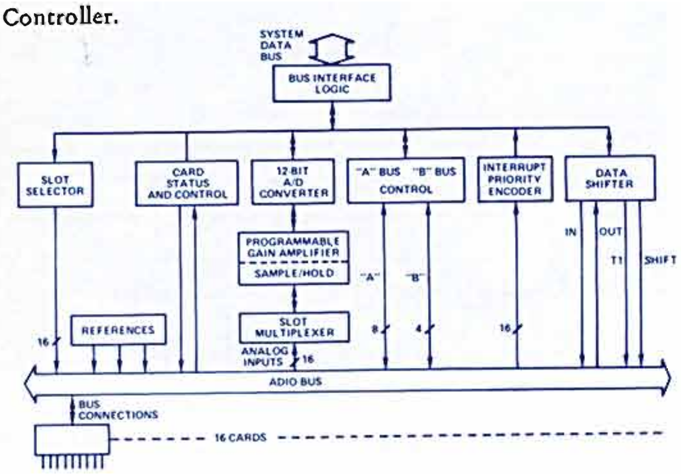

Figure 1. ADIO controller and bus.

The ADIO bus provides for the transfer of analog and digital data between the signal-conditioning cards and the ADIO Controller. Together, the ADIO Controller, Bus, and Cards allow MACSYM's software and the user's application program to interact with real-world signals.

The principal design criteria for the ADIO Controller and Bus were:

- Provide a simple, cost-effective measurement-and-control subsystem to be fully integrated with a digital processor.
- The subsystem must be capable of high-quality analog performance.
- Allow a wide variety of signal-conditioning functions to share common elements, where possible.
- Establish an environment in which individual signal-conditioning cards are not burdened with processor-dependent interface logic.
- Allow for the use of CMOS logic on the function cards to reduce power consumption, heat, and noise.
- Keep it simple and easy-to-apply so that a user need only be a specialist in his own field, not with computer systems.

The general-purpose ADIO Bus and its associated Controller form an effective solution to the above design criteria. The ADIO Controller contains all of the complex digital logic required to allow operation with the minicomputer bus and unburden the ADIO Cards of much otherwise redundant logic. Whenever possible, functions common to many ADIO cards reside in the ADIO Controller, allowing the cards to concentrate on their specialized signal-conditioning tasks. A cost-effective system for high-performance signal conditioning results.

The ADIO Controller performs six primary functions in servicing the needs of the ADIO Cards inserted into the backplane:

1. A means for placing a single ADIO card in communication with the Controller is provided. A dedicated *enable* line to each ADIO Card slot in the backplane eliminates the need for address decoding on the individual cards. When selected, an ADIO Card will make its status known to the Controller and stand ready to act on commands it may receive.

2. A set of two parallel bidirectional control buses pass parameters, such as local channel number and gain settings, to or from the selected ADIO Card. An 8-bit-wide "A" bus normally specifies the number of the card's input or output channel with which communication is to be established. A 4-bit "B" bus is used to specify the gain which a front-end amplifier will provide, if present on the card. The nature of the card determines the direction of information flow on the buses.

3. For cards having digital information to convey, a bit-serial communication register provides for data transfers between the selected ADIO Card and the Controller. The "A" bus provides channel-number information for the source or destination of the digital data being transferred, if there is more than one channel on the card. This technique eliminates much of the noise inherent in fast, power-hungry parallel transfers, making the environment quieter for nearby analog measurements.

4. A central fast, high-precision 12-bit a/d converter system is shared by all the I/O cards. Each ADIO Card presents the analog data from its selected channel on a dedicated line to the input multiplexer of the ADIO Controller, which selects the signal from the desired card for conversion. A programmable-gain amplifier (1, 2, 4, 8V/V) with sample-hold capability conditions the signal prior to conversion. Using this approach, cost-per-channel for a high-quality a/d conversion system can be quite low, since the cost may be shared among many channels.

5. A dedicated interrupt-request line from each ADIO Card slot allows any card to request service, irrespective of which card is then enabled. The ADIO Controller arbitrates the occurrence of these interrupts with a 16-level priority encoder, which vectors service to the appropriate card.

6. High-precision analog references are generated on the ADIO Controller board for use by the function cards. In addition, a 100kHz frequency reference is provided for synchronization of analog isolators, eliminating the possibility of error-producing beat frequencies.

CMOS logic is used wherever possible on the ADIO Cards to reduce power-supply requirements, heat generation, and system noise. Reduced power-supply and distribution requirements allow cost savings in supply and backplane design, while favorably affecting cooling requirements and overall system reliability.

The ADIO Bus and Controller form the heart of a general-purpose, high-performance measurement-and-control subsystem. Examples showing how the ADIO Cards interface with the Controller via the ADIO Bus will be found in the next few pages.

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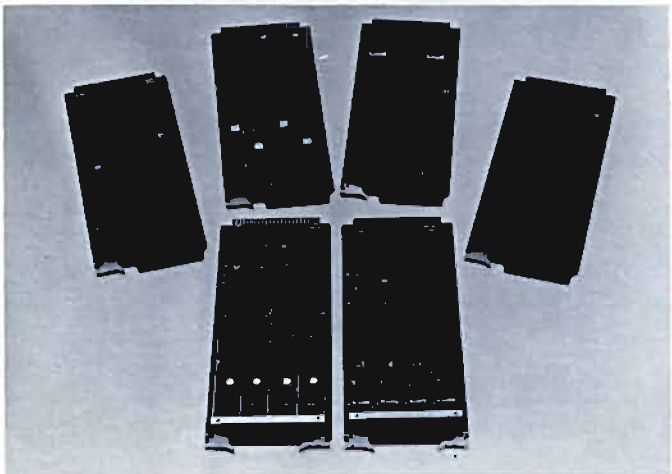
Card Library Provides Flexible Input/Output Capability

by Tom Kelly and Dave Pye



A growing signal-conditioning- and utility-card family is a major key to MACSYM II's usefulness and versatility. The cards connect to the ADIO Bus at one end and to the outside world at the other. Sixteen cards, in any variety, can be accommodated in MACSYM's card cage, and there is provision for an extension to 120 cards. The Chart (next page) shows a representative selection of cards currently available and their typical applications in the MACSYM environment. As new cards having possibilities of wide application become available, they will be included in the catalog and mentioned in these pages.

As we have noted earlier, the cards are specifically designed to interface with MACSYM's ADIO Controller and Bus. Elimination of much redundancy makes them economical; minimization of interfacing reduces interference; and compatible design maximizes the ability of MACSYM to meet the needs of user requirements in measurement and control.

Functions available on the cards include all of the basic functions found in many measurement and control systems: contact sensing and closure; voltage and current data acquisition; and voltage and current generation (digital input and output, analog input and output). In addition, there are a number of more-specialized but equally vital functions, including thermocouple measurement (with and without galvanic isolation), strain-gage inputs, frequency-counter inputs, event pacers, and interrupt generators for setting event priorities.

DIGITAL I/O CARDS

Digital input and output of the system is provided for by two separate cards. The 16-channel (16-individual-bit) isolated digital input card (DIN) is available in either a dc or an ac option, depending on the user's application (the dc option preserves the input levels, the ac option preserves the level shift). The 16-channel isolated Digital Output card (DOT) supplies the user with a choice of either low-power (TTL) or high power (relay) output capability on the same card. Each channel is isolated and independent from the others on both the DIN and DOT cards.

The dc version of the DIN card accepts a wide range of "on" voltages—everything from a standard TTL gate to a high-voltage (24V) amplifier output; "off" voltages can go below ground. The ac option can safely accept "on" voltages up to 24V rms. Because of the isolation, common-mode signals as great as 500V do not substantially affect the card's performance. Figure 1 shows the basic configuration of the 16-channel digital-input card. The inputs, translated through the optical isolators, arrive at the inputs of a 16-bit parallel-load shift register. When that card is selected by the ADIO Controller, T1 (*load*) pulse causes the parallel data to be loaded into the shift register, and *shift* pulses effect the bit-by-bit transfer to the Controller.

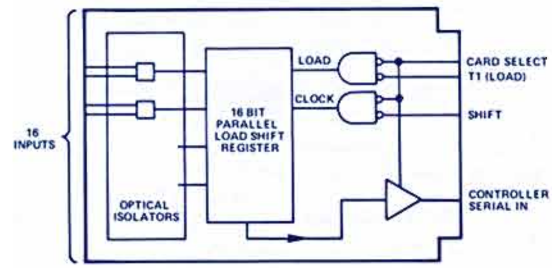


Figure 1. Basic configuration of 16-channel digital input card.

The DOT card is easily interfaced to TTL gates or relays with a remote user-supplied voltage of up to 30V dc or 21V rms. Since each channel is isolated and independent, some channels may be interfaced to 5V logic, while others are interfaced to ac-powered relays. On-card buffering permits each channel of the output to be switched individually, using standard MACBASIC statements, while leaving the other channels undisturbed.

MULTIPLEXED ANALOG INPUT CARD

The AIM family are multiplexed analog-input cards with 32 analog input lines. They are capable of 16-channel differential or 32-channel single-ended (or "pseudo-differential") voltage or current measurements (Figure 2). The front end comprises a set of CMOS multiplexers with overvoltage protection to ±35V dc. Both channel switching and mode switching are under software control; thus the software adapts performance to correspond to the physical external wiring configuration. The multiplexer is followed by a high-performance programmable-gain amplifier (PGA), with gains of 1, 16, and 256. This choice of gains, coupled with the ADIO Controller's gain range

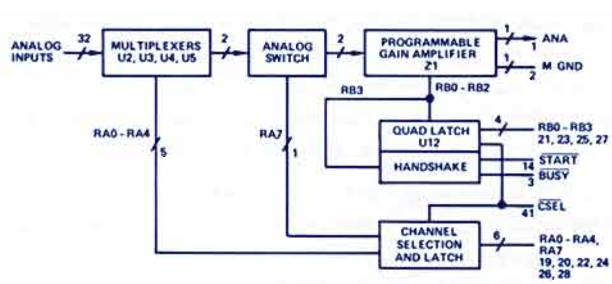


Figure 2. Block diagram of multiplexed analog input card.

(1, 2, 4, 8) allows the user to select a wide variety of gains *for each channel* under software control. If no gain is specified, the software will go through an autoranging routine to provide the highest possible conversion accuracy. The channel is selected by the signal on the "A" lines of the ADIO Bus, and gain is programmed by the "B" lines.

The software statement corresponding to the selection and configuring of an analog input when this card is used is:

Y = AIN(S,C,I,X)

where S is the card slot number; C is the channel number on the card; X is the gain mode (Gain = 2^X; -1 or no character = autoranged); and I is the input mode (1 = differential, 0 or no character = single-ended with reference to a common "ground" line). Thus, for

Y = AIN(5,3)

this statement will make the number at symbolic memory location, Y, equal to the numerical value of the single-ended voltage on channel 3 of the card in slot 5 and will autorange the binary gain-multiplier to use as much as possible of the input range of the ADIO Controller's a/d converter for maximum resolution. Furthermore, as noted elsewhere, AIN(5, 3) may be treated as a number and operated on as a variable in such powerful single-line statements as:

AOT(6, 2) = G* (S – AIN(5,3)) + C

which means: the analog output of channel 2, card 6 will be set equal to a constant "C" plus the product of a number "G" and the difference between a number "S" and the analog input of channel 3, card 5.

ANALOG OUTPUT CARDS

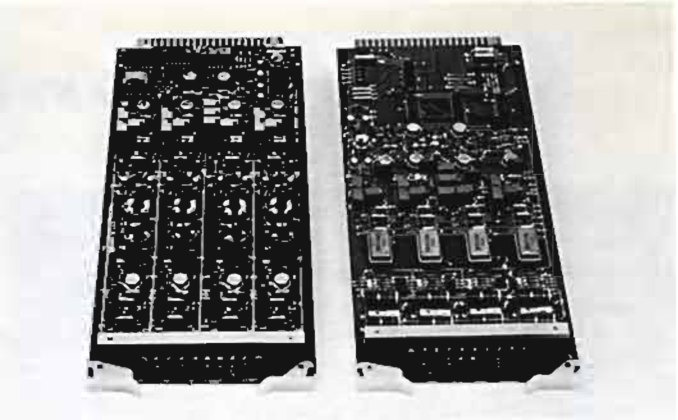
Three basic 4-channel analog output cards are currently available, differing only in the analog output format. The choice is among single-ended 0 to 10V, bipolar ±10V, and 4-to-20mA current loops, all with 10 bits of resolution. The channels all function independently, and the analog outputs are protected against shorts to ground or the supplies, or to accidental overvoltage (40V).

The analog output cards provide currents or voltages that may be used to control external devices, or provide analog indications of process variables. The example given above shows how easily analog outputs can be specified in software. In that case, AOT(6, 2), the analog output of channel 2, card 6, was made a function of an analog input and several numbers, in a single-line instruction.

THERMOCOUPLE CARDS

The isolated and non-isolated thermocouple cards accept four independent thermocouple voltages, provide cold-junction compensation, filtering, and signal-amplification, and furnish a multiplexed output to the ADIO Bus. The channels share a cold-junction compensation circuit and are factory-calibrated for type J, K, T, E, R, or S thermocouples, with factory-set gain of 128, 256, 512, or 1024V/V, corresponding to input spans of ±80mV, ±40mV, ±20mV, and ±10mV, respectively. The output of the card may be offset by ±25% of the span.

The card is preset at the factory for either upscale (standard) or downscale thermocouple-break protection; the isolated cards can operate with common-mode signals up to 1kV ac. It is easy to use the cards. A card is hooked up by inserting it into any available card slot and attaching the thermocouple



wires directly to the barrier-terminal-strip on the rear edge of the card. Addressing the cards is equally simple, using the standard analog-input MACBASIC I/O statement:

Y = AIN(8, 2)

for example, which accepts the analog input from channel 2 of the thermocouple card in slot 8 of the ADIO card cage. When this statement is executed, gain information hard-wired on the card is passed on to the software, and the output of the card is scaled accordingly. Where linearization is required for maximum accuracy, the MACBASIC "POLY" function, which calculates the value of a polynomial, may be used to linearize the output of a specific thermocouple type.

PROCESS INTERRUPT CARD

The Process Interrupt Card provides a means by which the user, or processes that he specifies, can generate interrupts and request service on a priority basis. The card has eight channels, which may be optionally isolated. Each input can be programmed to trigger an interrupt on a low-to-high transition, a high-to-low transition, a change in input state; or it can be ignored. When mechanical contacts are used, the input can be programmed to be ignored (disabled) after interrupt for approximately 10ms, to inhibit switch-bounce from causing further interrupts.

The card will stack and hold up to eight interrupts for as long as power is applied to MACSYM, and the interrupts are serviced on a user-determined priority basis. The user process requesting an interrupt is identified via a software routine.

PACER-CLOCK CARD

The Pacer-Clock card allows the user to make a programmable number of measurements at more-accurately determined time intervals (and delay times) than could be achieved through software. The time interval is programmable from 20μs to 0.65536s, in 10μs steps, and from 0.65536s to 42949.672s, with a resolution of 2^{-16} seconds. A single measurement can be delayed from a trigger signal by an interval from 0 to 0.65536s, in 10μs increments.

The trigger signal to initiate measurement may be internal or provided by the user. The pacer output may also be driven by the user's own clock, again with the capability of being either internally or externally triggered.

A key use of this card is to initiate conversions by the a/d converter at accurately timed sampling intervals. The pacer output is also bused to all the other ADIO card slots, and an output is provided on the card for precise timing of user "real-world" pheonomena. ▶▶▶

TYPICAL MACSYM II SIGNAL CONDITIONING CARDS

SIGNAL FUNCTIONS	CARD IDENTIFICATION	FEATURES	TYPICAL APPLICATIONS
DIGITAL Input/Output	DINØ1, DINØ2 16-Channel opto-isolated AC or DC Input	5 to 24 volt AC/DC input range	(Input digital data.) Event sensing (switch closure, etc.) Alarm sensing
	DOTØ1 16-Channel opto-isolated Open-collector output	TTL compatible High current output	(Output digital data.) Control relays and solenoids Set off alarms
ANALOG Input/Output	AIMØ3 Software selectable 32 single ended 32 pseudo differential 16-channel differential	Programmable gain	Input from: Position sensors, level sensors Temperature monitoring pH/ORP monitors, Conductivity Liquid analysis Temperature transmitters Pressure transmitters Flow and level transmitters Gas analysis
	AOCØ4 4-Channel unipolar Digital to analog converter	Output voltage 0 to 9.990V dc 10-bit resolution	Control stepping motors, motor speed controls, Control flow switches, Control pressure difference switches Remote and indication recording.
	AOCØ5 4-Channel Bipolar digital to analog converter	Output Voltage –10 to +9.980, 10-bit resolution	Same as AOCØ4
	AOCØ6 4-Channel unipolar digital to analog converter.	Output 4-20mA, current loop, 10-bit resolution	(Process control actuators.) Valve drive mechanisms, Power packages (SCR's and saturable core reactors) Converters for pneumatic valve operation
THERMOCOUPLE Cards	TICØ3 4-Channel Isolated	Factory preset gain 128, 256, 512, 1024 Factory calibrated for E, J, R, S, K, or T thermocouples	Temperature sensing
	TICØ4 4-Channel Nonisolated	Same as above	
MISCELLANEOUS Cards	INTØ1 8-Channel Isolated Process Interrupt	Isolation Selectable switch contact debounce	Event sensing
	INTØ2 8-Channel Nonisolated Process Interrupt	Selectable switch contact debounce	
	CLKØ1 8-Channel Pacer Clock	Programmable from 20μs to 0.65536s in 10μs steps, and from 0.65536 upwards in integral multiples determined by a 16-bit binary word, i.e., to a maximum of 42,949.0176s	High speed clock Automatic PID conversion

MACBASIC - Measurement-And-Control-Oriented Software

by John Vella and Arthur Miller

A Measurement and Control System can have an efficient processor, a set of highly useful cards, and an interface designed for the optimum in internal communication and control, yet it can fail to be useful if the software requires a great deal of programming expertise or so many steps that the programming chore causes the user to lose sight of the problem he originally set out to solve using the apparatus.

MACBASIC (Measurement And Control BASIC) is a high-level, interactive programming language based on standard Dartmouth BASIC, optimized for measurement and control applications. It retains the structure and all of the capabilities of Dartmouth BASIC, enhanced by a number of facilities that allow the user to perform measurement and control functions effectively.

PROCESS INPUT/OUTPUT

The first of these facilities is Process Input/Output, which allows real-world signals to be treated as ordinary variables in a program. The variables used to store the results of calculations in BASIC are represented by a letter, optionally followed by an identifying digit. For example, in the statements,

```
LET X = 5*2
PRINT X
```

5 is multiplied by 2, and the result, 10, is assigned the variable, X. In the second statement, the variable X is to be displayed by printing it. The numeric value of X may of course change during the execution of a program. In MACBASIC, certain variable names designate particular measurement-and-control functions, i.e., inputs and outputs, to make the task of addressing these functions easier for the user. The variable name consists of an alphabetic prefix and a numerical location code, set off by parentheses:

VARIABLE NAME	FUNCTION
AIN(S, C)	Analog Input at Slot S, Channel C
AOT(S, C)	Analog Output to Slot S, Channel C
DIN(S, C)	Digital Input at Slot S, Channel C
DOT(S, C)	Digital Output to Slot S, Channel C

To illustrate, for analog inputs, AIN(2, 0) and AIN(2, 1), the statement

```
V = (AIN(2, Ø) + AIN(2, 1))/2
```

means that the numerical value of the voltage at Slot 2, Channel 0 is added to the numerical value of the voltage at Slot 2, Channel 1, and the sum is divided by two, i.e., they are averaged. Thus, if the voltages applied at Channel 0 and Channel 1 of the Analog Input card in Slot 2 are 4.32V and 8.352V, the statement would be equivalent to

```
V = 6.336
```

The analog output variable, AOT(S, C), is used similarly. The statement,

```
AOT(3, 3)=3.42*1.3
```

causes the output voltage of the card at Channel 3 of the Analog Output card in Slot 3 to be numerically equal to 3.42 X 1.3 = 4.45 volts.

For digital input variables, DIN(S, C), a statement like

```
I' = DIN(4, 1)
```

means that variable I' is equal to the logic level at Channel 1 of the Digital Input card in Slot 4; i.e., I' = 1 when that input is 1.

Similarly, for digital output, a statement like

```
DOT(8, 3) = X
```

means that the logic level at Channel 3 of the Digital Output card in slot 8 is "0" if X is "0", "1" if X is "1".

TIMING

The second facility includes a group of features that allow a user-program access to and use of the system clock for timing and time-keeping functions. Normally, BASIC programs are asynchronous, i.e., time is not a variable. However, in MACBASIC, a statement such as

```
WAIT 5.6
```

causes the program to "wait" for 5.6 seconds before proceeding to the next statement of that portion of the program. Statements like PTIME, STIME H,M,S, SDATE M,D,Y, GTIME H,M,S, GDATE M,D,Y allow the user to print the time or date, set the time or date, or get the time or date (hours, minutes, seconds or month, day, year), under program control.

MULTITASKING

Measurement and control programs are written to make measurements and, as a result of those measurements, exercise control over a process that results in changes in the variables being measured. Most BASIC programs are written to perform a specific set of operations. When a different or unrelated set of operations is required, a separate program is written. The different programs are executed separately, one at a time.

Multitasking, one of the most useful and powerful facilities of MACBASIC, is the ability to execute a number of independent, related or unrelated tasks in one program, with execution of all tasks occurring in a seemingly simultaneous fashion. Tasks can operate independently of one another, and they can be started or stopped independently, from the keyboard, through software, upon the occurrence of an external event, or periodically. In multitasking, each task can be executed one-line-at-a-time, in "round robin" fashion. Thus, it appears that all tasks are operating simultaneously, in relation to perceived user time.

Based on reasonable memory allocation per task, a typical number of tasks that may be defined to operate concurrently is 18. If more than one task is active at a given moment, the active tasks share resources and appear to run simultaneously unless a higher priority is assigned to one of the tasks. A task can be in a suspended or dormant state for a specified period of time, or until a specific event occurs.

These features of multitasking might be better understood if we consider a specific application, in which three tasks are defined.

Task 1: Channels 0 through 9 of an analog input card in slot 0 are to be examined every 5 seconds.
Task 2: If any input is greater than 5.5V, an alarm, connected to Channel 5 of the Digital Output card, in Slot 1, is turned on.
Task 3: The alarm remains on until an operator activates a switch connected to Process Interrupt card, Channel 2, Slot 2 (this is defined as an *event*). When the switch is activated, the alarm turns off, and the current value of each channel is printed out.

The three different tasks can be simply and logically implemented in the following MACBASIC program:

```
 10  TASK 1, 100
 20  TASK 2, 200
 30  TASK 3, 300
 40  ACTIVATE 1, PERIOD 5
 50  ACTIVATE 3 ON EVENT (2, 2, 1)
 60  STOP
100  K=5.5
110  FOR I=Ø TO 9
120     IF AIN(0, I) > K ACTIVATE 2
130  NEXT I
140  DISMISS
150  GOTO 110
200  DOT(1, 5)=1
210  DISMISS
220  GOTO 200
300  DOT(1, 5)=Ø
310  FOR J=Ø TO 9
320     PRINT "CHANNEL"; J "="; AIN(Ø,J)
330  NEXT J
340  DISMISS
350  GOTO 300
```

Lines 10, 20, and 30 allocate the space for each of the three tasks and indicate the line number at which each is to begin—lines 100, 200, and 300. Task 1 is activated at line 40; it is re-activated every 5 seconds. Task 3 is activated (line 50) when Channel 2 of the Process Interrupt card in Slot 2 goes to 1.

All programs contain what is known as a primary task. In the above program, the primary task consists of lines 10 through 60, in which the original tasks defined at the outset were set up and activated. Once the primary task is completed, in this case at line 50, control is returned to the keyboard (line 60: STOP) and the user can interact with the program variables and/or list programs.

Task 1 begins execution at line 100 and sets the quantity K to 5.5. Lines 110 through 130 form a FOR and NEXT loop, causing line 120 to be executed 10 times, once for each channel. Line 120 reads each channel voltage (Ø through 9) of the Analog card in Slot 1 and causes Task 2 to be activated if any of the voltages measured exceeds 5.5V. The Channel number, I, is incremented for each pass through the loop.

When Task 2 is activated (line 200), Channel 5 of the Digital Output card in Slot 1 becomes a "1", which starts an alarm, and the task is halted at line 210. When the Operator activates the switch connected to Channel 2 of the Process Interrupt card in Slot 2, Task 3 is activated. The first statement executed (line 300) turns the alarm *off*.

Lines 310, 320, 330 comprise another FOR and NEXT loop. Statement 320 reads the input voltage of every channel (Ø through 9) of the Digital Input card in Slot Ø and prints the voltage. When the loop is completed, the task stops.

Meanwhile, Task 1 has completed the loop and stops at line 140 until the next period (5 seconds) occurs. When 5 seconds have been counted, task 1 is reactivated, and line 150 is executed.

There are other MACBASIC facilities, including extensive plotting and string-manipulation statements particularly suitable for measurement-and-control applications. Calculator-mode operation and high-speed execution are also built into the language (via the microprogrammed high-speed processor). The TABLE lists the MACSYM system software. MACBASIC is an advanced high-level language that brings a powerful tool to the laboratory and the process industry.[1]

MACSYM SOFTWARE SUPPORT
(Diskettes and/or Cartridges)

LANGUAGES	DESCRIPTION
MACBASIC	Interactive language that is a real world version of Dartmouth BASIC specifically designed for measurement and control. High level language that allows program development through the use of simple English phrases.
XBASIC (option)	A version of MACBASIC that is used for X-Y plotting option.
OPERATING SYSTEM	
XMAC (Executive Operating System)	A pure procedure and re-entrant software package written in unlocated code. Executes anywhere in addressable memory. Performs scheduling of user and interrupt tasks. Processes device independent I/O requests, non-I/O primitive system requests.
UTILITY PROGRAMS	
Assembler	Operates on symbolic input data to produce machine instructions by translating symbolic operation codes into computer operating instructions.
Command Line Interpreter	A user interface to XMAC that provides extensive file maintenance capabilities, control over system utilities, and a simple way to invoke complex sequences of program executions.
Text Editor	A utility program used to perform general purpose editing of an ASCII file.
DISKGEN	Operates under XMAC to generate a system diskette or to verify the integrity of an old diskette.
COPY	Used to transfer entire contents of one diskette to another, or to transfer single file from one diskette to another.

[1] See also "Writing P-I-D Control Loops Easily in BASIC", by James Fishbeck, *Control Engineering* 25-10, October, 1978, pp. 45-47. Reprints available upon request.

The Proof of MACSYM's Power Is In The Applications

by Alan Finger

In the preceding pages, you have been exposed to general information about the MACSYM concept and specific details of the various elements of hardware and software. The only really effective way to get a true appreciation of MACSYM's power and ease-of-use is to sit down at the keyboard, write a program, and see it executed, performing real-world measurement and control operations.* To give you a feeling for what MACSYM II—and its predecessor, MACSYM I—are being used for, we have provided a few illustrative examples that are true case histories.

First, however, it may be worthwhile to review some of the key features of the MACSYM II system:

Self-contained system The user is not faced with the necessity of choosing and tying components together to make a system (except, of course, for the external transducers and the user's own system elements). MACSYM arrives ready for use.

Integral signal conditioning The instrument and sensor signals can be brought to MACSYM II without special external conditioners and transmitters, in most cases.

16-Bit processor The user has at his fingertips computing power and speed unobtainable with 8-bit microcomputer systems.

High-level software Using MACBASIC, a computer novice can develop his own software solutions without having to call on outside programmers.

Problem-solving software MACBASIC allows the user to program mathematical, logic, and display functions and algorithms in infinite variety to reduce and present his data in the most efficient manner.

Real-time multitasking The software allows the implementation of complex real-time measurement-and-control functional sequences—involving the simultaneous execution of several programs— that might otherwise have required several independent systems.

The benefits provided by these features can be sumarized in the words: *power, flexibility*, and *ease of use*, as the applications will show. MACSYM is a solution to the problem of lack of flexibility posed by typical moderate-cost measurement and control systems used by the process engineer or research scientist. To perform some nonstandard function, he is faced with the prospect of either building special processing hardware himself or assembling a "kluge" of standard components to achieve the desired result. Small programmable controllers utilizing microprocessor technology are equally inflexible. A computer would probably be an effective solution, but most users don't want to have to become computer, circuit, or system experts—an interesting but time-squandering detour—on the way to getting their system problems solved. As a result, though effective, computer systems may not be *cost-effective.*

Now, MACSYM II provides the flexibility of a general-purpose computer at reasonable cost; and the integral signal-conditioning hardware and software and the easy-to-use MACBASIC language enable any user to write his own programs without having to resort to specialized computer personnel or extensive study and debugging.

*If you would like to have a demonstration of MACSYM II, use the reply card.

BATTERY LIFE-TESTING

Scientists performing long-term life tests on storage cells at the research laboratories of a major battery manufacturer needed an easy-to-use, "intelligent" system to perform data-acquisition and control functions. MACSYM I was on-line and instrumenting the tests in continuous operation within a few weeks after its purchase.

Three important functions must be satisfied in the life testing of storage cells. First, the cells must be charged and discharged in alternating cycles. Second, as soon as each cell has reached full charge or discharge, it must be disconnected to prevent damage while the others are still begin charged or discharged. Third, data on terminal voltage vs. time for each cell must be acquired, and the data must be stored and processed for presentation in tabular and graphic form.

The basic test-system configuration is shown in Figure 1. MACSYM provides constant current in either direction by switching load resistors and controlling the magnitude and polarity of voltage from a programmable power supply. The voltage developed across a precision current shunt provides feedback information for setting the current accurately.

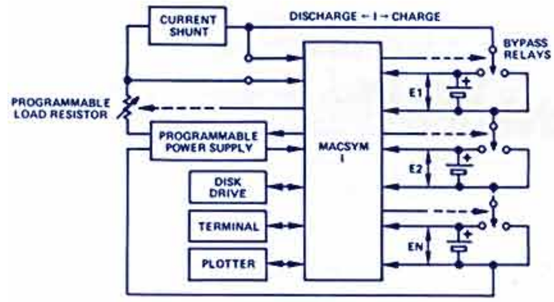


Figure 1. Battery test system block diagram.

During the charge cycle, MACSYM periodically checks the voltage across each cell; when the voltage reaches a preset level, the cell is disconnected from the circuit to prevent overcharging. By the same process, fully discharged cells are disconnected from the circuit during the discharge cycle. During each cycle, all the cell voltages are periodically sampled and the readings are stored on a floppy disk.

Since the system was designed for continuous operation, the software had to be capable of completing all control functions while performing the necessary data-reduction and presentation functions on command. The multitasking feature of MACBASIC provided this ability by allowing the entire program to be written as a series of simple independent tasks for each of the functions described above. MACBASIC also provides a full set of graphic commands, enabling the researchers to obtain fully annotated plots of such information as charge-discharge curves and capacity vs. charge-cycle plots for each cell.

The test system has been in continuous operation for more than six months; the test time required for each cell has been more than halved, a significant improvement that can free the staff for about 3 days out of every full week of involvement in testing (or more than doubles the test capacity).

TEMPERATURE-CONTROLLED REACTION TANKS

In the typical process-control application illustrated in Figure 2, four water-jacketed reaction tanks are independently temperature-controlled. A thermocouple measures the temperature in each tank, which is heated or cooled by introducing hot or chilled water into the jacket via a pair of solenoid valves. During the operation of any given tank, its temperature set-point is established by a predetermined profile in real time. If the thermocouple temperature falls outside of a predetermined deadband around the setpoint, one of the water valves is activated, to change the temperature in the desired direction. While the temperature is in the deadband region, both valves are shut off.

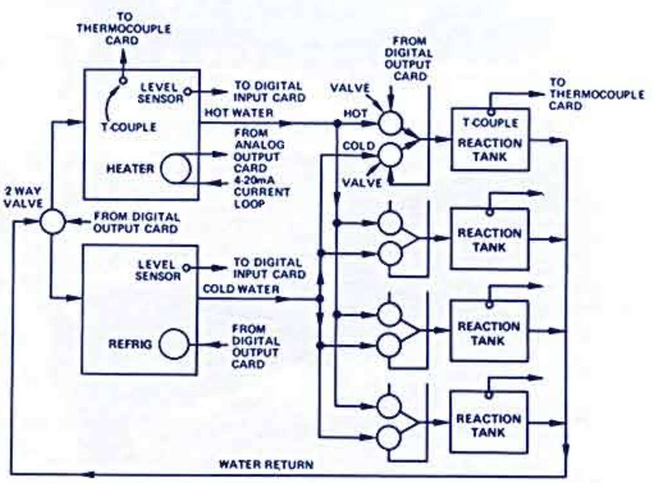


Figure 2. Reaction-tank temperature-control system.

A holding tank with a sensing thermocouple and a heater under proportional control with a 4-20mA current-loop input provides hot water to the system. Chilled water is provided by a similar tank with a digitally stepped refrigerator unit. Care must be taken that, once a stage is turned off, it not be turned on again for a specified time period, to avoid damage to the compressor motors. Since the water return is a single line, level sensors in the hot- and cold-water tanks control the position of a two-way valve in the return line.

MACSYM II easily handles all of the measurement and control functions defined above. All the sensor and actuator connections are brought directly to the signal-conditioning cards on the MACSYM II chassis, thereby eliminating the need for separate external signal conditioners and their associated wiring.

All of the control functions discussed are implemented in a set of simple real-time tasks, utilizing the multitasking capabilities of MACBASIC. Furthermore, since MACBASIC is a general-purpose language, it handles all of the various control-loop algorithms with equal ease and, in addition, provides full facilities for on-line troubleshooting.

DRUG PROBLEM

A problem commonly encountered by drug manufacturers is that of controlling autoclave temperatures to provide proper sterilization of the contents without damage due to excessive temperatures. In addition, an accurate log must be kept for each batch processed in order to meet U.S. Government requirements.

MACSYM I was originally used to fulfill this function at a major drug-manufacturing concern, using the configuration shown in Figure 3. MACSYM measures temperature by means of 12 thermocouples distributed throughout the batch to be sterilized, with signal-conditioning provided by a data logger, which provides a serial ASCII output. A digital switch output in the MACSYM controls a valve to allow steam to enter the autoclave when required.

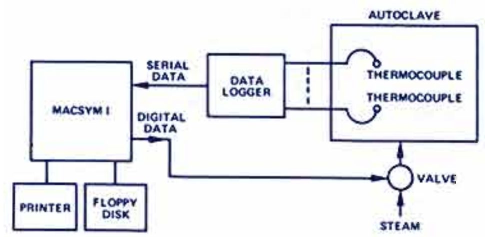


Figure 3. MACSYM I process control application.

At the beginning of each sterilization run, the operator, prompted by MACSYM, enters information relating to drug type, batch number, etc. When entry has been completed, the MACSYM opens the steam valve and begins monitoring the thermocouples. At each temperature scan, the MACSYM sorts out the highest and the lowest readings. If the highest exceeds 114°C, the steam valve is shut off, while the lowest reading is monitored until it reaches 112°C, at which time sterilization begins and the time is noted. Monitoring continues, along with logging of the data and reporting of exceptions. The value of the lowest temperature is integrated with time until a preset value (or quality factor) is reached. At this point, steam is shut off and the sterilization process is terminated. A full log of the run is printed out in conformance with Federal standards, and the log is also stored on floppy disk as a backup record.

Since MACSYM is programmed in easy-to-learn and easy-to-use MACBASIC, the instrumentation engineers using the system were able to design and implement the applications software without the need of recourse to a computer specialist. In addition, the multitasking feature of MACBASIC allows them to control four completely independent autoclave systems, utilizing the single terminal as a shared resource.

Although MACSYM I could have effectively continued to answer the process requirements of this and other users, Analog Devices used the experience gained from such applications, extensive market surveys, and the increasing availability of sophisticated electronic parts at low cost to develop MACSYM II, a measurement and control system with improved performance, capabilities, and cost effectiveness. In the last example, if MACSYM II had been used (Figure 4), the thermocouple-input cards and the integral data-cartridge system would eliminate the data logger and the floppy-disk system. Finally, the integral keyboard and display greatly simplify programming and reduce cost.

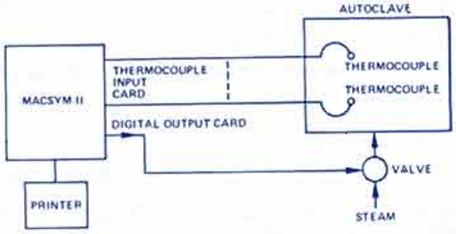


Figure 4. MACSYM II process control application.

The possibilities for MACSYM II applications are virtually limitless. It is a powerful tool that can be used by *anyone* to effectively answer real-time measurement-and-control requirements in the laboratory or industry. The Application Staff of our Instrumentation and Systems Group and their field-sales representatives are available to answer any questions you may have about MACSYM and its possible application to your problems. Phone 617-329-4700 and ask for MACSYM Applications. ▶▶▶

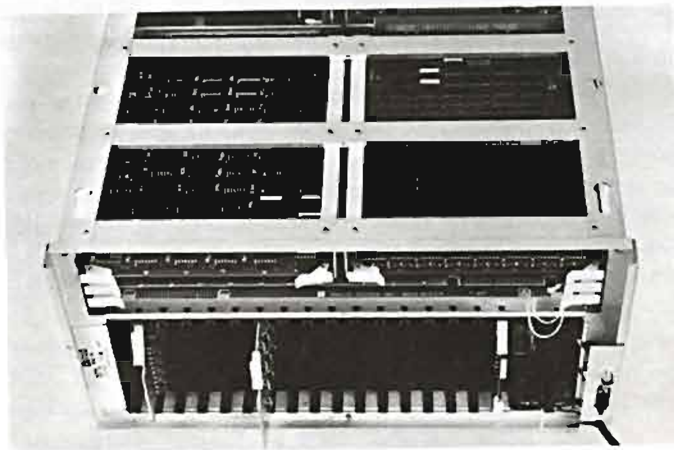
THE AUTHOR

Alan Finger (page 12) is the Senior Applications Engineer in the Measurement and Control Products Group. Before joining Analog Devices, he was a Research Physicist at Eastman Kodak Research Laboratories, developing hardware and software systems for photographic research. He has a BSEE from Clarkson College and occupies his spare hours with photography, bicycling, and personal computing.

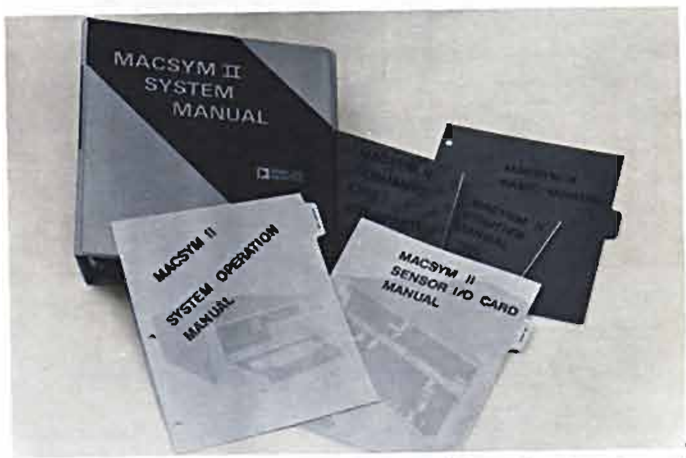
VIEWS OF MACSYM II

Every MACSYM II undergoes 100-hour burn-in at 50°C while running a multitasking program that exercises all of its capabilities. Subassemblies undergo separate burn-in before they are assembled in the mainframe.

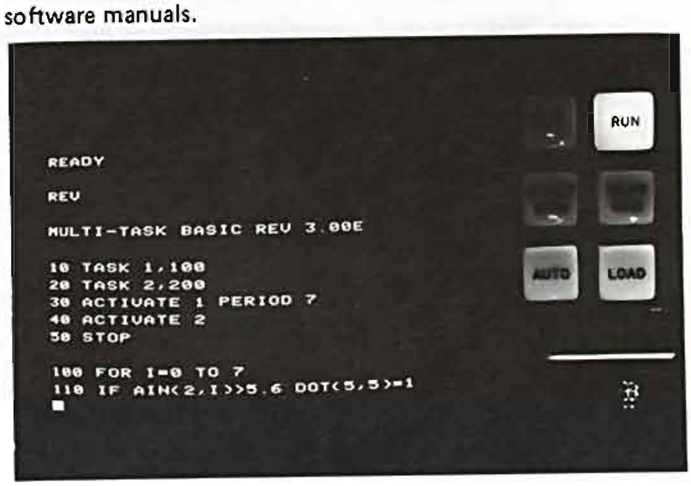
MACSYM's 16-bit processor is fast and efficient.



32K of read-write memory is available to the user.



MACSYM is heavily supported with instruction books and software manuals.



The monitor provides conversational capability.

GENERAL-PURPOSE TEMPERATURE PROBE

AC2626 Has Current Output, 1µA/K, from -55°C to +150°C

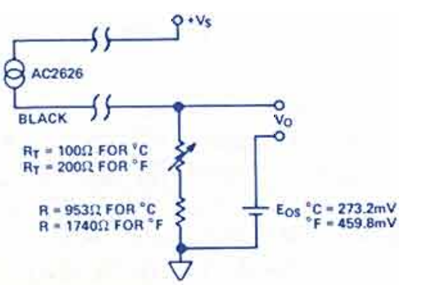
Stainless Steel, 3/16" OD, 4" or 6" Long; Compression Fitting Available

In recent editions of this Journal, we have introduced the AD590* temperature sensor, in a TO-52 package, and two families of electronic thermometers based on it: the AD2040* low-cost 3-digit thermometer and the AD2038* six-channel scanning thermometer. We now introduce the AC2626 stainless steel probe and—elsewhere on this page—the AD590F supercompact flat-packaged sensor.

Reviewing the AD590† briefly, it provides a current proportional to absolute temperature, 1µA/K, independently of the magnitude of the +4V to +30V excitation voltage, over the range −55°C to +150°C. A two-terminal device, it is easy to use, and the current-source output permits transmission over long wire runs with insensitivity to voltage drops and voltage noise. The excitation source and the measuring (I→V) resistor can thus be remotely located from the site of measurement, and multiplexing is easy. The AD590 is more cost-effective in its temperature range than thermocouples and RTD's because it is easy to use and doesn't require expensive signal conditioning.

The AC2626 is a stainless-steel tubular prove with 3/16" (4.76mm) outside diameter and choice of 4" (101.6mm) or 6" (152.4mm) length. Its response time-constant is 2 seconds in stirred water. The color-coded leads are Teflon-coated, and the device has an absolute-maximum voltage rating of ±200V, case to leads.

The probe is designed for applications involving liquid or gaseous immersion, for temperature measurements in refrigeration, and for any general temperature-monitoring application within its specified range.

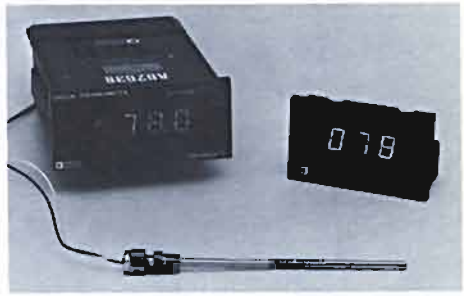


*Use the reply card to request technical data.
†Covered by U.S. Patent 4,123,698.

A compression fitting, the AC2629, is available for measurements in pipes or closed vessels. Available in either stainless steel or brass, the AD2629 (B or SS) may be applied anywhere along the probe.

The AC2626 probe is available with a variety of accuracy specifications, to permit cost-effective device choices in a wide gamut of applications. The range is from the AC2626M, with ±0.5°C calibration error (max at 25°C) and ±0.3°C max nonlinearity, to the AC2626J, with ±1.5°C max nonlinearity. The devices are color-coded ("high" lead is yellow/orange/blue/green for J/K/L/M, "low" lead is black). Prices in 100's are $16.50/$21/$27.50/$38.

The devices are easily calibrated and can be easily connected for Celsius or Fahrenheit measurements, instead of kelvin, as Figure 1 shows. For most applications, a



single-point calibration is sufficient. For the lowest cost-impact, the J and K grades are recommended, if calibration means are convenient. Where the probes must be interchangeable, we suggest grades L and M.

In addition to the *measurement* of temperature, applications may involve the *use* of an analog quantity (I or V) proportional to temperature to achieve a temperature-dependent function. Examples include flow-rate measurement, anemometry, level detection in fluids, and temperature compensation in wide variety, including cold-junction compensation. ▶▶▶

AD590F IS ONLY 2.66 x 5.84 x 1.42mm³

Two New AD590 Spec Grades Introduced

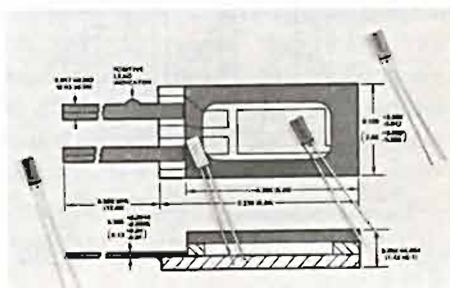
The AD590* temperature sensor has been well-received by engineers and scientists. They like its convenient two-wire current-source form; they like its linearity and accuracy, its ease of calibration where necessary; and they like its price.

Naturally, you can't please everybody. Although the original TO-52 package is quite compact, some applications call for even smaller size and/or a special probe. And lower prices never hurt anyone!

In response, the AC2626* probe and the AD590F* ceramic package are two new packages. And two new specification grades I (low price) and M (high accuracy), have been created. We have also published a new consolidated data sheet* for both the TO-52 ("H") and the "F" package, and a four-page Application Note, entitled "Accuracies of the AD590",* which specifies guaranteed accuracy for each grade over various temperature spans and ranges, trimmed and untrimmed.

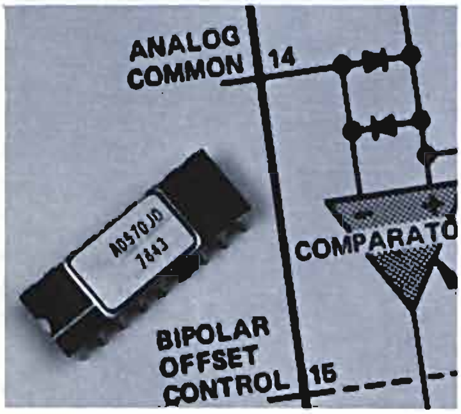
*For technical data on devices of interest, use the reply card.

A drawing of the F package is given below. As a consequence of its small size, it responds faster than the "H" package. For example, in stirred oil, τ is 0.6s for F, 1.4s for H. New grades (both F and H packages), the AD590I and AD590M, extend the accuracy spectrum; the M has initial error of ±0.5°C max, and max nonlinearity of ±0.3°C. The AD590I has max nonlinearity of ±3°C; its principal virtue is its price, $1.65 in 100's ("H"). ▶▶▶



COMPLETE MONOLITHIC 8-BIT ADC

No Missing Codes Over the Temperature Range AD570 Is Low in Cost - $14.95 in 100's(J)



The AD570* is a complete 8-bit successive-approximation a/d converter fabricated on a single silicon chip. It includes a precision DAC, voltage reference, clock, comparator, successive-approximation register (SAR), and 3-state output buffers. No external components are required to perform a full-accuracy 8-bit conversion in 25μs.

The key to its accuracy and low cost is the use of advanced integrated circuit technologies: I^2L (Integrated Injection Logic) in the fabrication of the SAR, automatic laser-trimming of the high-stability SiCr thin-film ladder network at the wafer stage, and a temperature-compensated stable subsurface Zener reference. Figure 1 is a block diagram of the complete device. Figure 2 shows its standard connection mode for conversion; the only external component is a single optional trim resistor for calibrating full scale. The AD570 will accept input ranges of either 0 to +10V, or ±5V, as determined by a digital logic input.

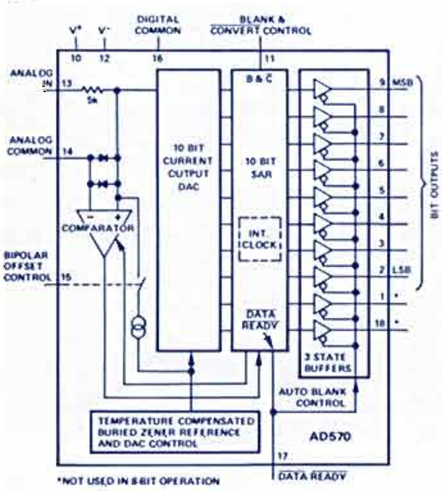


Figure 1. Block diagram of the AD570.

*For a complete data sheet, use the reply card.

Operating with a −15V and a +5V power supply, the AD570 provides true 8-bit accuracy, with no missing codes over its entire operating temperature range, 0°C to 70°C for "J" versions, −55°C to +125°C for "S" versions. It is packaged in an 18-pin hermetically sealed ceramic DIP and is available with full processing to MIL-STD-883B, Class B. The single-chip construction and functional completeness of the AD570 make it especially attractive for high-reliability applications, in chip and packaged form. Prices in 100's (AD570JD/SD/−883B) are $14.95/$29.50/$35.00.

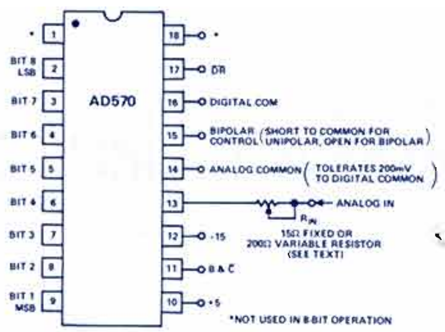


Figure 2. Standard AD570 conversion connections.

The AD570's outputs are three-state latches, permitting 570's to be multiplexed on an 8-bit bus. As the BLANK-and-$\overline{\text{CONVERT}}$ line is driven low, the three-state outputs will be open and a conversion will commence. Upon completion of the conversion about 25μs later, the $\overline{\text{DATA READY}}$ line will go low and the data will appear at the output. Pulling the B$\overline{\text{C}}$ line high again blanks the outputs, freeing the bus and readying the device for the next conversion.

The AD570 is a complete, high-precision 8-bit successive-approximation a/d converter featuring high conversion speed and low cost. It is reliable and easy to use; it is a first choice for general-purpose 8-bit conversion applications. ▶▶▶

IMPROVED RMS IC

AD536A: Wider Bandwidth; MIL Temp, TO-100 Versions

The AD536 is a complete rms-to-dc converter on a monolithic chip, requiring only an external user-chosen averaging capacitor. It can be used on single- or dual supplies and has an auxiliary log output, for dB applications. Its block diagram and DIP package pinout are shown in Figure 1.

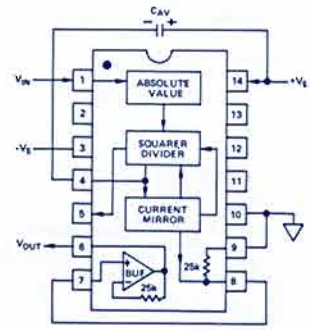


Figure 1. AD536A block diagram.

The AD536A* is an rms IC with improved performance and a wider range of user options than were available in the pioneering AD536, which it is designed to replace. Here are the salient benefits:

- 3x as much bandwidth (Figure 2).
- Operation from −55°C to +125°C ("S")
- All versions available in a 10-pin TO-100 can at lower cost than the DIP
- Halved drift specs for the "K" version (0.05mV ±0.005% of reading)/°C max
- Increased compliance and output-voltage range.

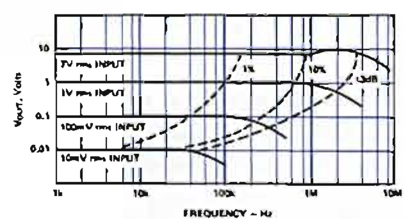


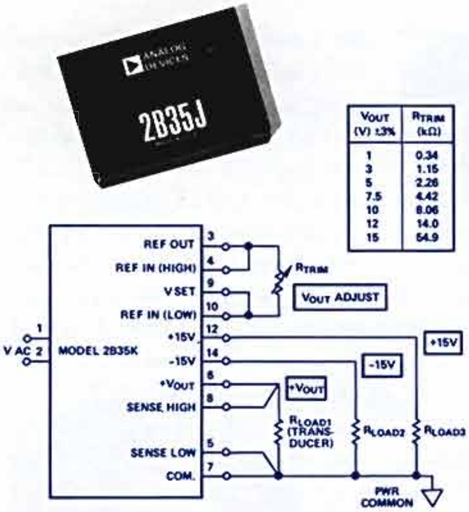
Figure 2. AD536A frequency response, showing 1%, 10%, and 3dB error frequencies.

The AD536A DIP versions have identical connections to those of the AD536, and performance is identical (or improved) at no increase in cost. Prices for the DIP versions (AJD/AKD/ASD) are $9.95/$18.50/$29.95, and for the TO-100 (AJH/AKH/ASH), $6.95/$10.95/$22.50, in 100's.

*Use the reply card for technical data. ▶▶▶

TRANSDUCER P.S.

Programmable V or I, Fixed ±15V @65mA



V_{OUT} (V) ±3%	R_{TRIM} (kΩ)
1	0.34
3	1.15
5	2.26
7.5	4.42
10	8.06
12	14.0
15	54.9

The 2B35* is a triple-output instrumentation power supply designed to provide regulated excitation to a wide variety of transducer types and ±15V power for amplifiers and other analog circuits, operating from mains power.

The regulated excitation is available in the form of either voltage or current, programmable by a single resistor.

In the voltage mode, a range of +1 to +15V is available, with load current from 0 to 125mA, suitable to excite four 350Ω transducers at 10V. Current limiting protects the output against accidental overload, and remote sensing corrects for line drops. The wide range of voltage adjustment allows the user to employ the 2B35 in applications with low-level transducers, where high excitation voltage is required, or to eliminate transducer self-heating effects. The illustration shows the voltage-mode connection.

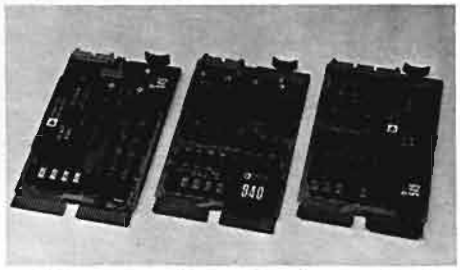
In the current mode, a range of 100μA to 10mA is available, with +10V maximum compliance-voltage range.

Two accuracy selections are available; the 2B35K is specified to be approximately 8 times as precise as the 2B35J, in both temperature stability and regulation, for both fixed and programmable outputs. Prices for the J/K are $69/$89 in small quantity. ▶▶▶

*Use the reply card for technical data.

INTERFACE BOARDS FOR DEC LSI-11

RTI-1250 Family: Inputs, Outputs, and I&O 12-Bit Converters, Memory-Managed Interfacing



Analog Devices augments its line of μC analog I/O boards by introducing 3 new products fully compatible with the DEC LSI-11 & 11/2. Significant new features offered by these boards include: analog inputs (16) and outputs (2) on the same board (RTI-1251), expanded input-channel capacity (32 inputs, S.E.), choice of resistor- or software-programmable gain (RTI-1250R & S), and a 4-channel DAC output board (RTI-1252). All boards interface to the μC as blocks of 4 consecutive address locations, and come equipped with on-board dc-dc converters for direct +5V operation.

The boards are:

- *RTI-1250 12 Bits, Input Only* Up to 32 input channels are available; amplifier gain is optionally programmable by resistors or by software; software inherently can control automatic multiplexer increment, external convert command, and interrupts. Price for these and other features: $560/$645 (RTI-1250-R/S).
- *RTI-1251 12-Bit Input/Output* 16 input channels and two 12-bit-DAC voltage outputs are provided. Price (small quantity) is $695.
- *RTI-1252 12 Bits, Output Only* Four channels of 12-bit DAC's and four digital logic drivers are available. Features include readback, remote sensing, and a single reference. 4-20mA current outputs are optional. Prices: 2 DAC's, $460, 4 DAC's $550. ▶▶▶

*For technical data, use the reply card.

DIGITAL-TO-SYNCHRO CONVERTERS

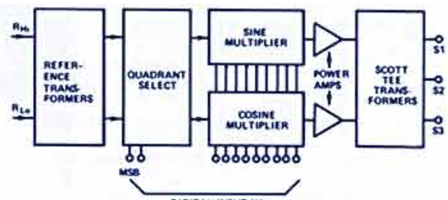
DSC1705: 14-Bit Resolution, 4′ Accuracy 0.1% max Radius-Vector Variation

The DSC1705 and DSC1706* are digital-to-synchro and digital-to-resolver converters capable of driving control transformer loads of up to 1.3VA. They accept a 14- or 12-bit digital input, representing angle, and a reference voltage of either 60Hz or 400Hz, and produce a 3- or 4-wire output suitable for driving synchros or resolvers.

The 400Hz versions are completely self-contained, including transformer; the 60Hz versions require external transformers (STM1679500/600). For loads greater than 1.3VA, transformerless versions to permit external power amplifiers are available.

RADIUS VECTOR

The outstanding and unusual characteristic of these converters is the nearly negligible radius-vector variation. It is possible and usual to build converters in which the ratio of sine to cosine (tangent) is accurate but the sine and cosine individually may be in error by as much as 7%. This is not always important, since the accuracy of the conversion depends on the ratio. In some cases, however, when driving torque receivers and certain servo control loops, this variation is unacceptable.



The design of the DSC1705/6 has reduced this variation to less than 0.1%. This means that in closed-loop servo systems, the gain of the closed-loop is independent of the digital input angle, and reference correction is unnecessary.

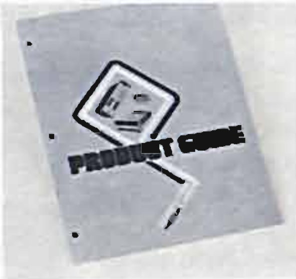
Price of the DSC1705/6 varies, depending on options, starting from $375/$298 (1's). ▶▶▶

*For technical data, use the reply card.

Worth Reading

Three new publications of potential interest to our readers have recently been made available from Analog Devices. For your *free* copy, use the reply card.

COMPUTER LABS HIGH-SPEED CONVERSION PRODUCTS



This 16-page short-form catalog describes the products of our new Computer Labs Division. Included are an extensive line of high-speed ADC's, DAC's, and accessories in the form of rack-mounted instruments, card cages, compact modules, and hybrid circuits, for video and radar applications. Also included are descriptions of Computer Labs' PDP-11-compatible computer peripherals, including disk and tape memory systems.

ISOLATION AND INSTRUMENTATION AMPLIFIERS

This comprehensive 24-page Designers Guide provides a wealth of practical information on the understanding and application of instrumentation and isolation amplifiers. In addition to covering such topics as theory, general characteristics, key specifications, selection, and applications of isolation amplifiers, it also includes a selection guide and detailed specification information. Also provided is tutorial and summary information on instrumentation amplifiers, including the new signal conditioner, the 2B30.

SYNCHRO-TO-DIGITAL CONVERTERS

This short-form guide to Analog Devices Synchro-Digital products includes data on tracking-type and sampling/multiplexed synchro-to-digital converters, digital-to-synchro converters, binary-to-BCD converters, angle-position indicators, two-speed processors, trigonometric multipliers, and synchro-to-linear dc conversion modules. ▶▶▶

THE AUTHORS

Fred Pouliot (page 3) is Division Marketing Manager for Measurement and Control Products in the Analog Devices Instruments and Systems Group. He has a BSEE from Northeastern University and has done graduate work, while teaching undergraduate courses. He is a member of both TBII and HKN. After several years of designing analog circuitry, he became a marketing specialist, then served as Marketing Manager for various product lines en route to his present assignment. He has written articles for *Analog Dialogue* and other publications and is well-known on the seminar circuit.

A Senior Project Engineer in the Analog Devices Instruments and Systems Group, and a key contributor to both MACSYM I and MACSYM II, *Charles L. Ehlin* (page 5) designed MACSYM II's CPU, memory, cassette controller, and analog inputs. Charlie has a BSEE from the Polytechnic Institute of Brooklyn. Before he came to Analog Devices, he was an Engineer at PRD Electronics, Inc., for the VAST/CVA Automated Test System.

Bill Gonsalves (page 6) is a Project Engineer with the MACSYM group and a key contributor to MACSYM I & II. He has had design responsibility for the CRT Controller, Quad Teletype, ADIO Controller, and System support/Disk Interface boards. Bill attended the R.I. School of Electronics and Southeastern Massachusetts University. He served in the U.S. Navy, was involved in acoustic ASW research.

DAVE PYE TOM KELLY

Tom Kelly (page 7) has a BSEE from Rutgers University, College of Engineering. Joining the MACSYM group at the inception of the design and development stage, he became involved with I/O and system integration. He has designed the thermocouple cards, the d/a output cards, the digital I/O cards, and has worked on the CMOS multiplexer card.

Dave Pye (page 7) is a Project Engineer on MACSYM II, with responsibility for the Power Supply and analog data acquisition. He has a B.S. from Clarkson College of Technology, and had worked on an analog measurement system for automatic test equipment while he was a Design Engineer at Faultfinders, Inc.

John Vella (page 10) is Section Leader, MACSYM Software. He has been developing systems software for small interactive systems for many years, especially in the areas of language processing, graphics, multitasking executives, file management, and process control. In MACSYM, he was involved most heavily in the development of MACBASIC. Before coming to Analog, John worked at Draper Laboratory, MITRE, and Honeywell. He has a degree in Mathematics from Fordham University.

Arthur Miller (page 10), Systems Programmer for MACSYM software, with responsibility for the MACBASIC programming language, has designed software for a variety of processors in areas directly relevant to MACSYM. Arthur has worked at MITRE and Raytheon. His B.S. from Boston College and M.S. from Northeastern U. are both in Mathematics.

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 12, No. 3, 1978) . . . Complete 12-Bit Two-Chip IC A/D Converter (AD574) . . . Three New CMOS Monolithic Multiplying DAC's (12-Bit AD7533, BCD AD7525, and Buffered 8-Bit AD7524) . . . Fast, 12-Bit Monolithic Current-Output D/A Converter (AD565) . . . *Multi-Channel Measurement of Temperature, Pressure, Flow, etc., Made Easy, Economical, and Expeditious* (with the AD2037 Scanning Voltmeter and the AD2038 Scanning AD590-Oriented Thermometer) . . . Low-Cost Bipolar-FET-Input Op Amp (AD542) . . . *Bridge Signal Conditioning the Easy Way* (with the 2B30 and 2B31) . . . Application Note: Versatile Digital Vector Generation (DTM1716 and 1717 14- and 12-Bit R sin θ, R cos θ modules) . . . and these New-Product Briefs: 3-Chip AD DAC 85 12-Bit Voltage- or Current-Output DAC; FET-Input AD545 Precision Low-Drift-and-Noise Op Amp . . . 46-page APPLICATION GUIDE TO CMOS MULTIPLYING DAC's: Use the reply card to order your copy.

REPRINTS, etc. The following items are available upon request: "IC Flexibility Comes to the Sample-Hold scene", by Dave Kress, *Electronic Products*, March, 1977, pp. 41-46 . . . "Writing P-I-D Control Loops Easily in BASIC", by Jim Fishbeck, *Control Engineering* 25-10, October, 1978, pp. 45-47 . . . "Accuracies of the AD590", 4-page Application Note, listing maximum errors for each grade as a function of temperature span and number of trims . . . New data sheet for the AD534 monolithic IC Multiplier/Divider, new DIP version included.

PATENTS The following U. S. patents have recently been issued: 4,092,698, to Paul E. Brefka, "Protective Case for Electrical Instruments on Circuit Boards;" if you copy the case of our AD2026 or AD2040, you'll be infringing this patent . . . 4,123,698, to Michael P. Timko and Adrian P. Brokaw, "Integrated-Circuit Two-Terminal Temperature Transducer;" if you copy the AD590, you'll be infringing this patent.

ERRATA . . . AD7524 Preliminary Data Sheet and page 318 of the *Data-Acquisition Products Catalog*: In the specification table, under "Power Supply", delete the 1st and 3rd lines. All numbers in the 2nd and 4th lines should be 500 (μA) . . . AD7533 Preliminary Data Sheet and page 328 of the Catalog: Under "Power Requirements", the V_{DD} range is +5V to +17V (functionality) for both grades. Delete the fourth line . . . On data sheets for the AD7541 and AD7520 (Figure 16) and the AD7530 (Figure 2), "Bipolar Operation", the external resistors connected to the inverting amplifier should be 5kΩ. Because the ladder resistance may be as low as 5kΩ, the published value of 10kΩ may lead to saturation of the inverting amplifier in extreme cases . . . In *Analog Dialogue* 12-1, on page 3, second paragraph of column 1, the operating temperature range in parentheses should read: (218.2K to 423.2K), to correspond with the range correctly shown on the adjacent photograph.

CLARIFICATIONS . . . On the AD522 data sheet, in the spec table under "Gain", the temperature coefficients are of *gain*, not nonlinearity. The order of the specs may have led to some confusion on that score . . . The absence of full data sheets on some of our popular older products in the *Data-Acquisition Products Catalog* does not mean that they are obsolete. On page 599, there are listed more than 65 additional modular products that are still in production and for sale. If a product you've been buying and intend to buy in the future is missing from the Catalog, don't panic! Consult Analog Devices or the nearest Sales office. (To keep the Catalog to manageable size, we list only those products that should prove cost-effective in the design of your *new* equipment.) . . . In the last issue, we showed how one might design a 15-bit-resolution ADC, using the new AD574. It is worth noting that complete, packaged, 14- (ADC1130, 1131) and 16-bit (ADC16QM) converters are available off-the-shelf if you'd rather "buy than make."

GOOD NEWS . . . The AD2040 thermometer (used with the AD590 sensor) now has the 0.6" bright easier-to-read Monsanto display. The new display is also optionally available on the AD2026 digital panel meter . . . Two new voltage (0 to +10V) to current (4mA to 20mA) converters will be available soon and will be described in the next issue. They are the 2500V-isolated 2B22 and the ground-based 2B20. Prices in 100's: 2B22, from $59; 2B20, from $26.

CMOS USERS (Especially MIL and Hi-Rel Customers) PLEASE NOTE: Our CMOS facility in Limerick, Ireland, has received plant approval from the European standardization authority. Our quality-assurance procedures and capabilities have met the standards of CECC (CENELEC Electronic Components Committee), which are essentially compatible with what are known in the U.S.A. as MIL-M-38510 and MIL-STD-883B.

5 COMMON MEASUREMENT PROBLEMS. SOLVED.

1. GROUND LOOPS.

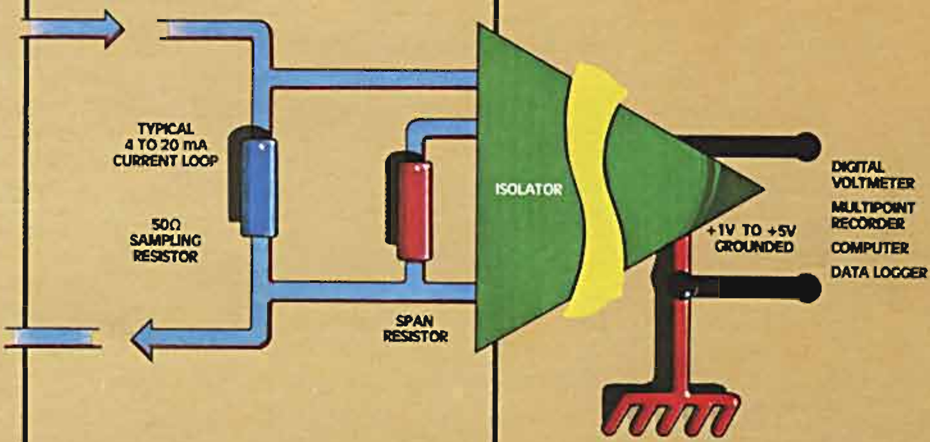
Low level signal processing in multi-channel data acquisition systems, especially in remote sensor applications such as strain gages and thermocouples, is often complicated by troublesome ground loop currents and ground disturbances. Our Model 288/947 Synchronous Isolator, with its fully floating two-wire input, complete galvanic isolation between inputs to output, and low nonlinearity error (0.05% max, Model 288K) is the answer.

2. HIGH COMMON MODE VOLTAGES.

Accurate measurement of low level signals riding on high common mode voltages—such as current shunt measurements in motor control and series cell voltage monitoring in fuel cells—requires high isolation CMV/CMR ratings. Our economy Models 284J and 286J both offer CMV ratings to 2500VDC continuous operation and CMR ratings of 114dB min @ 60 Hz.

3. ELECTRICAL NOISE.

The harsh, noisy environments often found in industrial process control and monitoring applications, can create high RFI/EMI components which will mask the low-level process signals. EMI/RFI interference from motors, relays and power lines requires the guarded input stage and the high CMR performance of our isolators, of Model 284J/286J.



4. FAULT PROTECTION.

Isolators protect monitoring and control systems against the detrimental effects of both voltage surges caused by inductive devices—relays, solenoids, transformers—and faults occurring in power transmission lines. In petrochemical manufacturing, raw aluminum processing plants and industrial motor controller applications, Models 284J and 286J protect against catastrophic surge damage with 5kV pk pulse (10ms) CMV ratings.

5. SAFETY.

In biomedical and EKG patient monitoring, and in critical industrial interfacing, such as nuclear power system monitoring, reliable, safe isolation is essential. Our Model 284J offers built-in defibrillator protection (to 6.5kV pk pulse, 10ms), low leakage (2uA rms max, @ 60Hz 115VAC), low input noise (8uV pk-pk, .05 to 100 Hz), fault current of 10uA rms max—all at a low cost ($41-100's).

The Isolation Amplifier is your best protection from high voltage surges, as well as isolation from ground disturbances. Whether your application involves process control instrumentation, data collection, patient and equipment safety, high voltage equipment, or whatever.

Send for a free copy of our new Isolation and Instrumentation Amplifier Designers' Guide. Write to Analog Devices, Inc., P.O. Box 280, Norwood, MA 02062.

ANALOG DEVICES

WAY OUT IN FRONT.

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