

analog dialogue

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

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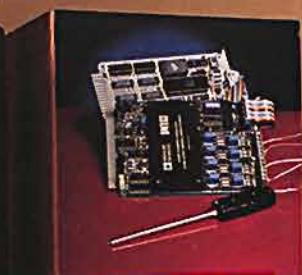
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AMPLIFY
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AMPLIFY
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ISOLATE

Volume 16, Number 3, 1982

 **ANALOG
DEVICES**

Editor's Notes

INTEGRATION

We were caught on the points of a pentalemma! Our cover usually features the most-significant product introduced by Analog Devices during the period immediately preceding publication of *Analog Dialogue*. Much of the time, the choice—an industry first—is obvious, unquestionable, and universally endorsed within our family. But not this time.



Would it be the world's highest-precision and most functionally complete monolithic instrumentation amplifier, the AD524?

Would it be the world's first monolithic thermocouple preamplifier, itself providing cold-junction compensation and a temperature reference, the AD594?

Or would it be the first analog I/O multichannel signal-conditioning subsystem specified for the harshest industrial environments, the 3B series?

Would it be the first STD-bus-compatible analog-input subsystem with all the necessary signal conditioning—from sensor wires to data in-engineering-units—and local μ P control, the RTI-1270?

Or would it be the impressive MACSYM 350 measurement-and-control computer system, the first to combine at low cost a 16-bit co-processor system, up to 1 megabyte of read-write memory, multitasking MACBASIC, MP/M-86 operating system, dual floppy disks, communications and color graphics, with the comprehensive ADIO family of analog-digital input-output signal-conditioning cards that can be field-wired directly to transducers?

(And if these, what then of the AD390 quad of 12-bit DACs in a 28-pin DIP, the two-channel AD539 monolithic multiplier-divider with signal bandwidths to 60MHz, the voltage-output AD7240 CMOS 12-bit DAC, the LTS-2015 faster tester?)

The key that made the answer obvious was the common thread joining the five prime contenders—signal conditioning for measurement and control. Each represented a higher level of integration, essentially comprising all of the functions of the previous ones, and together they are an impressive reminder of how far we've come since the 601, our first instrumentation amplifier, was introduced (as a forward integration from our op-amp product line) in 1968.

THIRTY YEARS OF OP AMPS

Forgive us if we wax historical (we were there!) It is within a few weeks of thirty years since George A. Philbrick introduced the Model K2-W Operational Amplifier. The first modular octal plug-in general-purpose op amp, it had two 12AX7 dual triodes, ± 50 -volt at ± 1 mA output, gain of 15,000, 200kHz unity gain-bandwidth, and it required only ± 4.5 mA at ± 300 V, plus nearly 4 watts of filament power (0.6 A at 6.3 V).



Dan Sheingold

THE AUTHORS

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Barrie Gilbert (page 20), a Division Fellow at Analog Devices Semiconductor, is a prolific designer, writer, teacher, and inventor, with numerous patents, publications, and awards. A native of England, with a Higher National Certificate in Applied Physics (with honors), from Bournemouth Municipal College, he has worked at Mullard and Plessey. Joining ADI from Tektronix, his most visible linear-IC contributions have been the AD534 multiplier, the AD536 rms IC, the AD537 VFC, and now, the AD539.



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ANALOG SIGNAL CONDITIONING ICs TAKE TWO GIANT STEPS

AD524: Low-Drift-and-Noise Wideband IC In-Amp with Pin-Programmable Gains

AD594: Monolithic Thermocouple Amplifier with Ice-Point Reference and Alarm

by Scott Wurcer and Moshe Gerstenhaber

Monolithic technology is making ever deeper inroads into low-level analog signal conditioning; now it is less necessary than ever for the instrumentation and systems engineer to be concerned with details of circuit design. The make-vs.-buy decision continues to be tilted towards "buy" by the evolution of new generations of cost-effective monolithic signal-conditioning products.¹

In these pages, we consider two such products that have been recently introduced: The AD524*—a fast, low-drift, low-noise, self-contained multiple-gain ($\times 1$, $\times 10$, $\times 100$, $\times 1000$) instrumentation amplifier (the closest approach yet to a low-cost ideal gain block for preamplification and transducer interfacing)—and the AD594*—a complete self-contained ice-point-compensated thermocouple amplifier with a basic $10\text{mV}/^\circ\text{C}$ output sensitivity for temperature measurements with a wide range at low cost.

It's worth noting that these ICs did not suddenly materialize out of thin air. While they represent innovative monolithic solutions to instrumentation needs, they are also the culmination of a continuum of competence in amplifier design and applications, as well as advanced linear-IC processing. Analog Devices IC precursors include the first- and second-generation AD520 and AD521 instrumentation amplifiers, the AD580 precision band-gap voltage-reference family and the AD590 temperature transducer, plus many years of experience with the design and manufacture of products using Si-Cr on-chip thin-film resistors, with laser-trimming at the wafer-probe stage for precision.²

WHAT ARE THEY?

AD524 Instrumentation Amplifier, designed for high accuracy under worst-case operating conditions, is a differential-input gain block in a 16-pin DIP; It requires no external components for pin-programmable gains of 1, 10, 100, 1000. The C version has lowest input offset voltage ($50\mu\text{V}$) and drift ($0.5\mu\text{V}/^\circ\text{C}$), nonlinearity (0.003% at $G = 1$), and noise ($0.3\mu\text{V}$ peak-to-peak, 0.1 Hz to 10 Hz). Common-mode rejection is 120 dB minimum ($G = 1000$).

The AD524's dynamics are superb: internally compensated, it has a gain-bandwidth ranging from 25 MHz ($G = 1000$) to 1 MHz ($G = 1$), full-power response of 75kHz and settling time of $15\mu\text{s}$ to 0.01% of a 10V output step ($G = 100$). The input circuit is protected against damage under both power-off and power-on conditions. Last, but not least, the AD524 family provides low error budgets without straining a user's cost budget. Prices (100s) are \$9.90/\$12.95/\$17.95/\$23.95 for AD524A/B/C/S.

Figure 1 shows how easy it is to obtain a gain of 100, with provision for an optional input offset null adjustment. The preset gain of 100 is selected by simply connecting the "G = 100" terminal to RG_2 . The AD524 can be connected for gains other than the

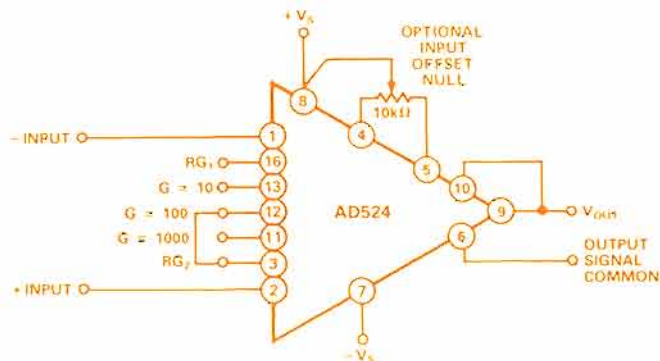


Figure 1. Operating the AD524 at a gain of 100.

fixed values by the use of external resistors, as we shall show later.

AD594 Thermocouple Amplifier-Compensator is a complete thermocouple signal conditioner on a monolithic chip in a 14-pin DIP. Combining an ice-point reference with a precalibrated differential amplifier, it produces a high-level ($10\text{mV}/^\circ\text{C}$) output directly in response to a thermocouple signal. In the open-loop (comparator) mode, it can function as a set-point controller; and—when used without a thermocouple—it will itself function as an ambient temperature transducer with low-impedance output voltage directly proportional to degrees Celsius ($10\text{mV}/^\circ\text{C}$).

Precalibrated to work directly with Type J (iron-Constantan) thermocouples, the AD594 can be configured to work with other types as well, using external trims. In addition, it provides a TTL-compatible alarm signal when either lead of the thermocouple is open-circuited. It is specified in two grades (A and C), distinguishable

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¹For useful discussions of the considerations in analog signal conditioning, see *Transducer Interfacing Handbook*, D. Sbeingold, ed., Analog Devices (1980), \$14.50.

²At the time they were introduced, the devices were described in *Analog Dialogue*: AD520, 7-1 (1973); AD521, 9-1 (1975); AD580, 8-2 (1974); and AD590, 12-1 (1978). Laser-wafer trimming was described in 9-3, (1975).

³For technical data, use the reply card.

by maximum-calibration-error ($\pm 3^\circ\text{C}$ and $\pm 1^\circ\text{C}$) and temperature-rejection specs. Price in 100s is only \$9.50 (A) and \$14.50 (C).

Figure 2 shows the device's basic connections, when used with an iron-Constantan thermocouple to measure temperatures greater than 0°C . For positive temperatures, only a single supply is needed, in this case +5V. Output-voltage range (hence measurement temperature span) is a function of the excitation voltage.

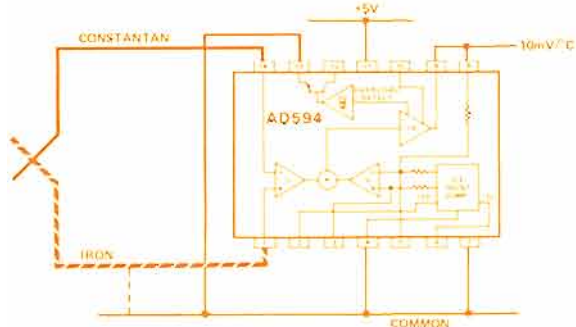


Figure 2. Basic connections to the AD594 for measuring positive temperatures.

HOW THE AD524 WORKS

Figure 3 is a simplified diagram showing how the AD524 works. A close relative of the conventional 3-amplifier in-amp, its gain is established in the same way. The differential input voltage is im-

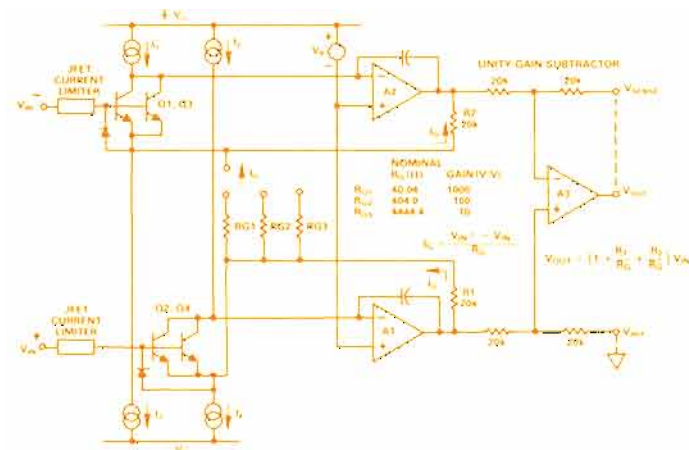


Figure 3. Functional diagram of the AD524.

pressed across a measuring resistor, R_C , and the resulting current develops additive voltages across two resistors, R_1 and R_2 , effectively in series with R_C , and connected to the outputs of A_1 and A_2 . Since the common current must be equal to V_{IN}/R_C , the differential output voltage, V_D , is

$$V_D = (V_{IN}/R_C)(R_1 + R_2 + R_C) \quad (1)$$

$$= V_{IN} \left(1 + \frac{R_1}{R_C} + \frac{R_2}{R_C} \right) \quad (2)$$

If $R_1 = R_2$, to obtain the performance benefits of symmetry,

$$V_D = V_{IN} \left(1 + 2R_1/R_C \right) \quad (3)$$

The differential output of the op amps associated with R_1 and R_2 is brought "down to earth", i.e., to the output signal common level, by a unity-gain subtractor. If R_1 and R_2 are both $20\text{k}\Omega$, then gains of 1000, 100, and 10 can be obtained when R_C is equal to 40.04 ohms, 404.04 ohms, and 4444.4 ohms, respectively. For unity gain, R_C is simply open-circuited.

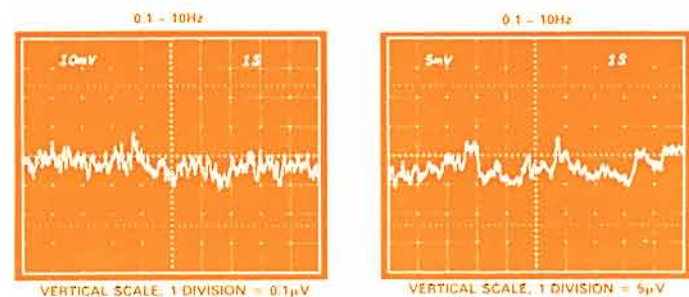
The differential input voltage, $V_{IN} = V^+ - V^-$, applied to the bases of input dual-transistors, Q_1 - Q_3 and Q_2 - Q_4 , is reproduced at the emitters, appearing across R_C , and producing a current, $I_{IN} = V_{IN}/R_C$. The collectors are connected to the negative input terminals of ion-implanted-FET-input op amps, A_1 and A_2 . The amplifiers must maintain the collectors at constant bias voltage, V_B ; they do so by keeping the currents in the collector circuits constant. Since the input transistors are operated from constant-current sources in the emitter and collector circuits (I_1, I_2, I_3, I_4), and the amplifiers have negligible bias-current, I_{IN} must flow from the output of A_1 , through R_1, R_C , and R_2 , and back through the output of A_2 , and the amplifiers must maintain their outputs at the appropriate voltage levels to cause this to happen. The resulting differential output voltage is expressed by equation (3). Since amplifier A_3 is connected as a unity-gain subtractor, the differential output voltage will be the same, referred to the Reference node.

This circuit approach has a number of advantages. First, since all the resistors on which the gain depends (for the fixed values of gain) are on the chip, and track with temperature, the initial values of gain can be laser-trimmed at the wafer stage, and the ratios change but little with temperature. Second, at the higher gains, reduced R_C causes the input transconductance—hence the overall input-stage open-loop gain—to increase, resulting in lower gain-related errors, wider bandwidth, and lower noise.

Since instrumentation amplifiers, as interface amplifiers for data-acquisition systems, are often subjected to voltage in excess of full-scale, overvoltage protection is essential. The input junctions of the AD524 are protected against the excessive currents that would result from overvoltage (power off or on) by reversed diodes and current-limiting bilateral FETs, employing an innovative device architecture. The additional noise that would be generated by fixed protective resistors is avoided, yet the current is limited to 3mA over a 36V range, the equivalent of a 12kΩ series resistance.

Bias-current compensation maintains the input current within $\pm 15\text{nA}$ at 25°C (AD524C), with a $\pm 0.1\text{nA}/^\circ\text{C}$ tempeco, without the increased flicker and wideband noise associated with superbeta transistors.

Low noise was, in fact, one of the key design objectives for the AD524. Low-frequency voltage noise waveforms are shown in Figure 4, using an overall gain of 10^3 (amplifier gain of 1000, followed by a gain of 100). It confirms that voltage noise in the important 0.1 to 10-Hz band ranges from $0.3\mu\text{V}$ peak-to-peak at gains above 100 (a) to $15\mu\text{V}$ peak-to-peak at unity gain (b).



a. Amplifier gain = 1000, amplified by 100 (100nV per division RTI).
b. Amplifier gain = 1, amplified by 1000 (5µV / div RTI).

Figure 4. Amplified output noise waveforms at low frequency (0.1 to 10Hz).

The dynamics of the AD524 are typified by its settling-time performance. For ± 10 -volt swings, typical settling times to 1%, 0.1%, and 0.01%, are 6, 10, and 13 microseconds, respectively.

THERMOCOUPLE COMPENSATION

The thermocouple consists of two wires, made of different materials, in contact at the point of measurement. It is cheap, small, works over a wide temperature range, and has been in widespread use for a long time; data for seven standard types is widely available. It does have a few problems: the output is small—in millivolts (typical tempcos are in the 4 to 80 $\mu V/^\circ C$ range); the output indicates a temperature *difference*, rather than the temperature at a given location; and the output of most types is noticeably non-linear. The AD594 deals with the first two of these problems—which relate to specific system conditions—and produces a standardized output. The nonlinearity problem can then be readily dealt with in a variety of ways, using either hardware or software, because of the predictability of thermocouple characteristics.

Why ice-point compensation? If the junctions at the ends of a paired length of thermocouple wire are at different temperatures, there will be a voltage difference, the magnitude depending on the composition of the thermocouple. If junction B (see Figure 5a) is at the absolute temperature being measured, T_B , and if the junctions A and A' to the (e.g., copper) output leads are at identical temperatures, T_A , then the voltage between A and A' will be a quasi-linear function of the temperature difference, $T_B - T_A$, passing through zero when $T_B = T_A$. If T_A is constant, or has a small range of variation, it can be used as the reference; the thermocouple tables list the output voltage when the reference temperature is at 273.2 K (0°C), the ice point of water, because it is a relatively easy temperature to obtain (at least in the laboratory!).

However, for practical temperature measurement in the real world, it is useful for T_A to be the freely variable ambient temperature at some point in the instrumentation circuitry. To a first approximation (since ambient temperature changes tend to be small compared to the range of temperatures for which thermocouples are generally used), the reference can be derived from the ambient temperature, T_A , and the known electrical output and sensitivity of the thermocouple in the vicinity of a representative value of T_A , +25°C (298K): $V_{25^\circ C}$, and $dV/dT_{25^\circ C}$. Thus,

$$V_{TO} = V_{TB} - V_{TA0} \quad (\text{desired output voltage})$$

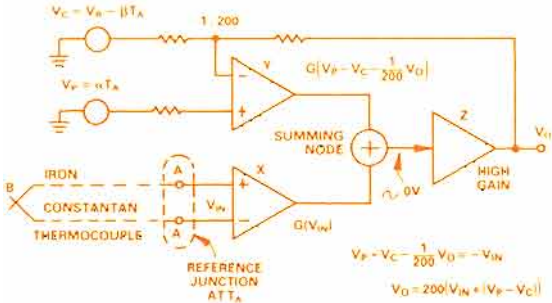
$$= V_{TB} - V_{TA} + V_{25^\circ C} + (T_A^\circ C - 25^\circ C)(dV/dT)_{25^\circ C} \quad (4)$$

where $V_{TB} - V_{TA}$ is the actual thermocouple output.

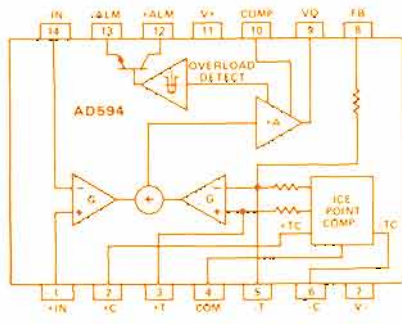
HOW THE AD594 WORKS

The AD594 is essentially a differential-input instrumentation amplifier with a gain of almost 200, nominal offset of 1,277mV at 25°C (about the same as the output of a Type J thermocouple at 25°C with the reference at 0°, i.e., V_{25°), and a laser-trimmed drift rate of 10mV/°C at the output, or about 52 $\mu V/^\circ C$, referred to the input (the same as $dV/dt_{25^\circ C}$ for a Type J thermocouple). If we connect a Type J thermocouple to the differential input of the AD594 and are careful to keep the temperature of the reference junction equal to the ambient temperature of the AD594, the output voltage of the AD594, referred to its input, will be a faithful representation of the first-order approximation of (4).

Figure 5(a) shows how the AD594 basically works, and (b) is a functional diagram of the AD594. The AD594 is a feedback amplifier having two identical input stages, X and Y, with outputs



a. Operating principle.



b. Functional diagram of the AD594.

Figure 5. Feedback thermocouple preamplifier.

combined in a summing node and the result amplified at high gain. To keep the error small under feedback, the output of Y must balance the output of X, which occurs when the input of Y equals (minus) the input to X. The resistance ratio of an on-chip feedback divider establishes the gain. The chip's temperature is measured by the difference between a P(TAT)* voltage, $V_P = \alpha T_A$, and a complementary voltage, $V_C = V_T - \beta T_A$. ($V_P - V_C$) is 0V at 0°C and increases at 52 $\mu V/^\circ C$; Since $(V_P - V_C) - V_C/200$ must be equal to $-V_{IN}$ (the thermocouple output),

$$V_O = 200(V_{IN} + (V_P - V_C))$$

$$= 200(V_{IN} + 0.000052 T_A (^\circ C)) \quad (5)$$

As supplied, the laser-trimmed AD594C is calibrated to within $\pm 1^\circ C$ max at +25°C to match Type J (iron-Constantan) thermocouples. It maintains a temperature stability to within 0.025°C/°C max and gain error less than 0.75%, over the ambient range 0°C to +50°C. The ideal linearized output, and the actual output bounded by these specifications are compared in Figure 6. If a

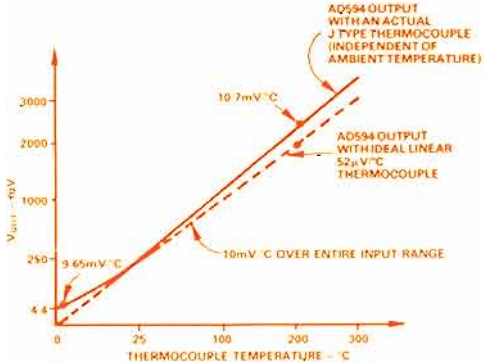


Figure 6. Comparison of *actual* thermocouple response, using a 25°C reference (solid), with ideal straight line (dashed). Exaggerated vertical scale.

linear temperature reading is desired, this predictable output can then be linearized by analog or digital methods. For some applications P(TAT): Proportional To Absolute Temperature (kelvin = °C + 273.2°)

tions, it may suffice to adjust the system gain and offset for a best fit over the temperature range of interest.

For excitation, a negative supply is necessary if the Celsius temperatures to be measured are negative, or if the output load is grounded or returned to positive voltage. The device will operate with a total supply current of $160\mu\text{A}$, for minimum self-heating (less than 0.07°C in free air), but it can deliver more than $\pm 5\text{mA}$ to a load. An overload detector senses open thermocouple leads, and can furnish a TTL alarm signal, or operate a relay or lamp. External resistors rescale the compensation for other types of thermocouple.

APPLICATIONS OF THE AD594 & AD524

Alarm and Comparator Besides simple thermocouple cold-junction compensation and amplification, the AD594's alarm circuit may be connected to operate a TTL gate, a LED, a CMOS switch, or a relay to indicate an open thermocouple. If the feedback loop is opened, and voltage representing a set-point temperature is connected to the feedback input (FB), the AD594 will act as a binary comparator, providing about zero volts at temperatures below the set-point and 3.5 volts at higher temperatures (see Figure 7).

Stand-alone temperature measurement The AD594 can be used to measure temperature directly. In one mode of application, it can provide directly a low-impedance drive signal for compensating one or more reference junctions that are at the same ambient temperature as the AD594 in multichannel instrumentation. Perhaps more interesting is its ability to function directly as a centigrade thermometer for measuring temperatures over the range, -55°C to $+125^\circ\text{C}$, with sensitivity of $10\text{mV}/^\circ\text{C}$.

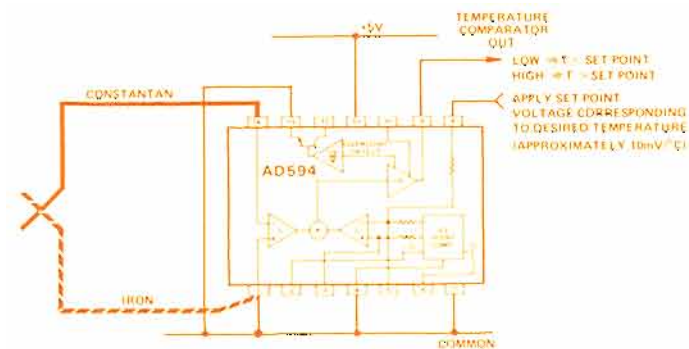


Figure 7. AD594 as a set-point comparator.

Adjusting Instrumentation-Amplifier Gain For fixed gains that differ from the AD524's repertoire of 1, 10, 100, and 1000, there are several ways to go. For intermediate gains in any decade, connect an appropriate value of external resistance (see Figure 8)

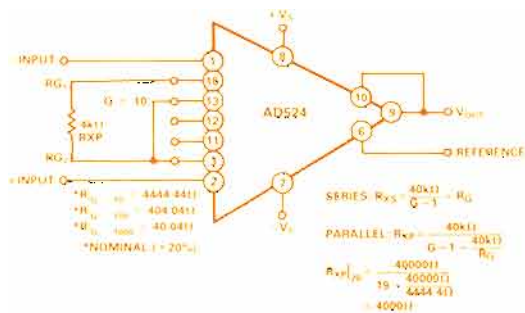


Figure 8. AD524 connected for gain of 20, using external resistance.

either in parallel with the greater R_{C1} , to increase the gain, or in series with the lesser R_{C1} , to decrease the gain. Use the technique that requires the smaller percentage change in gain. For example, *reduce* gain from 100 to 50, rather than increasing it from 10 to 50; the nominal resistance in series with 404.04 ohms is 412 ohms . *Increase* gain from 10 to 20, rather than reducing it from 100 to 20; the nominal resistance in parallel with 4444.4 ohms is 4000 ohms . Gains will be sensitive to the difference in tempo between the internal resistors and the added resistor(s).

Additional gain can also be had in the output stage, using either active or passive circuitry. The simplest approach is passive, using "H"-attenuator feedback to the Sense and Reference terminals of the AD524. The resistances should be small (without overloading the output) to minimize gain tempo and common-mode errors. Figure 9 shows a configuration for gain of 2000, using gain of

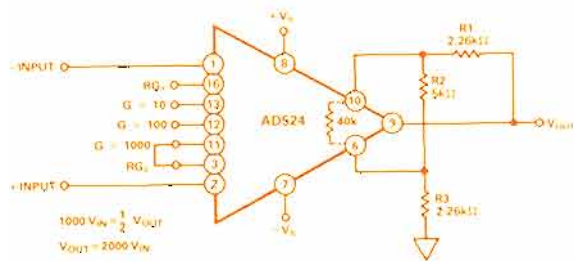


Figure 9. Connection for gain of 2000, using symmetrical passive feedback.

1000 and 2:1 feedback attenuation. If, instead, the gain is 100—with 20:1 feedback, obtained by changing R_2 to about 238 ohms —bandwidth and gain stability with temperature will be improved, but noise, drift, and offset will be somewhat worse.

Active circuitry may also be used, in order to make the feedback attenuation independent of internal resistance values, by driving the sense terminal at low impedance with an op-amp output. A resistive divider and follower-connected op amp is the simplest scheme. High-resolution digital variation of gain, using an AD7528 dual 8-bit multiplying DAC, is shown in Figure 10. Gain is inversely proportional to digital input. DAC A sets the gain coarsely to 8 bits, and DAC B provides interpolation. ▶

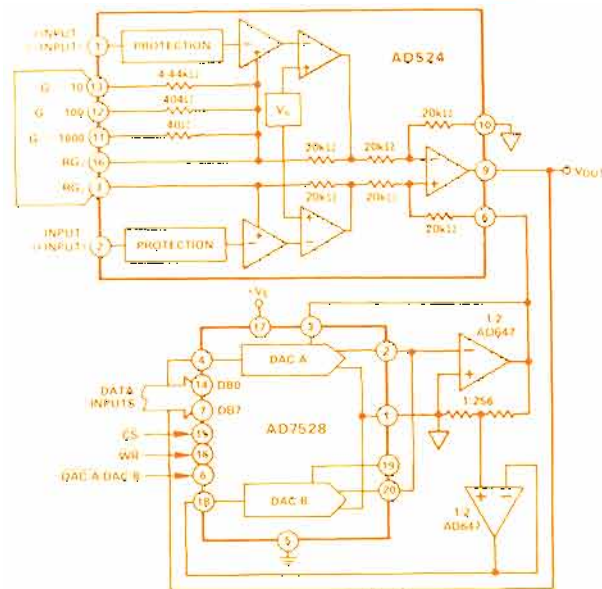


Figure 10. Connection for a wide range of digitally set gains greater than 10.

MULTI CHANNEL SIGNAL-CONDITIONING INPUT/OUTPUT SUBSYSTEM

3B Series: Direct Data-Acquisition from Sensors, Interchangeable Functions Includes 1500-V Isolation, High-Level Voltage & Current Outputs

by Dave Reynolds

Until the Analog Devices 3B* Series Signal-Conditioning Subsystem became available a short time ago, high-performance, fully satisfactory general-purpose multi-channel signal conditioning had not been available off-the-shelf at low cost for interfacing an arbitrary set of transducers in the field to data-acquisition or control systems at standard voltage or current levels.

At one end of the range, *components†* are available to the circuit-savvy system design engineer, who adds knowhow and a considerable amount of design effort. Alternatively, the system user can buy a complete custom package, engineered to specifications. In both cases, the cost of engineering and building a one-time design having adequate performance and reliability can be—and usually is—high.

What has long been needed is a low-cost modular system with a number of useful electrical and mechanical features. First of all, enough interchangeable functions should be available to handle low- or high-level signals, whether they be millivolts or volts; to handle a variety of transducers, whether they be thermocouples (of whatever type), RTDs, or strain gages; to handle voltage outputs at ± 10 -volt levels and/or current outputs at 4-to-20 or 0-to-20mA. Isolation, of up to 1500 volts, should be available—if needed—and inputs should be protected against ac line voltage and high-voltage transients. Output signal conditioning should also be available for driving loads, such as current-controlled valves.

The system should be self-powered, modular, rugged, and compact enough to handle a large number of channels in a small space. It should be capable of operating over a wide temperature range. And it should be possible to connect or reconfigure it with no tool more complex than a screwdriver.

It is this solution that the 3B series has been designed to embody, and it meets all of these criteria—and more.

WHAT THE 3B SUBSYSTEM IS

As Figure 1 shows, the 3B Series Subsystem consists of a 19"-relay-rack-compatible universal mounting backplane and a family of color-coded plugin input and output signal-conditioning modules. A rack-width backplane will accommodate 16 modules; 8- and 4-channel backplanes are also available for smaller or decentralized systems (Figure 2).

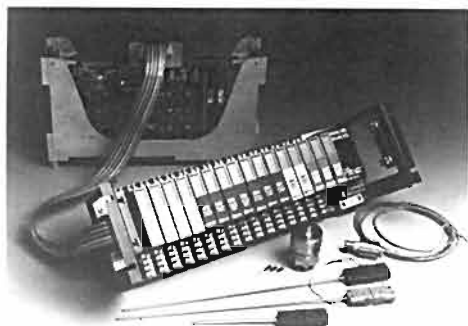


Figure 1. A rack-mounting 16-channel 3B subsystem.

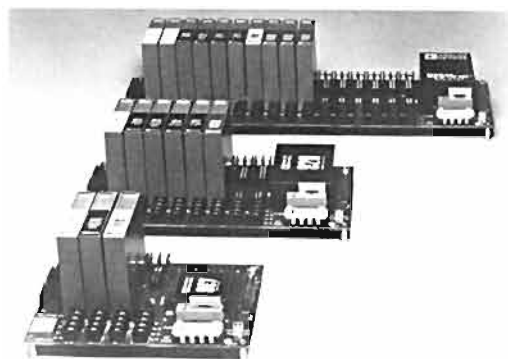


Figure 2. 4-, 8-, and 16-channel subsystems are available.

Backplanes will accept any member of the family of input and output modules interchangeably in any location. A backplane incorporates screw terminals, for connections to input transducers and current-loop signals, and a connector—which outputs high-level analog signals to or inputs them from the user's equipment (Figure 3). The modules are all identical in size (3.150" \times 0.775" \times 3.395") and have the same pin-connection pattern. All modules include a printed-circuit board incorporating electronic circuitry housed in a protective plastic shell. The shell contains provisions for securing each module to the backplane without tools.

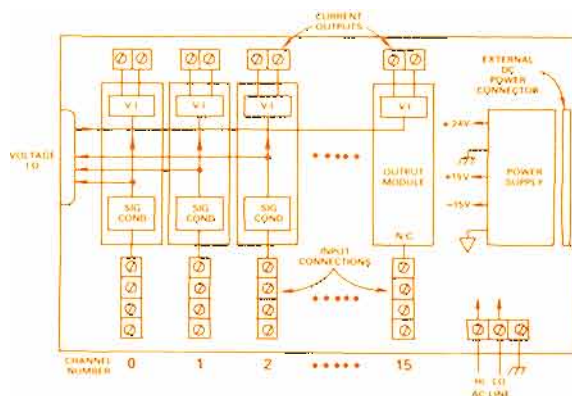


Figure 3. Functional block diagram of a 3B series subsystem.

The input and output modules are available in both isolated (± 1500 V peak) and non-isolated versions. Each type of *input* module has signal-conditioning circuitry that is optimized for specific kinds of sensors or analog signal levels and furnishes two forms of high-level analog output simultaneously: 0 to 10 V (or ± 10 V) and 4-to-20 mA (or 0 to 20 mA). *Output* modules accept high-level single-ended signals and provide an isolated—or non-isolated—4 to 20 mA (or 0 to 20 mA) process signal. The modules connect to the backplane via a universal pin configuration; they may be mixed or matched and types can be readily interchanged without disrupting field wiring.

*For technical data, use the reply card.

†Active components, from transistors and op amps to modular and I.C. instrumentation and isolation amplifiers (e.g., AD524, AD594, AD293) and signal conditioners (e.g., 2B series modules), plus additional circuit components and mechanical hardware.

Each backplane provides for $\pm 15\text{-V}$ dc subsystem power and $+ 24\text{-V}$ loop power, either from an on-board supply or externally. A dc-dc or an ac-dc power supply may be mounted directly on each backplane. Two LEDs provide visual indication when power is applied. A typical system might comprise, for example, a backplane, power supply, rack mount, 4 isolated thermocouple modules, 5 low-level millivolt modules, 5 current-input modules, and two isolated current-output modules. The average per-channel cost would be \$172, or \$2,745 total.

WHERE AND WHY THEY ARE USED

Signal conditioning plays an important role in interfacing industrial signal sources to a data-acquisition system. Signal conditioning generally requires input protection, isolation, filtering, amplification, and transducer excitation.

The 3B-Series Signal-Conditioning Subsystem is designed to provide an easy and convenient solution to multi-channel signal-conditioning problems in measurement and control applications. A typical use would be in mini- and microcomputer-based systems, where—for example—it might provide the protected sensor-based inputs to an RTI-1251 microcomputer analog I/O subsystem, for use with (say) a DEC LSI-11 bus. Figure 4 shows a rudimentary application in a control loop.

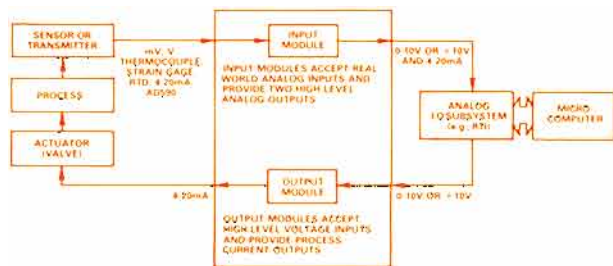


Figure 4. Rudimentary control loop, showing the functions of input and output modules. Intelligent control of the loop is provided by the microcomputer via the RTI-type analog I/O subsystem.

Other applications might include standard data-acquisition systems, programmable controllers, analog recorders, dedicated control systems, and any other applications where monitoring and control of temperature, pressure, flow, and other analog quantities are required.

Each input module has both a voltage and a current output. This means that the voltage output can be used to provide an input to a microprocessor based data-acquisition system, while the current output is being used for analog signal transmission through noisy environments, for operator interfacing, or for an analog backup system.

As noted earlier, the 3B subsystem was designed for high performance, high reliability, and ease of use. Some of the factors that contribute to making it a powerful interfacing tool for users include:

- Modular design, with standardized high-level outputs, precalibrated at the factory, and complete signal-conditioning functions, including such necessary features as cold-junction compensation for thermocouples, sensor excitation for RTDs and strain gages, and linearization of RTD output signals.
- Screw terminals, for direct interface to sensors and current-loop twisted pairs.

- Rugged packaging that is easy to install and maintain.
- Gold-plated pin and socket connections for reliability and corrosion resistance.
- 130V or 220V rms normal-mode protection at all field-wired terminations, for protection against line faults.
- $\pm 1500\text{-V}$ common-mode voltage ratings (continuous) for all isolated modules and $\pm 2500\text{-V}$ transient protection, meeting the requirements of IEEE Standard 472-1974: Surge Withstand Capability.
- $\pm 0.1\%$ calibration accuracy and chopper-based amplification, to ensure low drift ($\pm 1\mu\text{V}/^\circ\text{C}$) and excellent long-term stability.
- Availability of zero suppression and ranging, to permit mapping any portion of the input range onto the full output range.

FUNCTIONS AVAILABLE

Table 1 is an outline of the key properties of fourteen signal-conditioning modules now available for plugging into the 3B subsystem backplane. This list is by necessity not all-inclusive, but since the design is modular, the selection of plugins is open-ended; as requirements for the line grow, it is not likely that an interface suitable for any popular type of sensor will be omitted for very long.

Table 1. Available Input and Output Modules.

INPUT MODULES				
Input Type/Span	Voltage Output	Current Output	Nonisolated Modules	Isolated Modules
dc, $\pm 10\text{mV}$, $\pm 50\text{mV}$, $\pm 100\text{mV}$	$\pm 10\text{V}$	4-20mA 0-20mA	3B10	3B30
dc, $\pm 1\text{V}$, $\pm 5\text{V}$	$\pm 10\text{V}$	4-20mA 0-20mA	3B10	3B31
dc, $\pm 10\text{V}$	$\pm 10\text{V}$	4-20mA 0-20mA	3B11	3B31
dc, 4-20mA, 0-20mA	0-10V	4-20mA 0-20mA	3B12	3B32
Thermocouple Types J, K, T, E, R, S, B	0-10V	4-20mA 0-20mA		3B37
100 Ω Platinum RTD, 2, 3, 4 wire $\alpha = 0.00385$ (linearized)	0-10V	4-20mA 0-20mA	3B14	3B34
100 Ω Platinum RTD, Kelvin 4-wire $\alpha = 0.00385$ (linearized)	0-10V	4-20mA 0-20mA	3B15	
Strain Gage $\pm 30\text{mV}$, $\pm 100\text{mV}$	$\pm 10\text{V}$	4-20mA 0-20mA	3B16	
AD590 AC2626 Solid State Temperature Transducer	0-10V	4-20mA 0-20mA	3B13	
OUTPUT MODULES				
Input Type/Span	Current Output	Nonisolated Modules	Isolated Modules	
0-10V, $\pm 10\text{V}$	4-20mA 0-20mA	3B19	3B39	

A typical module, the 3B14. Consider, for example, the 3B14, which interfaces with RTDs (Resistance Temperature-Detectors). Figure 5, a block diagram of the module, shows its principal functions. Even though it is not an isolated module, 130-V normal-

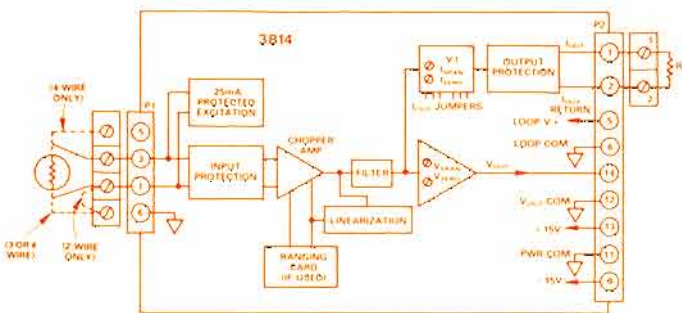


Figure 5. Model 3B14 RTD Signal Conditioner.

mode protection is inherent for all field-wired circuits to prevent damage if line voltage is accidentally connected across a pair of input or output screw-terminals. Filtering is built in, to reduce

pickup due to ac noise appearing on the signal leads.

The device provides constant-current excitation for 2-, 3-, and 4-wire RTDs, and the input signal is linearized internally. The modules are factory calibrated for standard ranges and, if necessary, can be fine-tuned in the field with zero and span adjustments for both the output voltage and the output current. The voltage and current outputs are independent and can be adjusted without interaction, which permits rapid and precise calibration.

Isolated Thermocouple Module. Figure 6 is a diagram of the 3B37 transformer-isolated thermocouple input module. The isolation, specified at ± 1500 V peak continuous, provides both protection and 160dB of common-mode rejection, and assures compliance with IEEE Standard 472-1974: SWC.

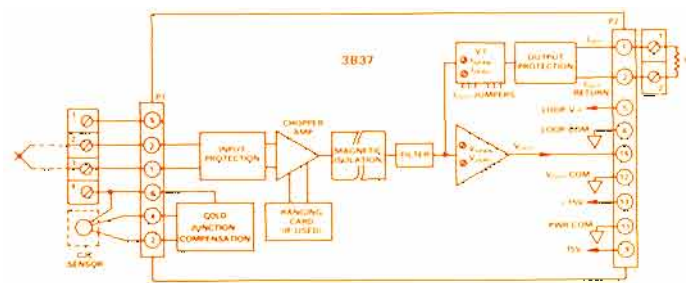


Figure 6. Model 3B37 Thermocouple Signal Conditioner.

As is the case with all the isolated modules, 220-V normal-mode input protection is provided to prevent damage if the line voltage is accidentally connected to the screw terminals. Cold-junction compensation (CJC) circuitry is included to provide correction for the ambient temperature and its variations. A CJC sensor is provided on each channel of the backplane.

Isolated Output Module. Figure 7 is a block diagram of the 3B39 isolated output module. It provides the same kind of protection as the isolated input modules. Its current output can be field calibrated with its on-board pair of adjustment potentiometers.

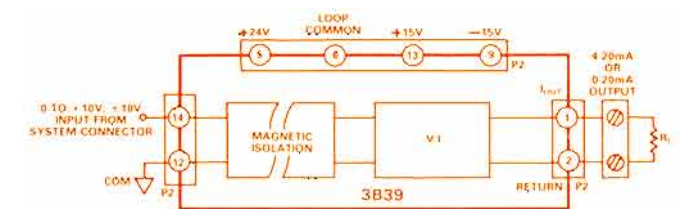


Figure 7. Model 3B39 Voltage-to-Current Converter.

Ranging card for zero suppression and span modification. The block labeled "Ranging Card (if used)" highlights an unusual extra feature of 3B modules. A unique plug-on ranging card (Model AC1310), that fits in a recess in the module, allows the user to provide zero suppression of up to and beyond 100% of the input range and provide a very wide range of span modification. This capability allows the user to map any portion of the input signal onto the full output swing. For example, if you want to measure temperature with a thermocouple in the span of 800° to 900°C, the ranging card can be used for greater system resolution in that 100° temperature span.

If a special signal range is desired for any input function, it can be provided by ordering the externally programmable version of the desired module (for example, 3B32-00) and the plug-on ranging

card (AC1310), which houses user-supplied resistors that determine the zero and span of the new range. The resistor values are established by equations defined for each module.

Table 2 lists the general specifications for input modules. Especially noteworthy are the wide operating temperature range for rated performance, -25°C to $+85^{\circ}\text{C}$, and—except for isolation and common-mode ratings—the minor difference in performance between isolated and non-isolated modules.

Table 2. General Specifications for Input Modules.

(typical @ $+25^{\circ}\text{C}$ and $\pm 15\text{V}$, $+24\text{V}$ dc power)		
Model	Isolated Modules	Nonisolated Modules
Inputs	Per Table 1	*
Outputs ¹	0 to $+10\text{V}$ or 5mA or $\pm 10\text{V}$ or $\pm 5\text{mA}$ $4\text{-}20\text{mA}$ or $0\text{-}20\text{mA}$ (i) $R_L = 0$ to 850Ω ²	*
Accuracy ³	$\pm 0.1\%$ span	*
Nonlinearity ⁴	$\pm 0.01\%$ span	*
Stability vs. Ambient Temperature		
Voltage Output		
Zero	$\pm 1\mu\text{V}/^{\circ}\text{C}$ (or $G - 100$ (RTI))	*
Span	$\pm 0.0025\%$ reading/ $^{\circ}\text{C}$	*
Current Output (w.r.t. Voltage Output)		
Zero	$\pm 0.0025\%$ span/ $^{\circ}\text{C}$	*
Span	$\pm 0.0025\%$ reading/ $^{\circ}\text{C}$	*
Common Mode Voltage, Input to Output	$\pm 1500\text{V}$ pk max	$\pm 6.5\text{V}$ ⁵
Common Mode Rejection (w/ 50Hz or 60Hz 1k Ω Source Unbalance)	160dB	90dB ⁶
Normal Mode Rejection (w/ 50Hz or 60Hz 60dB)	60dB	60dB
Differential Input Protection ⁷ rms, cont.	220V	130V
Voltage Output Protection	Continuous Short to Ground	*
Current Output Protection	130V rms, cont.	*
Zero and Span Adjustment Range ⁷	$\pm 5\%$ of span	*
Input Transient Protection	Meets IEEE-STD 472 (SWC)	N/A
Input Resistance	15M Ω	100M Ω
Input Bias Current	3nA	*
Input Noise	0.2 μV rms at 10Hz bandwidth	*
Bandwidth	31Hz (-3dB)	*
Power Supply ⁸	$\pm 15\text{V}$ dc, $+24\text{V}$ dc	*
Size	3.150" \times 0.775" \times 3.395"	*
Environmental		
Temperature Range, Rated Performance	-25°C to $+85^{\circ}\text{C}$	*
Storage Temperature Range	-55°C to $+85^{\circ}\text{C}$	*
Relative Humidity Conforms to MIL Spec 202	0 to 95% (w/ 60 $^{\circ}\text{C}$ noncondensing)	*
RFI Susceptibility	$\pm 0.5\%$ span error, 5W (w/ 400MHz or 3 ft.)	*

NOTES

- ¹Voltage output range is determined by the module input range while the current output range is user selectable.
- ²For a 0-20mA range, a typical minimum output current is 10 μA .
- ³Accuracy spec includes the combined effects of repeatability, hysteresis and linearity. Does not include sensor or signal source error.
- ⁴RTD Models 3B14, 3B15, and 3B34 have a linearization conformity error of $\pm 0.05\%$.
- ⁵Models 3B13, 3B14, 3B15, and 3B16 each have the common mode voltage determined by the internal excitation circuitry.
- ⁶Includes excitation circuitry for models 3B13, 3B14, 3B15, 3B16 and 3B34.
- ⁷A wide range of zero suppression and custom calibration may be accomplished with a custom ranging card, AC1310.
- ⁸ $+24\text{V}$ dc power is only needed for driving the current output at up to 9501. If only voltage output is used, or a current output load of 400 Ω or less is desired, $+15\text{V}$ is all that is required.
- *Specifications same as isolated modules.
- *Specifications subject to change without notice.

WHAT'S NEXT?

The 3B Series Subsystems and hardware accessories (mounting kits, cables, etc.) are the first in an extended family of plug-in signal-conditioning modules and backplanes. A useful new member of the family, to be introduced soon, is the 4B Series Alarm Limit Subsystem, which provides alarm and limit-monitoring capability for high-level or process current signals, such as those available at the outputs of 3B Series input modules.

This growing family, of which 3B is the parent, will provide all of the functions necessary for off-the-shelf multichannel industrial data acquisition, while allowing for the diversity of individual user requirements. The combination of a wide range of functions with high performance, 100% burn-in at the factory, and easy *in situ* expansion at low cost, makes this system worth investigating whenever you are considering the design of a new data-acquisition system, or even extending—or protecting—an on-line system. ▶

SENSOR-BASED INTELLIGENT DATA ACQUISITION FOR STD BUS

Signal Conditioning, A/D Conversion, Pre-processing with RTI-1270 Subsystem

From Sensor Screw-Terminals to the Data Bus via Memory Mapping—at Low Cost

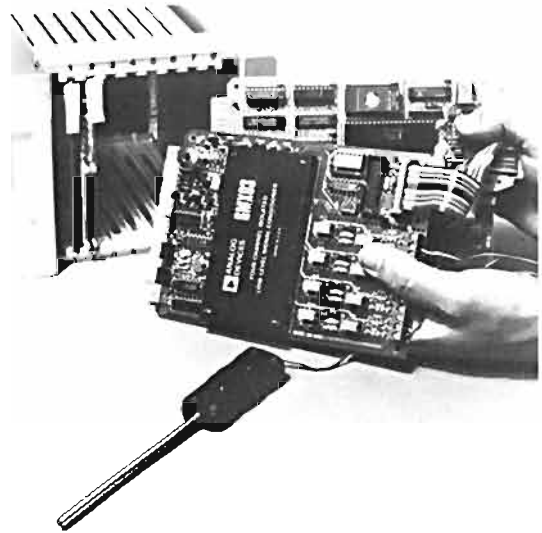
by Frank Melanson and John Mills

The STD bus is one of the most popular microcomputer buses; it is supported by more than 100 manufacturers, and the number of STD-bus applications is growing at a rate of about 35% per year. The reasons are the usual ones—low cost, compatibility with a wide range of processors and supporting hardware, flexible modular configuration, and a positive-feedback “bandwagon” effect: success breeds success.

For this reason, it makes sense for a manufacturer of analog input-output data-acquisition subsystems to offer products that simplify the interfacing of analog signals to microcomputers by users of the STD bus. This philosophy was explained in our introduction of the STD-compatible RTI-1225/26 and RTI-1260/62 10- and 12-bit I/O-card families* in *Analog Dialogue* 16-1 (page 10).

The catch with most such cards is that the system integrator must still deal with various levels of analog front-end circuitry and related software support. Such problems as isolation from high common-mode voltages, preamplification of low-level signals to match a given transducer, cold-junction compensation of thermocouples, linearizing of nonlinear signals from transducers, and conversion of the digital representation of analog data to engineering units that represent the measured variable, all inconvenient at best—and exceedingly difficult at worst—must be dealt with in the analog front-end circuitry and in software.

It is precisely this dilemma that is resolved by the RTI-1270* data-acquisition subsystem. It is the first intelligent STD-bus-compatible subsystem to provide all the necessary signal conditioning, as described above, for interfacing to a wide range of commonly used sensors and input conditions. The former include thermocouples, RTDs, strain gages, voltage and current signals in the millivolt, volt, and milliampere ranges; the latter include electrical noise, ground loops, and common-mode voltages.



WHAT IS THE RTI-1270 SUBSYSTEM?

An RTI-1270 subsystem (Figure 1) consists of an RTI-1270 13-bit converter/processor card and from one to four RTI-1271 four-channel signal-conditioning/multiplexer cards. All cards are electrically and mechanically compatible with the STD bus.

The RTI-1271 permits direct screw-terminal connection of analog inputs; it provides 130-V rms input protection, filtering, cold-junction compensation, sensor excitation, and multiplexing. Two types of signal-conditioning cards—isolated (RTI-1271-B) and non-isolated (RTI-1271-A)—are available. In addition to isolation, the RTI-1271B features 130-V rms normal-mode input protection and 160-dB common-mode rejection. A DIP switch on the card permits the user to configure the card for any one of the input ranges or types listed in Table 1.

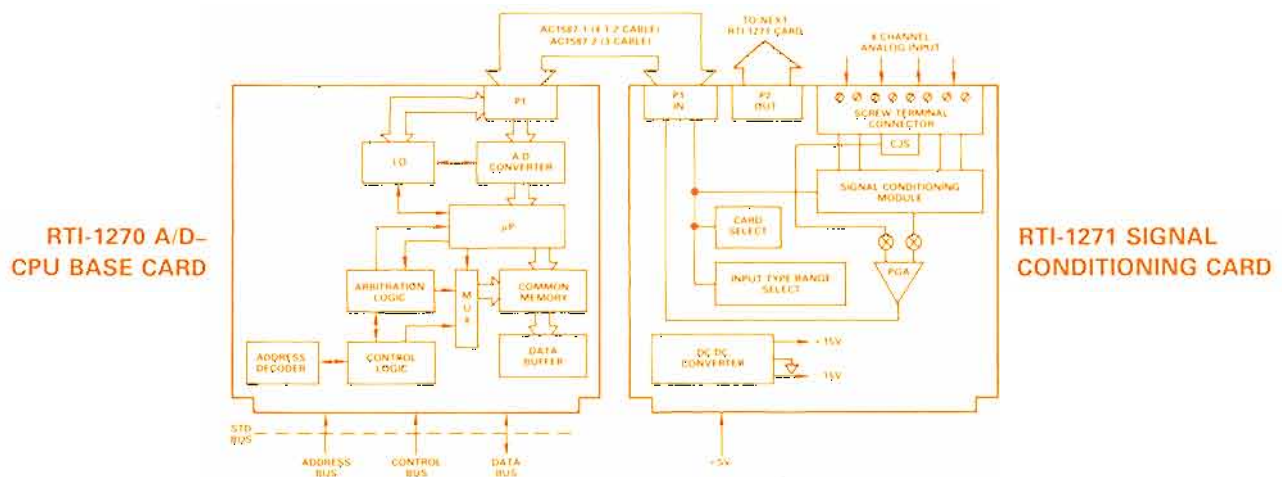


Figure 1. In RTI-1270 Analog Input Subsystems, analog input data is automatically scaled, linearized, and converted to engineering units. This allows the user to simply connect sensors via industrial-type screw terminals, plug the cards into the STD bus, and go.

*Use the reply card for technical data.

Up to four RTI-1271s can be plugged into an STD backplane and interconnected with an RTI-1270, in daisy-chain fashion, with a factory-supplied ribbon cable. The cards can be mixed or matched to provide the required complement of isolated and non-isolated channels, in increments of 4 channels.

The RTI-1270 a/d converter-central processor card contains a 13-bit integrating-type a/d converter, a microprocessor, and bus-interface logic. This local processor controls the data-acquisition process, by scanning and converting the analog inputs at a preset rate of either 15 or 30 conversions per second.

Once input data has been digitized, it is linearized, converted to engineering units in binary, BCD, and ASCII formats, and stored in memory (1K). This data, which is continuously updated, can be read by the host CPU, using simple Memory Read instructions. The use of the dedicated processor in this unit significantly reduces software overhead and the need for software development.

Table 1. Signal Conditioning Cards: Sensor types and input span selection available.

Input Type/Span	Signal Conditioning Card	
	RTI-1271-A (Nonisolated)	RTI-1271-B (Isolated)
dc, $\pm 25\text{mV}$, $\pm 50\text{mV}$, $\pm 100\text{mV}$	✓	✓
dc, $\pm 1\text{V}$, $\pm 5\text{V}$, $\pm 10\text{V}^*$	✓	✓
dc 0-1mA, 0-20mA, 4-20mA**	✓	✓
Type J, K, S, T Thermocouple	✓	✓
100 Ω Platinum RTD	✓	✓
Strain Gage $\pm 30\text{mV}$, $\pm 100\text{mV}$ Inputs	✓	✓
AD590, AC2626 Temperature Sensor	✓	✓
*Requires resistor divider kit.		
**Requires shunt resistor kit.		

The RTI-1270 subsystem requires only a +5-V power supply; it will operate with any STD bus system employing a Z80 or 8085 CPU. Prices in small quantity are: RTI-1270 card, \$395; RTI-1271A non-isolated/RTI-1271-B isolated cards, \$395/\$485.

HOW IT WORKS


The on-board microprocessor cycles through the active analog input channels and initiates conversions at either 15 or 30 channels per second. The converted data is read, converted to engineering units, cold-junction compensated and/or linearized, depending on the setting of the DIP switches, formatted, stored in a common RAM, and updated continuously.

The RTI-1270 subsystem uses a memory-mapped I/O interface scheme to interface to the microcomputer. Since the subsystem is treated as a block of memory, simple memory-reference instructions can be used to access the RAM and read out the most-recent data corresponding to any of the input channels. Conflicts between the RTI-1270 (Write) and the STD bus (Read) in accessing the common memory are arbitrated by making use of the HOLD state of the RTI-1270's μP and the WAIT state of the STD-bus CPU.

APPLICATIONS

RTI-1270 subsystems can be easily integrated into a broad range of industrial and laboratory measurement applications. Sensor-based applications include engine test stands, food-processing equipment, oven controllers, production machinery, and process monitoring.

Figure 2 shows how a group of four thermocouples are instrumented with an RTI-1271-A. The devices are directly connected to the screw terminals; an on-board cold-junction sensor monitors the temperature in the vicinity of the screw terminals, providing a reference temperature input for cold-junction compensation,

which is computed digitally. The thermocouple output voltage is linearized, and Fahrenheit or Celsius thermocouple data is stored in memory in binary, BCD, or ASCII format. For types J, K, S, and T thermocouples—selected by a DIP switch—temperature ranges, typical resolution and accuracy are shown in Table 2. 

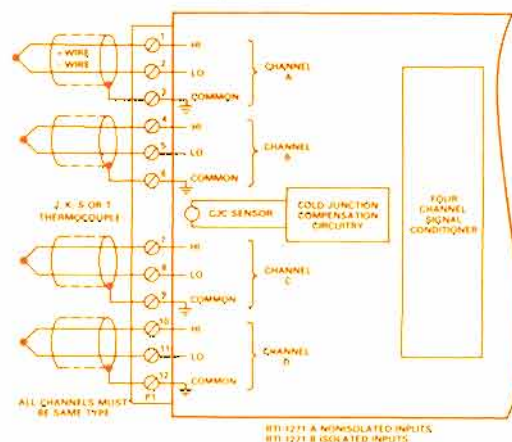
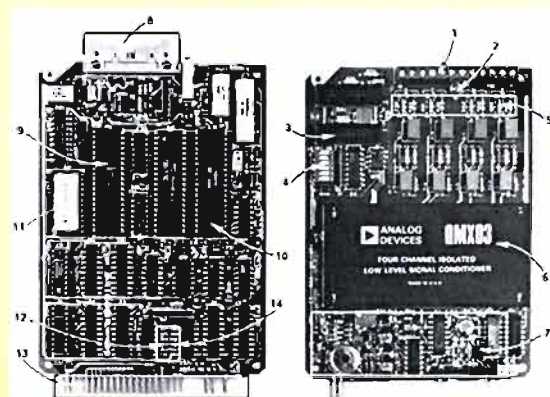


Figure 2. Connecting thermocouples to RTI-1271 (A or B).

Table 2. Thermocouple resolution and accuracy (Celsius setting).

Type	Output Range(°C)	Resolution(°C)	Error(°C)
J	-100.0 to +760.0	0.2	± 1.0
K	-100.0 to +1232.0	0.3	± 1.1
S	+300.0 to +1768.0	0.6	± 3.2
T	-200.0 to +400.0	0.1	± 1.0

RTI-1270 and RTI-1271 FEATURES



- Industrial screw terminals provide direct field wire connection.
- Reference junction sensor provides cold-junction compensation for thermocouples.
- Channel expansion allows up to four RTI-1271s to be connected to the RTI-1270 thus providing a total of sixteen input channels.
- Input type switch programs each RTI-1271 independently for any one of the input ranges listed in Table 1.
- Provisions are made for user-installed current sensing and voltage divider resistors.
- Two types of signal conditioning modules handle a full range of sensor and other analog signals.
- On-board dc/dc converter allows direct operation from the STD bus +5V supply.
- Ribbon cable interconnect cards in a daisy chain fashion.
- μP unburdens STD bus CPU by performing data acquisition control, sensor linearization and conversion to engineering units.
- 12-bit integrating analog-to-digital converter provides high accuracy conversion.
- Firmware dedicated to continuously scanning input channels stores the resultant data in the common memory.
- 1K byte of common memory can be accessed by the STD bus CPU host using memory reference instructions.
- STD bus compatible interface allows operation with any 8085 or Z80 CPU.
- Jumpers allow the 1K of common memory to be mapped on any one of 64 1K blocks.

POWERFUL MEASUREMENT-AND-CONTROL SYSTEM...AND MUCH MORE

MACSYM 350: Based on a 16-Bit Computer, Can Address up to 1 Megabyte of RAM Floppies or Winchester, MP/M-86, Multitasking BASIC, B&W or Color Graphics

by Richard Quinn

MACSYM 350*, the third generation of MACSYM Measurement-And-Control SYstems, consists of the stand-alone MACSYM 150 and its optional companion, the MACSYM 200 intelligent front end. MACSYM 350 has many of the features that have fostered MACSYM's widespread acceptance in the industry, including easy-to-use real-time multitasking MACBASIC and a wide choice of interchangeable specialized analog and digital input/output and communication interface cards.

The MACSYM 150 work station (Figure 1) is a completely self-contained 16-bit minicomputer with integral floppy and/or exter-

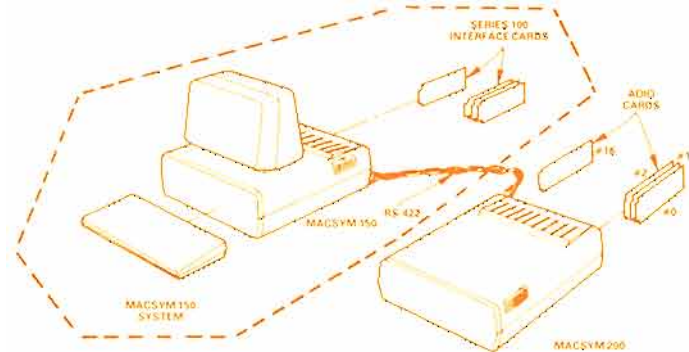


Figure 1. System view of MACSYM 150 and its relationship to MACSYM 200.

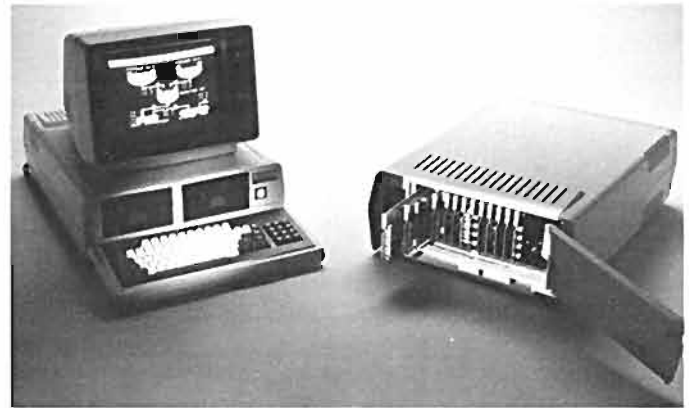
nal Winchester disk storage and internal RAM with up to one million bytes, plus keyboard and display. Specialized I/O cards (Series 100) plug into a 6-slot internal backplane; they provide analog, digital, & communications I/O, and memory expansion. With its MACBASIC 3 software, high-resolution monochrome or color graphics capability, and 16-bit 8086 CPU plus 8087 floating-point co-processor for fast number-crunching, the MACSYM 150 provides the speed, processing power, memory, I/O capability, flexibility, and ease of use required for handling a wide variety of real-world data acquisition, display, storage, transmission, and control functions.

EXPANDABLE

More than that, it is expandable, in both hardware and software, to handle systems of larger scope and range of functions. As Figure 1 shows, it can be expanded into a MACSYM 350 system by the addition of the MACSYM 200 front end, which provides for up to 16 additional slots for data acquisition and control. More than 30 types of analog-digital input/output (ADIO) cards can plug directly (and interchangeably) into these I/O slots. A 16-bit CPU provides intelligence, controls the ADIO backplane, and handles local data-processing needs. Resolution of a/d conversion is software-selectable: 12 or 16 bits. Communication between the MACSYM 150 and the MACSYM 200, completely transparent to the user, is provided via an RS-422 interface.

A user's system can be further expanded to include up to 31 MACSYM 200s (and/or other peripherals, such as CRTs, printers,

*For technical data, use the reply card.



etc.) by means of MACNET—a coaxial-cable based 1-megabit-per-second local-area network, resulting in a powerful distributed MACSYM 150 system capable of addressing an expandable range of complex applications in measurement and control.

In software, the MP/M-86 (superset of CP/M-86) operating system allows the user to draw on the existing wide range of CP/M-86 compatible software, such as FORTRAN, Pascal 8086 Assembler, word-processing, database management, and financial analysis. This suggests the possibility of using the same system to perform an experiment and then to write the report, including the graphics.

MACSYM 150 WORKSTATION

Figure 2 is a functional block diagram of the MACSYM 150. The blocks outlined by solid lines are standard features; those outlined with dashed lines are available options. The standard model in-

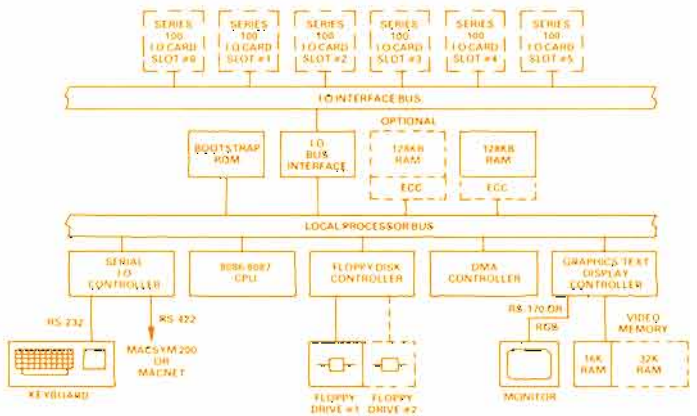


Figure 2. Functional block diagram of the MACSYM 150.

cludes the 16-bit microcomputer, with its dual bus system, a 5 1/4" floppy-disk drive with 320K bytes of storage, graphics with 640 × 240 pixels of resolution, 128K bytes of RAM, a 12-inch green phosphor monitor, an 82-key detachable keyboard, and MACBASIC 3 software. Price of the standard model is \$6,540.

The MACSYM 150 can be expanded to include a second 320 Kbyte floppy disk, color graphics (640 × 240 × 8 colors), Winchester hard disk (10 Mbytes), Hamming-code error correction, RAM/PROM memory expansion to 1 Mbyte, communications

cards (IEEE-488, RS-232, RS-422, RS-423, 20-mA current loop), digital and 12-bit analog I/O cards, 12-inch color (RGB) monitor, MACNET interface, and the gamut of CP/M-86-compatible software.

The photograph shows the outside of the MACSYM 150's housing, a custom minimum-parts-count, high-strength, rim-molded polyurethane enclosure, which supports the integrated-circuit board, power supply, and floppy-disk drives. The unit is easy to service, because all circuit boards are accessible from the front. An optional 19" rack-mount kit is also available.

The Series 100 interface cards plug directly into the 6-slot backplane of the MACSYM 150 main processor board, providing analog & digital I/O, serial communications, IEEE-488 bus control, memory expansion to 1 megabyte, and Winchester disk interface.

Typical cards include a two-channel Serial-Interface Card (DSI-100) to communicate with printers, plotters, terminals, modems, μ MACs, and other peripherals; an Analog Input Card (AIM100) for 12-bit, 16-32 channel data acquisition; an Analog Output Card (AOT100) for 4 or 8 channels of 12-bit analog output; and a Digital I/O Card (DIO100) for 16 TTL-compatible channels of switch-selectable input or output (open collector) that can interface directly with the 2500-volt-ac isolated MACSYM SSR01 solid-state relay panel.

MACSYM 200 INTELLIGENT FRONT END

The MACSYM 200 is an intelligent measurement-and-control front end that can provide MACSYM 150 and 350 systems with slots for up to 16 similar or different analog-digital input/output functions, using proven MACSYM ADIO cards. As Figure 3 shows, the on-board CPU is a 16-bit 8088; other features include a dual-mode 12/16-bit data-acquisition system, permitting a speed/resolution tradeoff, automatic self-calibration, programmable analog gain, and up to 256 Kbytes of RAM. Its 16-slot ADIO bus supports the entire family of MACSYM ADIO cards. An optional 19" rack-mount kit is available. When the standard MACSYM 150 and a standard MACSYM 200 are combined to form a MACSYM 350, its price is \$9,990.

The digital system electronic circuitry is located on a single circuit board, physically separated from the ADIO bus. This approach, used in the MACSYM 2 family, isolates the ADIO bus from the digital hardware, minimizing interference with low-level analog signals.

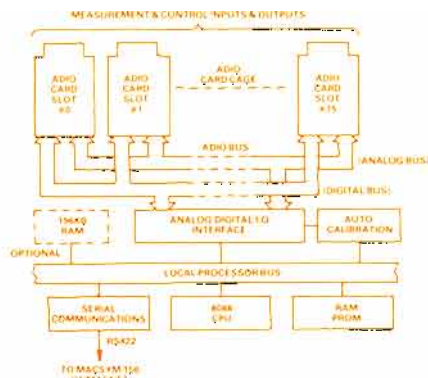


Figure 3. Functional block diagram of the MACSYM 200.

The a/d converter, multiplexer, and a programmable-gain amplifier for scaling analog signals are resources shared by all ADIO cards, minimizing the cost per analog input card. Automatic calibration, at a software-selectable rate, calibrates out input and

output offset errors and gain errors, for excellent overall long-term stability and performance in changing environmental conditions.

The MACSYM 200 communicates with the MACSYM 150 via a synchronous RS-422 communication port, running at 307.2 kilobaud and maintaining this data rate at locations up to 1000 feet away from the MACSYM 150.

ADIO CARDS

The processing capability of MACSYM computer systems is interfaced to real-world signals through our extensive library of ADIO cards. They provide all of the signal conditioning necessary for direct connection to thermocouples, strain gages, flow meters, relays, tachometers, valves, alarms, controllers, and other sources and destinations of analog and digital voltage and current signals. You merely select the card you need, connect your sensors and actuators to them, using convenient screw terminals, and the system is ready to go. Changing applications is almost as easy as changing cards. Table 1 lists a set of cards currently available*.

Table 1. Available ADIO Card Functions.

MEASUREMENT INPUT	
AIM02	Isolated Analog Input
AIM03	High Speed Analog Input
AIM05	Strain Gage Input
RTO01	RTD Input
TTC01	High Speed Thermocouple Input
TTC02	Isolated Thermocouple Input
TTC03	High Isolation Thermocouple
TTC04	High Speed Thermocouple Input
TTC05	AD590 Temperature Transducer Input
ANALOG INPUT	
AOC01	12-Bit Analog Voltage Output
AOC02	12-Bit Analog Current Output
AOC04	10-Bit Unipolar Analog Voltage Output
AOC05	10-Bit Bipolar Analog Voltage Output
AOC06	10-Bit Analog Current Output
DISCRETE INPUT/OUTPUT	
DIN01	Isolated ac Input
DIN02	Isolated dc Input
DIO01	Isolated Solid State Input/Output
DOT01	Isolated Digital Output
DOT03	Form "A" Relay Output
DOT04	Form "C" Relay Output
PULSE I/O AND CLOCK FUNCTIONS	
CLK03	Battery Backed Calendar/Clock
EVC01	Event Counter
FIN01	Frequency Input, 8-Channel
FIN02	Frequency Input, 16-Channel
INT01	Isolated Priority Interrupt
INT02	Priority Interrupt
POC01	Pulse Output
WDT01	Watch Dog Timer
SPECIAL FUNCTIONS	
BNK01	Blank ADIO Card Breadboard
SSP01	Speech Synthesizer
STR01	Screw Termination Board

MACBASIC 3

MACBASIC 3 is an expanded version of BASIC, optimized for real-time measurement and control. Special variable names are provided for the most common m & c functions, while graphics commands let the user display and update measured variables in real time. *Multitasking* lets you write sections of your total process as independent tasks and have them run with independent schedules and rates. MACBASIC 3 automatically allocates CPU time and system resources, so that all tasks appear to run simultaneously.

Because MACBASIC 3's line-by-line compiler translates program statements directly into machine code as they are entered, it combines the ease-of-use of interpreted languages with the execution speed of compiled languages. MACBASIC 3 uses the MP/M-86 operating system, a real-time multitasking superset of the popular CP/M-86 operating system. ▶

*Detailed specifications for ADIO cards can be found in the new 62-page catalog, *Analog/Digital Input/Output for MACSYM Systems*.

FASTER TESTING WITH NEW μ C-BASED BENCHTOP TESTER

LTS-2015 Reduces Test Time by 10 to 50%, Tests Op Amps, DACs, ADCs, Etc.

LTS Accuracy Verifiable Automatically via LTS-2410 Calibration Board

The LTS-2015* Linear Test System is a minicomputer-based automatic benchtop system for testing linear and digital ICs. Retaining all the features that insured the widespread acceptance of its progenitors, the LTS-2000* and BASIC-programmable LTS-2010*, it adds high-speed floating-point operation. The LTS-2015 will automatically test op amps, d/a and a/d converters, and other devices, with resolutions and accuracies to 16 bits, but with higher throughput, comparable to that of much larger mainframe ATE systems. It also takes full advantage of the File Manager software†, provides twice as much mass storage as the earlier LTS systems, and has simpler operator controls.

The LTS-2015 was designed to provide higher throughput for manufacturers and large-volume users of devices, and improved mathematical power for users who require on-line analytical test capabilities. Typical application areas include incoming inspection, semiconductor production, and component evaluation.

The key to its improved performance is the use of a dual processor architecture. An Intel 8086-8087 chip set performs floating-point mathematical manipulations, freeing the Texas Instruments 9900 16-bit main processor from the necessity to perform time-consuming number crunching; this facilitates test operations and the many required housekeeping, control, and communication functions performed by the main processor.

The dual-disk drive structure, besides doubling mass storage capability and allowing the user to take full advantage of the File Manager operation, also eliminates the need to shuffle disks into and out of a single drive. In addition, improved human engineering details make operation easier, surer, and less susceptible to tampering.

Throughput improvement depends on the test program and the device type. However, an example of what can be accomplished can be seen in the testing of 741-type op amps: the entire dc parametric test sequence is performed in 480 milliseconds, as compared to 880 milliseconds with the LTS-2000 and LTS-2010. Like the others, the LTS-2015 will also perform dynamic op-amp tests, such as gain-bandwidth products up to 100MHz, slewing rates up to 1000V/ μ s, and input bias currents from 50fA. When testing 12-bit ADCs, using the intelligent ADC family board‡, an all-codes test can be performed in 800 milliseconds, compared to *seconds* for other test systems.

In other respects, the LTS-2015 is fully compatible with other members of the LTS tester family, including the whole range of family test boards, socket assemblies, and the library of software written for the LTS-2000 and LTS-2010. All systems offer such features as data logging of individual test results, statistical analysis of data in cumulative, histogram, and/or graphical form for trend study, and yield analysis of device lots. And all systems interface conveniently to automatic probing and handling equipment

* Use the reply card for technical data.
 † See *Analog Dialogue* 16-2, page 19.
 ‡ See *Analog Dialogue* 16-1, page 12.



(while maintaining unimpaired accuracy) via their handler interface, as well as to other peripherals via RS-232 and IEEE-488 buses. The LTS-2015 System Console is priced at \$35,000.

AUTOMATIC CALIBRATION WITH THE LTS-2410

Besides self-calibration, performed automatically at hourly intervals—and more frequently upon demand—the LTS-2015 (and other LTS systems) can be traceably—and automatically—calibrated to established precision standards. The key is the new LTS-2410 Calibration and Functional-Test Family Board.

It is plugged into the Family-Board slot of LTS testers (Figure 1), like any other family board. When connected to a user's Hewlett Packard 3455A or 3456A digital voltmeter, the LTS-2410 automatically performs all the required handshaking with the voltmeter (via the IEEE-488 bus and the signal input) to exercise all the critical functions of the LTS console (including the handler port). It also provides both verification of performance and guidance for the user to precisely adjust the system's 10-V reference and source-board calibration points.

The user's Hewlett-Packard voltmeter, controlled via the IEEE-488 port, functions as both an autonomous measurement system and a reference against which accuracy of the LTS Console can be compared. ▶

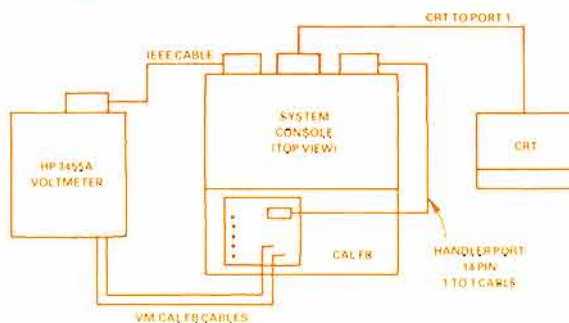


Figure 1. LTS automatically calibrates itself with an HP3455A voltmeter.

INDUSTRY'S FIRST QUAD 12-BIT DAC IN A 28-PIN DIP

Space-Saving AD390 Contains Four 12-Bit Voltage-Output DACs on a Bus Complete Including Stable Reference; Double-Buffered for μ P Compatibility

The AD390[®], the industry's first quad DAC, is a 28-pin hermetically sealed ceramic DIP that contains four pre-trimmed double-buffered 12-bit digital-to-analog converters, served by a common 12-bit-wide input data bus. Included in the package (see photograph and Figure 1) are four double-buffered 12-bit DACs, four fast-settling op amps, a reference-buffer follower, and a precision 10-volt reference, which may serve as the common reference. An external reference—or an attenuated version of the on-board reference—may be used instead for system applications or where other than $\pm 10V$ full-scale output is desired.

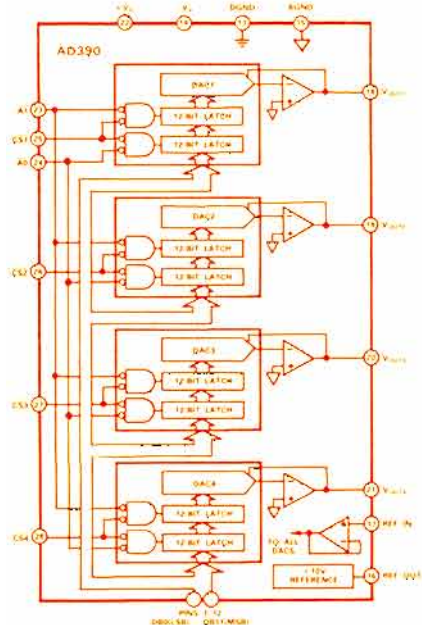


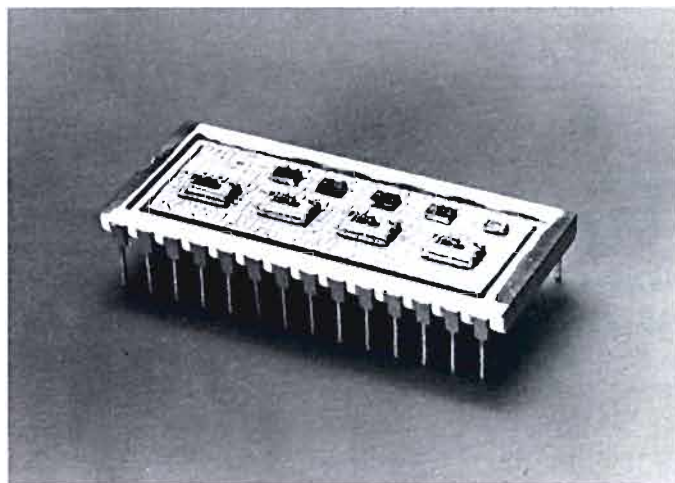
Figure 1. Functional diagram of the AD390.

The AD390 contains a 12-bit internal data bus, a 4-line Chip-Select bus for decoded addresses, and Load/Enable control buses for transferring data for local storage and/or conversion. The bus architecture combines independent DAC addressability with economy of pinout—for compactness and reliability—and compatibility with microprocessors, for simplified system integration.

Aimed at automatic test equipment and general microprocessor-based data-distribution applications, the AD390 may also be used in process control, multi-axis numerical control, and positioning of flight-control surfaces. Where printed-circuit board space is at a premium, the Quad-DAC is an ideal solution. The AD390 offers high functional density, guaranteed precision over temperature, and elimination of external support components and trims.

Although it is available in several selected accuracy and temperature grades, *all versions of the AD390 are guaranteed monotonic over temperature.* Maximum settling time for all grades is $8\mu s$ to $\pm 0.01\%$ for full-scale output changes; and the internal reference is trimmed to within $\pm 0.03\%$. J and K grades operate from $0^\circ C$ to $+70^\circ C$, and S and T grades operate from $-55^\circ C$ to $+125^\circ C$.

[®]For technical data, use the reply card.



S and T grades are also available with MIL-STD-883B processing. Performance is summarized in Table 1.

Table 1. AD390 DAC performance.

SPECIFICATION	AD390JD/SD	AD390KD/TD
Gain Error, max (% of full-scale range)	± 0.1	± 0.05
Offset, max (% of full-scale range)	± 0.05	± 0.025
Linearity Error, max (LSBs)	$\pm 1/4$	$\pm 1/2$
Differential Linearity Error, max (LSBs)	$\pm 1/4$	$\pm 1/2$
Temperature Drift		
Gain, Internal Reference (ppm/ $^\circ C$)	± 40	± 20
Gain, External Reference (ppm/ $^\circ C$)	± 10	± 5
Zero (ppm/ $^\circ C$)	± 10	± 5
Linearity Error, T_{min} to T_{max} (LSB)	$\pm 1/4$	$\pm 1/2$
Differential Linearity, T_{min} to T_{max}	Monotonicity Guaranteed	
Price (100s)	\$115/\$296	\$136/\$347

Figure 2 shows the simplest example of how the AD390 is typically interfaced to a microprocessor bus, using a 74LS139 2-bit decoder for the last two address bits to obtain the four chip-select inputs. In this case, the second-rank registers are made transparent by hard-wiring $\overline{A1}$ low, allowing only one DAC at a time to be updated. The data sheet* shows other schemes that take greater advantage of the AD390's flexibility.

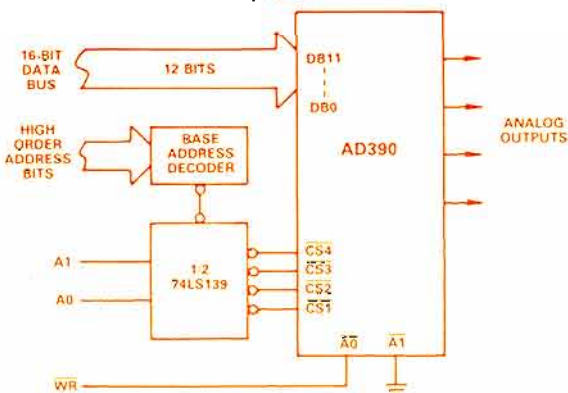


Figure 2. Interfacing the AD390 to a 16-bit bus.

UNDERSTANDING INTERFERENCE-TYPE NOISE

How to Deal with Noise without Black Magic

There Are Rational Explanations for—and Solutions to—Noise Problems

by Alan Rich

If the circuit doesn't work, add a decoupling capacitor anywhere—a 0.01 μF ceramic disc, of course; they'll fix anything! Or when your circuit is broadcasting its noise, a shield will cure it; just wrap a piece of metal around the circuit, connect that shield to "ground," and watch the noise disappear!

Unfortunately, Nature is not that kind to us in real life. That 0.01 μF disc you added only increased the noise; and the shield you added was totally ineffective—or, worse yet, the noise reappeared in a remote part of the circuit.

This article is the first of a two-part series to help you understand and deal effectively with interference noise in electronic systems. We will consider here the mechanism that causes noise to be picked up, since the first step in solving any noise problem is to identify the source of the noise and the coupling mechanism; only then can an effective solution be implemented.

The second article will suggest specific techniques and guidelines for effective shielding against electrostatic and magnetically coupled noise.*

WHAT KIND OF NOISE ARE WE TALKING ABOUT?

Any electronic system contains many sources of noise. Three basic forms in which it appears are: *transmitted noise*, received with the original signal and indistinguishable from it, *intrinsic noise*, (such as thermally generated Johnson noise, shot noise, and popcorn noise) originating within the devices that constitute a circuit, and *interference noise*, picked up from outside the circuit. This last may either be due to natural disturbances (e.g., lightning) or be coupled in from other electrical apparatus in the system or its vicinity, for example computers, switching power supplies, SCR controlled heaters, radio transmitters, switch contacts, etc.

This article will consider only the last category, man-made noise, the most pervasive form of system noise in data-acquisition or test systems. Although it is most annoying in low-level circuits, no part of the system is immune to it. But it is the only form of noise that can be influenced by choices of wiring and shielding.

ASSUMPTIONS AND ANALYTICAL TOOLS

Although Maxwell's equations—with all the mathematical agony that they imply—are necessary for a complete and accurate description of how electrical systems behave, conventional circuit analysis is a useful tool in most cases. The assumptions that permit circuit analysis to be valid in solving these problems are:

1. All electric fields are confined to the interior of capacitors.
2. All magnetic fields are confined to the immediate vicinity of inductors.
3. Dimensions of the circuits are small compared to the wavelengths under consideration.

Using these assumptions, we can model noise-coupling channels as lumped circuit elements. A magnetic field coupling two conductors is modeled as a mutual inductance. Stray capacitance can be modeled as two conductors with an electric field between them. Figure 1 shows an equivalent circuit of a situation where two short wires are adjacent to one another over a system ground.

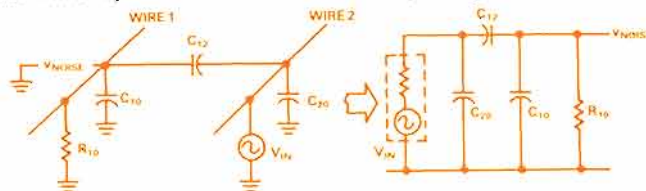


Figure 1. Noise-equivalent circuit of two adjacent wires and a ground plane.

Once the complete noise equivalent-circuit is obtained for a system, the problem becomes one of solving network equations for a desired parameter. All standard linear circuit analysis techniques can be applied, including node equations, loop equations, matrix algebra, state variables, superposition, Laplace transforms, etc. When circuits exceed 5 or 6 nodes, manual calculation becomes difficult; at this point, computer-aided programs, such as SPICE, and other CAD techniques become necessary. Experienced designers can make appropriate simplifying assumptions; but their validity should always remain in question until proven.

The lumped-element approach will not always give an accurate numerical answer, but it will show clearly how noise depends on system parameters. Just the act of drawing a reasonably faithful equivalent circuit may offer clues to methods to reduce noise levels. Once network equations or CAD programs are written, the quantitative effects of noise-suppression techniques can be studied.

In spite of all the modern technical advances, such as microprocessors and switching power supplies, wires still have resistance and inductance, capacitance still exists in the real world, and such phenomena must be reckoned with.

THE BASIC PRINCIPLE

There are always three elements involved in a noise problem: a *noise source* (line transients, relays, magnetic fields, etc.), a *coupling medium* (capacitance, mutual inductance, wire), and a *receiver*, a circuit that is susceptible to the noise (Figure 2).

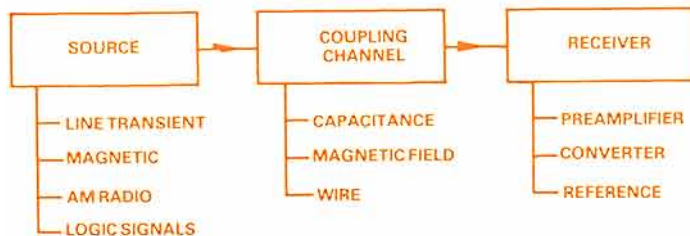


Figure 2. Noise pickup always involves a source, a coupling medium, and a receiver.

To solve the problem, one or more of these three elements must be removed, reduced, or diverted. Their role in the problem must be thoroughly understood before the problem can be solved. If the

*Another helpful and relevant article that appeared in these pages was "Analog Signal Handling for High Speed and Accuracy," by A. Paul Brokaw, *Analog Dialogue* 11-2, 1977, pp. 10-16.

solution is inappropriate, it may only make the noise problem worse! Different noise problems require different solutions; adding a capacitor or a shield will not solve every such problem.

TYPES OF SYSTEM NOISE

Noise in any electronic system can originate at a large number of sources, including computers, fans, power supplies, adjacent equipment, test devices; noise sources can even include improperly connected shields and ground wires that were intended to combat noise. Our discussion of noise sources and coupling mechanisms will include the following topics:

- Common-impedance noise
- Capacitively coupled noise
- Magnetically coupled noise
- Power-line transients
- Miscellaneous noise sources

Common-Impedance Noise. As the name implies, common-impedance noise is developed by an impedance that is common to several circuits. Figure 3 shows the basic configuration, which might occur when a pulse output source and an op amp's reference terminal are both connected to a "ground" point having tangible impedance to the power-supply return terminal. The noise current (the noisy return current of Circuit 1) will develop across impedance, Z , a voltage, V_{noise} , which will appear as a noise signal to Circuit 2.

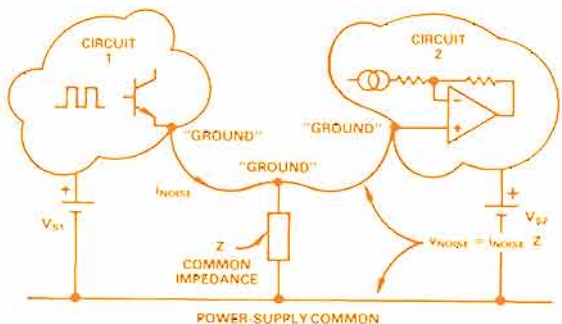


Figure 3. How noise is developed by a common circuit impedance.

Typically, this type of noise has a repetition rate that is set by the rate of the noise source. The actual waveshape is determined by the characteristics of the impedance, Z . For example, if Z is purely resistive, the noise voltage will be proportional to the noise current and of similar shape (Figure 4a). If Z is an R-L-C, the noise voltage will ring at a frequency, $1/(2\pi\sqrt{LC})$ and decay exponentially at a rate set by L/R (b).

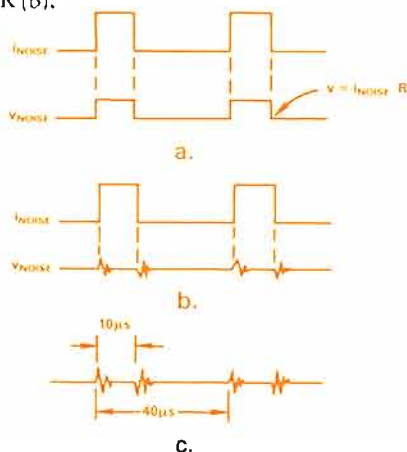


Figure 4. Noise effects in a common impedance. (a) Resistance. (b) An R-L-C circuit. (c) Switching-supply noise response.

If noise of this kind is found in a circuit, its origin may be readily deduced from the repetition rate and waveshape. The repetition rate will point to the source of noise, since the noise and its source are synchronized. For example, a noise waveform like that shown in (c), at a 25kHz repetition rate and a 25% duty cycle, might be typical of a switching power supply containing a regulating loop using pulse-width modulation.

The waveform will help identify the impedance that is actually generating the undesired noise. If, for example, the waveform of the noise is the simple damped sinusoid shown in Figure 5, the following features allow us to deduce the nature of Z :

- A constant resistance, R , is in series with the line. The voltage change, V_1 , is the product of R and a current step, I_1 .
- The natural frequency of the oscillation, f_1 , is determined by the series L and shunt C , $f = 1/(2\pi\sqrt{LC})$.
- The damping time constant, τ , is determined by L/R .

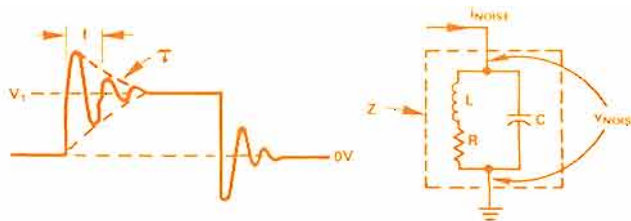


Figure 5. Waveshape for an underdamped R-L-C circuit.

Capacitively Coupled Noise. Noise is also produced by capacitive coupling from a noise source to another circuit. This type of noise is often seen when signals with fast rise-and-fall times or high frequency content are in close proximity to high-impedance circuits. Stray capacitance couples the fast edges of the signal into adjacent circuits, as the circuit model of Figure 6 shows. The nature of the impedance, Z , determines the shape of the response. Typical capacitances are listed in Table 1.

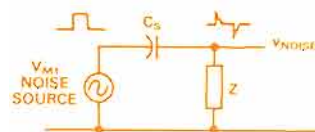


Figure 6. Stray capacitance couples noise into high-impedance circuits.

Table 1. Typical capacitances.¹

Condition	Capacitance
Human standing on an insulator to earth	700 pF
Power input (ac) to output (dc) of ± 15 -V dc supply	100 pF
Two-conductor shielded cable:	
Conductor to conductor	40 pF/ft
Conductor to shield	65 pF/ft
RG58 coaxial cable, center conductor to shield	33 pF/ft
Connector, pin to pin	2 pF
Optical isolator, LED to photodetector	2 pF
1/2-watt resistor (end to end)	1.5 pF

Capacitive pickup can occur in many ways, shapes, and sizes. Here are a few examples:

- A TTL digital signal produces fast edges, with a typical rise time of 10 nanoseconds and voltage swings of 5 volts. If Z is a 1-megohm resistor, even 0.1 pF will produce 5-volt spikes with decay time constants of 100 nanoseconds.

¹Sources: Excerpts from Ralph Morrison, *Grounding and Shielding Techniques in Instrumentation*, Second Edition (New York: John Wiley & Sons, 1977), p.30, and actual measurements.

• Crosstalk may result between two adjacent wires. For example, if two wires in a 10-foot (3-meter) length of cable have a capacitance of 40 pF/ft, the total capacitance is 400 pF. If a test voltage of 10 V at 1 kHz is on one conductor, 250 mV at 1 kHz will be coupled into the adjacent wire if Z is a 10 k resistance.

• Noise on the ac power line, developed through common impedances, will couple into other circuits. A common case is when transients couple through the interwinding capacitance of power-supply transformers.

It is amazing how little capacitance can cause serious problems. For example, consider the situation where high noise-immunity CMOS logic is used in an industrial circuit where 2500-volt, 1.5 MHz noise transients (IEEE Standard 472-1974) are present. Suppose that stray capacitance of only 0.1 pF exists between a CMOS input and the noise source, as shown in Figure 7. The calculated noise voltage, V_c , will be 2.4 volts, steady state, with an initial 50-V transient, which will cause improper logic operation or worse!

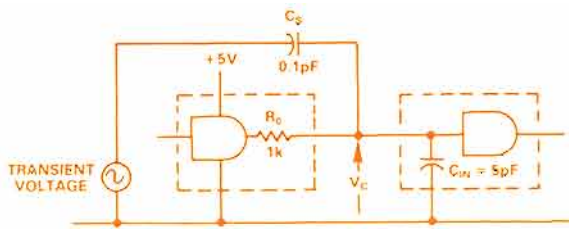


Figure 7. Coupling of high-voltage transients from test generator to logic.

Magnetically Coupled Noise. Strong magnetic fields are found where cables carry current, where ac power is distributed, and near machinery, power transformers, fans, etc. There is an analogous relationship between circuits coupled magnetically and those coupled capacitively, as shown in Figure 8 and Table 2.

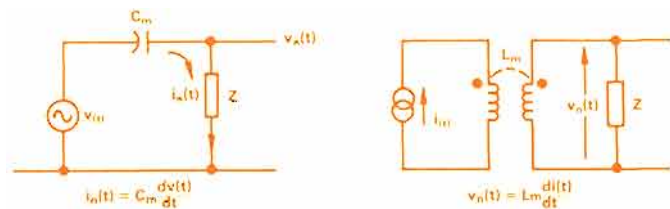


Figure 8. Comparison of magnetic and capacitive noise coupling.

Table 2. Characteristics of capacitive and magnetic coupling.

	Capacitive Coupling	Magnetic Coupling
Noise Source	Voltage change (dV/dt)	Current change (dI/dt)
Coupling Medium	Mutual capacitance	Mutual inductance
Coupled Noise	Current (frequently converted to voltage by Z)	Voltage

This analogy helps us consider some differences between capacitively and magnetically coupled noise:

• When the noise is magnetically coupled, voltage noise (V_n) appears in series with the receiver circuit; in the capacitive situation, the voltage noise produced between the receiver and ground is the voltage in Z caused by the noise current, i_n .

• Reducing the receiver impedance, Z, will reduce capacitively coupled noise. This is not the case in magnetically coupled circuits; lowering Z will not dramatically reduce voltage noise.

The voltage, V_n , induced in a closed loop (single turn) by a magnetic field is given by

$$V_n = 2\pi fBA \cos\theta \times 10^{-8} \quad (1)$$

volts, where f is the frequency of the sinusoidally varying flux density, B is the rms value of the flux density (gauss), A is the area of the closed loop (cm²), and θ is the angle of B to area A.

For example, consider the circuit of Figure 9. It shows the calculation for two one-foot conductors, separated by 1 inch, in a 10-gauss 60-Hz magnetic field (typical of fans, power wiring, transformers). The maximum voltage induced in the wires is 3 mV.

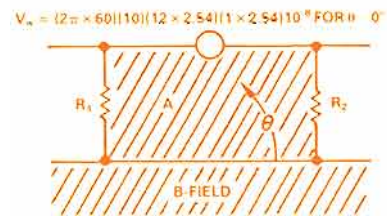


Figure 9. Example demonstrating magnitude of magnetic pickup.

The equation tells us that the noise voltage can be reduced by reducing B, A, or $\cos\theta$. The B term can be reduced by increasing the distance from the source of the field or—if the field is caused by currents flowing through nearby pairs of wires—twisting those wires to reduce the net field to zero by alternating its direction.

The loop area, A, can be reduced by placing the conductors closer together. For example, if the conductors in the example were placed 0.1" apart (separated only by insulation), the noise voltage would be reduced to 0.3mV. If they can be twisted together, the area is, in effect, reduced to small positive and negative increments that cancel, practically nullifying the magnetic pickup.

The $\cos\theta$ term can be reduced by proper orientation of the receiving wires to the field. For example, if the conductors were perpendicular to the field, the pickup would be minimized, while if they were run together in the same cable ($\theta = 0$), pickup would be maximized.

The rms induced voltage, V_n , in a conductor in parallel with a second conductor, carrying a current I_2 at an angular frequency $\omega = 2\pi f$, with a given mutual inductance, M, is

$$V_n = \omega M I_2 \quad (2)$$

The application of this relationship shown in Figure 10 illustrates why only one end of a shield should be grounded. A 100-ft length of shielded cable is used to carry a high-level low-impedance signal

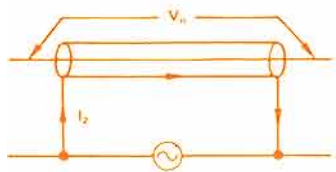


Figure 10. Magnetic pickup from current flowing through a cable shield.

(10V) to a 12-bit data-acquisition system (1 LSB = 2.4 mV). The shield, which has series resistance of 0.01 ohms per foot and mutual inductance to the conductor of 0.6μH/ft, has been grounded at both the source and the destination. A potential of 1 volt at 60 Hz exists between the two ground points, causing a current of 1 ampere to flow in the 1-ohm total resistance of the shield. By (2), the noise voltage induced in the conductor is

$$V_n = (2 \pi 60 \text{ Hz})(100 \times 0.6 \times 10^{-6} \text{ H})(1 \text{ A}) \\ = 23 \text{ mV},$$

or 10 LSBs, thereby reducing the effective resolution of the system to less than 9 bits. This noise voltage is a direct consequence of the large current flowing in the shield because it is grounded at both ends. And the 1-volt potential assumed between the grounds was conservative! In heavy-industry environments, 10 to 50 volts between earth grounds is not uncommon.

Power-Line Transients. Another type of system noise is that generated by high-voltage transients in inductive circuits, such as relays, solenoids, and motors, when they are turned on and off. When devices having high self-inductance are turned off, the collapsing fields can generate transients of the order of kilovolts, with frequencies from 0.1 to 3 megahertz, that appear on the power line.

Besides creating noise in sensitive circuitry, via capacitive and conductive coupling and radiated energy, these transients are hazardous to equipment and people. Standards exist to characterize certain transient waveforms for the purpose of protection; however, besides being designed to withstand them, systems should also be designed to deal with their potential interference with signals. Figure 11 shows 4 typical waveforms existing in industry standards.

Miscellaneous Noise Sources Finally, there is a group of noise sources that can be considered as miscellaneous—or just “flakey.”

For low-level signals at high impedance, the cable itself can become a noise source. A charge can be produced on the dielectric material within the cable; if the dielectric does not maintain contact with the conductors, this charge will act as a noise source within the cable, unless the cable can be kept rigid. This noise is highly dependent on any motion of the cable; noise levels of 5 to 100 mV were reported by Belden Corporation. Noise of similar character (5 to 25 mV) was observed in the laboratory for RG188 coaxial cable, as it was moved and flexed.

Another type of motion-related noise occurs when a cable is moved through a magnetic field. Voltage will be induced in the cable as the cable cuts fixed flux lines or the flux density, B , changes. This kind of noise is troublesome in a high-vibration environment, where the cables can be in rapid motion. If the cable can be kept from vibrating relative to the field, this noise will not occur.

Finally, if instrumentation is operating in close proximity to a radio or television station, signals may be picked up from the transmissions. In addition to AM, FM, and television transmitters, the RFI may come from CB radios, amateur radios, walkie-talkies, paging systems, etc. High-frequency noise should be considered as a possible source of mysterious drifts in dc circuitry, due to rectification of picked-up rfi; investigations of drift should always be conducted with a wideband oscilloscope.

SUMMARY

We have described here the different types of interference noise that will exist in any electronic system. Table 3 lists the noise sources discussed above and some effective approaches to solving the pickup problem. It is important to understand the complete noise system (source, coupling medium, receiver, and relationships) before noise-reduction techniques are employed.


Noise reduction is not a mystical job for wizards; it is a practical and analytical job for engineers. Needless to say, the most effective

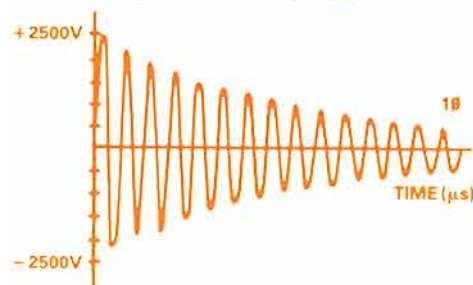
approach is *prevention*—applying noise-reduction analysis and minimization techniques *before the system is built*.

In part 2 of this article, we will describe the proper application of shielding and guarding techniques for noise reduction.

Further Reading:

Ralph Morrison, *op. cit.*

Henry W. Ott, *Noise Reduction Techniques in Electronic Systems* (New York: John Wiley & Sons, 1976). 



a.



b.

c.

d.

Courtesy of Key Tek Instrument Corp., Burlington, MA

Figure 11. Examples of transients existing in standards for industrial power-line equipment. (a) IEEE Standard 472-1974 “Guide for Surge Withstand Capability.” (b) Impulse wave, 8×20 , 1000V peak, $5\mu\text{s}/\text{div}$. (c) Impulse wave, 10×1000 , 1500V peak, $0.2\text{ms}/\text{div}$. (d) 100kHz ac surge, 6kV peak (500kHz leading edge); successive peaks down by 40% ($1\text{kV}/\text{div}$, $2\mu\text{s}/\text{div}$).

Table 3. Noise sources and possible solutions.

Common-Impedance Noise

- Proper circuits for distributing power
- Isolation transformers, optical isolators, analog isolators
- Shielding of sensitive circuits

Capacitively Coupled Noise

- Reducing noise sources
- Properly implemented shields (very effective)
- Reducing stray capacitance

Magnetically Coupled Noise

- Careful routing of wiring
- High-permeability (mumetal) shields (the most effective)
- Reducing area of receiver circuit (twisted pairs, physical wire placement)
- Reducing the noise source (twisted pairs, driven shields to cancel field)

Power-Line Transients

- Coil suppression on relays, solenoids, etc.
- Zero-crossing turnoff for relays, solenoids, etc.
- Shielding
- Reducing stray capacitance

Miscellaneous

- Rigid wiring
- Low-noise cable
- Shielding from RFI source

WIDEBAND 2-CHANNEL MONOLITHIC ANALOG MULTIPLIER/DIVIDER

AD539 Provides Linear, Logarithmic, Square-Law Gain Control, Signal Bandwidths to 60MHz, Control Bandwidth of 5MHz, with Low Distortion

by Barrie Gilbert

Model AD539* is a fast, low-distortion analog multiplier-divider with two wideband signal channels controlled by common inputs providing either linear or logarithmic gain control. It is fabricated monolithically, using laser-trimmed thin-film resistors, and packaged in a 16-pin DIP. With low-impedance loads, a bandwidth of over 60MHz is possible. When used with external op amps and on-chip application resistors, it performs the function

$$V_{W1} = -V_X V_{Y1} \quad \text{and} \quad V_{W2} = -V_X V_{Y2} \quad (1)$$

(inputs in volts), where V_X is the control voltage (0 to +3V FS), and V_{Y1} & V_{Y2} are the signal voltages (0 to ± 2 V FS).

A separate pair of control inputs (+dB and -dB) is provided for applications in which gain or attenuation needs to be varied logarithmically over a wide range.

A wide variety of applications exist wherever precise voltage-control of gain is required with good amplitude and phase response. Examples include tunable filters and oscillators using "state-variable" techniques, video switching and effects generators, and dynamic-range compression.

The two channels of the AD539 can be used in several ways: they may be used independently—with very low crosstalk between channels; in parallel, to double the output current; in series, for square-law control of gain or attenuation over a 100-dB range; or differentially, to achieve state-of-the-art distortion levels as low as 0.01%. The AD539 can also be configured as a dual- or single-channel analog divider for use in wideband automatic gain-control (AGC) and signal-leveling applications.

Power dissipation is only 1.33mW with the recommended ± 5 V supplies. The AD539 is available in three versions: "J" and "K"—for 0°C to +70°C—and "S", for -55°C to +125°C. Prices in 100s are \$14.95 (J), \$19.95 (K), and \$30.00 (S).

HOW IT WORKS

Figure 1 shows the key elements of the AD539: A bandgap reference generator is used to set the scaling factor and provide all internal biasing. Six special transistors (Q1-Q6) form the translinear core, optimized for very low distortion. A pair of transconductance stages convert input voltages V_{Y1} and V_{Y2} to current; after

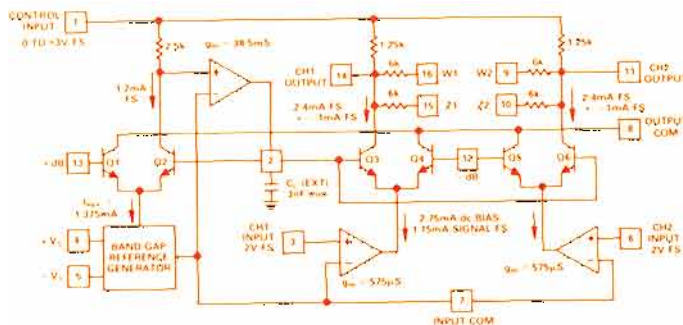


Figure 1 Simplified schematic of the AD539 Multiplier.

* Use the reply card for technical data.

multiplication in the core, the output currents can be converted back to voltage, using either external load resistors or op amps in conjunction with the on-chip application resistors, as shown in Figure 2. A simplified explanation of the operation is as follows:

Q1-Q2, Q3-Q4 and Q5-Q6 are connected in such a way that the ratios of each pair of collector currents are identical (assuming for now that +dB and -dB inputs are connected to common), i.e.,

$$I_2/I_1 = I_3/I_4 = I_6/I_5 \quad (2)$$

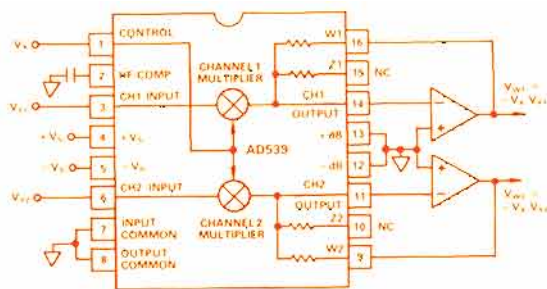


Figure 2. AD539 used as a dual-channel multiplier. Types of op amps, their supply voltages, and any additional frequency compensation depend on the application.

The reference generator furnishes a precision common emitter current of 1.375mA for the pair Q1-Q2. The fraction of this current steered to Q2 by the control amplifier ($g_m = 38.5\mu S$) depends on the linear control input V_X ; it has a value of 0.873 when V_X is at its nominal full-scale input of 3V, since the collector of Q2 is maintained at common potential by the negative feedback loop. High-frequency compensation of the loop is provided by an external capacitance of 3nF.

The common emitter current to Q3-Q4 is supplied by the 575- μS transconductance stage, which sums a 2.75-mA bias current from the reference generator with the current derived from the Channel 1 input voltage. The same fraction of this current is steered to Q3; thus, for $V_X = +3.0$ V and $V_{Y1} = 0$, 0.873×2.75 mA, or 2.4mA, appears at the output. This bias is absorbed by the 2.4mA generated by V_X via the 1.25k feedforward resistor, resulting in complete suppression of the control input. This suppression applies for all values of V_X . The fraction of the signal current in Q3, however, is available as output. For the full-scale input of $V_{Y1} = \pm 2$ V, this current is nominally ± 1 mA. Using one of the 6000-ohm resistors as the feedback element around the external op amp, the voltage output under these conditions is ± 6 V, as shown in (1). Clearly, as the fraction of the 1.375-mA reference current steered to Q2 is varied by V_X , so the fraction of the signal current steered to Q3 varies in exact proportion. Operation of the second channel, which converts V_{Y2} to a signal current, which is then controlled by Q5-Q6, is in principle identical.

When the +dB and -dB pins differ in potential, the gain or loss of the system can be made approximately logarithmic, with a much larger dynamic range than is possible in the linear mode. ▶

HIGHEST-PERFORMANCE 12-BIT MONOLITHIC D/A CONVERTER

LC²MOS Voltage-Output AD7240 Requires No Adjustment, Has Sub- μ s Settling Single-Supply Operation; Is Latchproof, Guaranteed Monotonic Over Temperature

Model AD7240* is a fast-settling 12-bit voltage-output multiplying digital-to-analog converter on a single chip, available in a 18-pin DIP. Pretrimmed to a maximum total error less than $\pm 1/2$ LSB, -1 LSB (K,B,T versions), it requires no user adjustment and remains within $\pm 1/2$ LSB, $-1 1/2$ LSB at any code over the entire operating temperature range. It has a constant output resistance with less than 3pF parallel capacitance and settles to within $\pm 1/2$ LSB of final voltage within 900 nanoseconds maximum (550 typical), with an exponential response characteristic (see Figure 1).

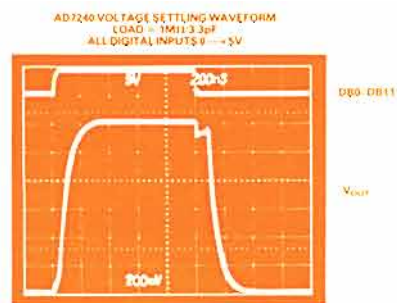


Figure 1. Voltage response to full-scale step input (all 0's to all 1's and return).

The key to the AD7240's excellent performance is a new high-speed Linear-Compatible CMOS (LC²MOS) process, which has been developed for the specific purpose of allowing high-speed digital logic circuits and high-precision analog circuits to be integrated on the same chip. The result is extremely small propagation delay—100 ns max—from 50% digital input to 90% of final analog output change.

As the functional diagram of Figure 2 shows, the AD7240 uses an R-2R ladder, with switching circuitry optimized for voltage output¹. The benefits of this connection include single-supply operation,

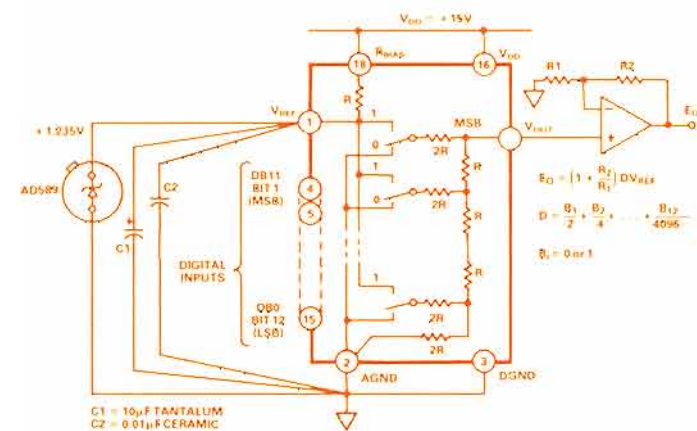
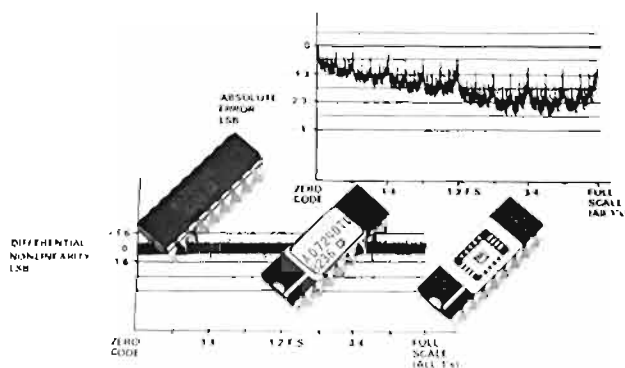


Figure 2. Functional diagram of AD7240 connected as voltage-output DAC.

* Use the reply card for technical data.

¹ See Stephenson, S., "CMOS DACs in the Voltage Switching Mode," *Analog Dialogue* 14-1, 1980, page 16, Figure 1b.



same polarity of input and output voltage, constant output resistance and capacitance— independent of digital code, direct voltage output—eliminating the need for feedback resistance tracking, and (again) fast voltage settling.

The AD7240 is latchup-proof; it doesn't require Schottky-diode protection, and it has low power dissipation (30mW).

Typical applications of the AD7240 occur wherever high speed and accuracy, with freedom from adjustment (or even provisions for adjustment) are important—for example, in remote installations, field and vehicular equipment, and portable instruments), or where low power drain is important (for example, in battery-powered instrumentation). Its combination of high speed and reduced glitch energy will stand it in good stead in display graphics, function generation, and a/d conversion. Although optimized for voltage output, the AD7240 can also be used as a conventional current-steering wide-range multiplying DAC with excellent performance (it has a built-in tracking feedback resistor), including low distortion and 1 ppm/ $^{\circ}$ C typical gain tempo.

The AD7240 is available in two basic accuracy grades, and three temperature ranges, AD7240J/A/S (0° C to $+70^{\circ}$ C/ -25° C to $+85^{\circ}$ C/ -55° C to $+125^{\circ}$ C) and AD7240K/B/T. Prices (100s) are JN/KN (plastic): \$9.70/\$10.70, AQ/BQ (cerdip): \$11.20/\$12.20, and SD/TD (hermetic ceramic): \$39.95/\$44.80.

Figure 2 shows the basic connection scheme for voltage output, with unipolar binary coding. For best results, the voltage between V_{REF} and AGND should be less than 2.0V, with a $+15$ V supply. In this example, a $+1.23$ -volt reference is used, developed by an AD589LH* two-terminal bandgap reference, conveniently biased by the connection of the R_{BIAS} pin to the positive supply.

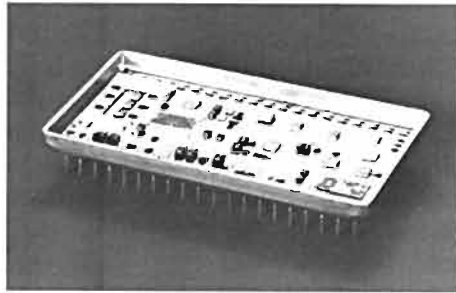
To avoid introducing error, the output amplifier should have high input impedance and low bias current, low offset voltage, wide bandwidth, and good settling characteristics, without long thermal tails. A good-quality wideband bipolar-FET amplifier, such as the AD544*, is a cost-effective choice. The resistors employed in the feedback-gain circuit (if used) should track each other well. \square

14/16-BIT DIGITAL/RESOLVER CONVERTERS

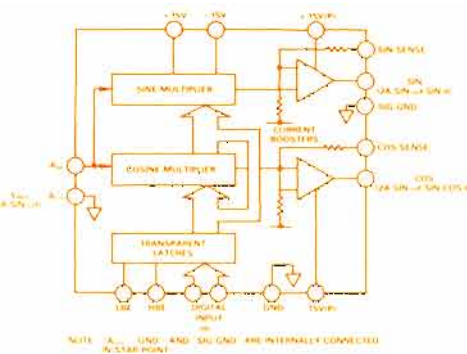
**Hybrid DRC1745/46 Have Buffered Inputs, 2 VA Outputs
Low Radius-Vector Variation, 2 or 4 Arc-Minute Accuracy**

Models DRC1745 and DRC1746* are 14- and 16-bit Digital to Resolver Converters, housed in 40-pin double-DIP packages, with latched inputs (low-power Schottky or CMOS), and 2 volt-ampere load capability for driving all standard control transformers. Remotely sensed analog outputs reduce errors caused by lead resistance over long wire runs.

As interfaces from processor to servo



systems, instruments, or position-sensing equipment, the devices accept digital words, representing angular information, and produce sine and cosine output voltages, multiplied by the dc-to-2.6kHz reference input. Applications include driving control transformers and torque receivers for position control in naval and aircraft simulators, fire-control systems, display indicators, and radar and avionic equipment. Unit prices start at \$515/\$666 (DRC1745/1746). ▶

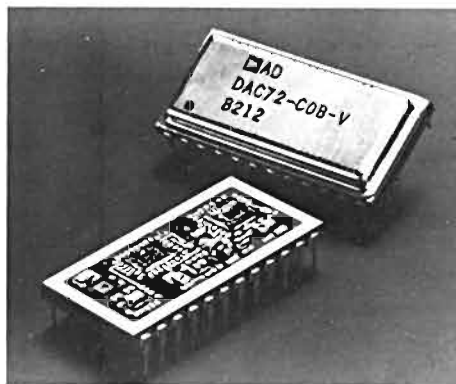


NEW DACS WITH EXISTING SECOND SOURCES

**16-Bit AD DAC71/DAC72: Fewer Chips Improve Reliability
12-Bit AD3860 Is Buffered, Complete, Has Voltage Output**

The AD DAC71/72* and AD3860* hybrid DAC families are improved versions of existing industry-standard devices with considerably reduced chip and bond-wire count and comparable or better performance.

The AD DAC71 (0° to 70°C, ceramic DIP) and AD DAC72 (-25° to +85°C, hermetic ceramic DIP) guarantee maximum non-linearity of $\pm 0.003\%$ and are available with either current output or a buffered voltage output, which settles to within $\pm 0.003\%$ in 10 μ s, maximum. Prices for



AD DAC71/72 (25-99) start at \$53/\$65.

The AD3860, linear to within $\pm 1/2$ LSB over temperature, is a complete buffered voltage-output 12-bit DAC. It includes an internal 6.3-V reference and input data latch, in a single hybrid package, and is available processed to MIL-STD-883B. Prices in 100s (AD3860K/S) are \$79/\$115. ▶

*Use the reply card for technical data.

IC ATTENUATOR

**AD7115 Range Is 0 to -19.9dB
0.1dB Steps, 2 1/2 BCD Coding**

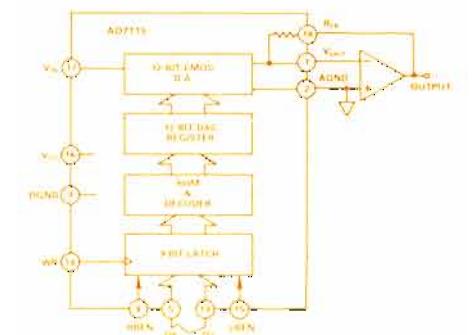
The AD7115* monolithic LOGDAC™, housed in an 18-pin plastic, Cerdip, or ceramic DIP, is a digitally programmable attenuator for ac or dc analog signals, over the range, 0 to -19.9dB, in 0.1-dB† steps.

The attenuation is established by a 2 1/2 digit BCD input word; its 9 bits may be latched in from a 16- or 8-bit uP bus, using compatible on-chip latches. The analog output voltage is provided via an external op amp, chosen to fit the needs of the application. With the AD544*, response is essentially flat to 100kHz.

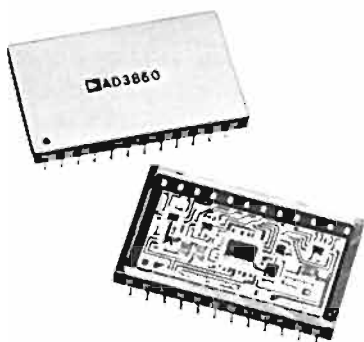
Applications include programmable attenuation in μ P-based telephone and professional audio equipment, distortion analyzers, function generators, and digitally controlled AGC systems. The AD7115 can also be programmed manually by thumbwheel switches. Its dynamic range of high-resolution adjustment can be extended by cascading, with attenuation—usually in powers of 10 (i.e., 20dB).

Powered by a +5-volt supply, the AD7115 will accept analog signals of up to ± 25 V peak; maximum output depends on the amplifier's ratings and its power supply. Maximum error (over the temperature range) is ± 0.05 dB, relative to 0 dB, and ± 0.12 dB for gain at 0 dB. Analog feed-through at 1 kHz is -92dB max at 25°C and -68dB max over temperature.

Three grades are available, AD7115KN (0°C to +70°C), AD7115BQ (-25°C to +85°C), and AD7115TD (-55°C to +125°C). Prices in 100's are \$18.75/\$21.75/\$65.25. ▶



†dB = 20 log₁₀ (voltage ratio). 0.1 dB corresponds to a ratio change of 1.16%.



FAST TRACK-HOLD

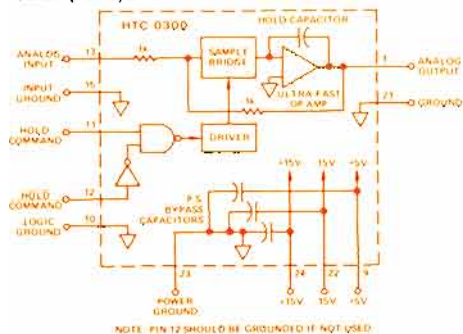
**HTC-0300A: Improved Hybrid
170ns Acquisition Time to 0.1%**



The HTC-0300A* is a high-speed hybrid track-and-hold amplifier with guaranteed maximum acquisition time of 170 ns to $\pm 0.1\%$ and maximum droop rate of $5\mu\text{V}/\mu\text{s}$. Its maximum gain nonlinearity is $\pm 0.01\%$; and its specified output current rating of $\pm 50\text{mA}$ at $\pm 10\text{V}$ ensures low-enough output impedance to handle rapidly varying loads (such as a/d-converter inputs) with high resolution.

Full-power bandwidth (-3dB) of 8MHz and maximum aperture jitter of 100ps allow the HTC-0300A to rapidly track and acquire fast ac signals in a wide variety of data sampling applications. Besides its usefulness with a/d converters (such as the Analog Devices HAS series and models ADS78, ADS79, ADC84, ADC85), it can also be used in peak measurement, analog delay, and other analog signal-processing applications.

The HTC-0300A, housed in a 24-pin glass package, is rated for operation from 0°C to $+70^\circ\text{C}$. The HTC-0300AM, in a hermetically sealed metal package, is specified for -55°C to $+125^\circ\text{C}$ and is optionally available processed to MIL-STD-883B, Method 5008. Prices in 100s are \$164(A) and \$227(AM). ▶



*Use the reply card for technical data.

9-BIT 20-MHz VIDEO A/D CONVERTER

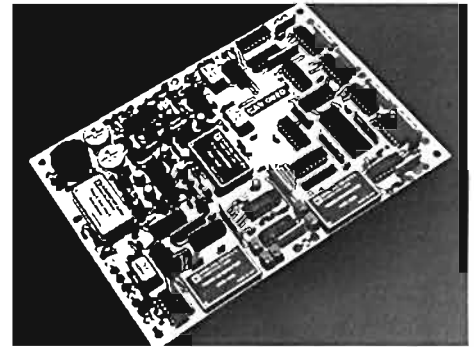
**Complete-on-a-Card CAV-0920 Includes Track-Hold Amp
Use It In Video, Radar, Digital Signal Processing**

The CAV-0920*, a 9-bit a/d converter on a $5" \times 6"$ card, digitizes signals at word rates from dc to 20 MHz without extra support circuitry. Unlike currently available single-chip encoders, the CAV-0920 guarantees no missing codes over temperature and a small-signal-input bandwidth of 30MHz. The CAV-0920 includes a track-and-hold amplifier, encoder (using digitally corrected subranging), timing logic, reference, and output latches in order to eliminate the costly design effort associated with monolithic encoders.

In addition to television, application areas for the converter include radar digitizing, spectrum analysis, medical instrumentation, and digital communications. For use in digital communications, typical signal-to-noise and noise-power ratios are specified at 61dB and 41dB.

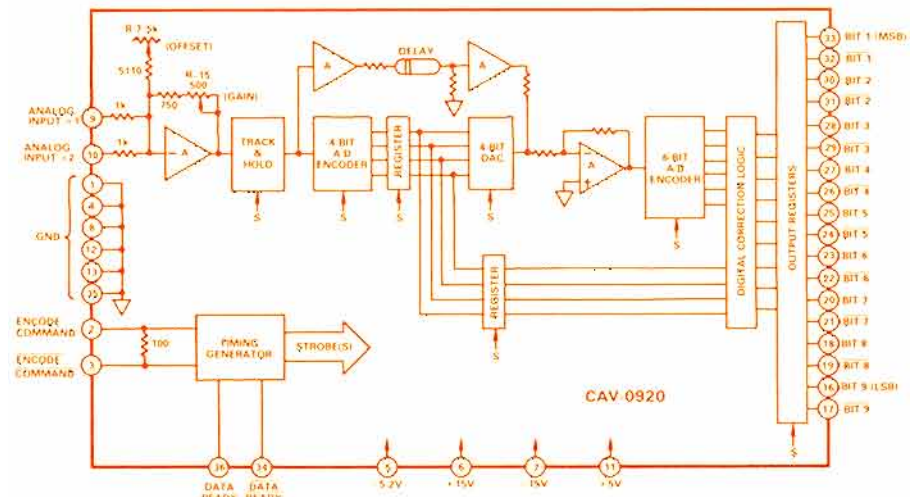
Characterizing the CAV-0920's dynamic performance for radar and spectrum-analysis applications, ac linearity is specified in terms of spurious in-band signals generated at different input-signal frequencies at a 20-MHz encode rate. For dc to 1 MHz, spurious signals are typically 55dB below full scale; for 5 MHz to 10 MHz, spurious signals are typically 45dB below full scale. Differential gain and phase are specified at $\pm 2\%$ and ± 1 degree.

Total error at dc, including nonlinearity, is



specified at $\pm 0.1\%$ of full scale. Nonlinearity vs. temperature is specified at $\pm 0.001\%$ F.S./ $^\circ\text{C}$. Initial offset voltage is adjustable to zero with an on-board potentiometer; offset and gain drift are specified at $\pm 0.01\%$ and $\pm 0.02\%$ of F.S./ $^\circ\text{C}$ over the CAV-0920's 0° to 70°C operating temperature range. Aperture jitter is typically 25ps, and typical transient response and overvoltage recovery are both rated at 50ns.

The ECL-compatible a/d converter is constructed on a $7.0" \times 5.0" \times 0.5"$ ($178 \times 127 \times 12.7 \text{ mm}^3$) printed-circuit card and provides pin-selectable analog inputs of 1V p-p at 500 ohms or 2 V p-p at 1000 ohms, allowing termination in any lower impedance. Power-supply requirements for the CAV-0920 are $\pm 15\text{V}$, $+5\text{V}$, and -5.2V . Maximum power dissipation is 17.4W. Available from stock, the CAV-0920 is priced at \$995 by the ones. ▶

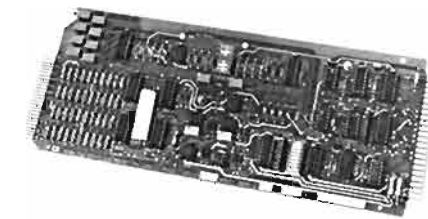


MACSYM: 8-CHANNEL RTD MEASUREMENT CARD RTD01 Provides Excitation, Measurement, and Filtering Selectable Temperature Ranges, Protection to 240V rms

The RTD01* 8-Channel RTD Input Card for MACSYM Measurement And Control Systems plugs directly into the MACSYM Analog/ Digital Input/Output (ADIO) bus to provide accurate and repeatable temperature measurements in laboratory and industrial environments, using 100-ohm 3- or 4-wire RTDs (Resistance Temperature Detectors).

A typical RTD is a platinum resistance element with 100-ohm resistance at 0°C and a highly reproducible temperature coefficient of about 0.39%/°C (0.39 ohms/°C) at 0°C (with a small but predictable nonlinearity). It is either connected in a bridge or excited with current, and the small output voltage is amplified and conditioned.

The RTD01 provides each channel with a precise excitation current of 0.5mA ± 0.01%, and amplifies the resulting output signals (about 200µV/°C) with an accuracy to within ± 0.1% of full scale. The user



can choose among a variety of switch-selectable temperature ranges, from -98°C to +100°C, with 0.05°C resolution, to 0° to +800°C, with 0.2°C resolution. Gain can be "tweaked" by the user (±5%) for close channel-to-channel tracking.

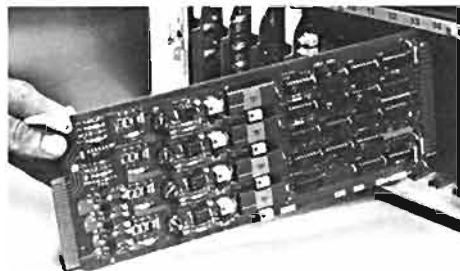
Switch-selectable filtering is provided—either a wideband filter and high-speed sampling, with digital filtering, or a 35-Hz filter and about 20 samples/second for rejection of 50/60-Hz noise. The card's price: \$595—about \$75/channel. ▶

FOUR CHANNEL SETPOINT/ALARM CARD SPA01 Compares Inputs with Software-Adjusted Set Points Causes Interrupt on Crossing Only, Saves MACSYM Time

Each channel of the SPA01 † Setpoint/Alarm Card compares an input voltage with a software-programmed setpoint, or threshold, voltage. When the analog signal crosses the threshold, a local circuit is closed (or opened), and an interrupt is generated back to the MACSYM software.

Thus, the SPA01 provides the MACSYM user with an efficient and convenient way to generate a setpoint voltage in software and continuously perform a comparison locally, without attention from the computer until an interrupt occurs. This capability reduces the system software load where constant monitoring of a variable is required for alarm conditions, on/off control, or differential gap control (on and off at two programmed setpoints).

The circuit closures by each channel are made without processor intervention, are available externally, and are hence especially useful where crossings must be reli-

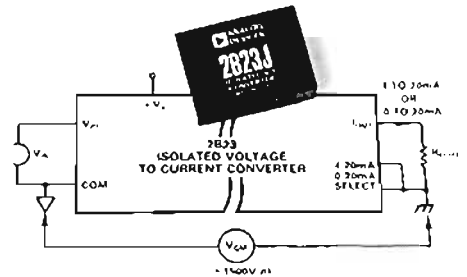


ably determined—and/or acted upon—irrespective of the processor's load.

Each channel's setpoint is settable from -10.00 to +9.995V, with 12-bit resolution; it can also be provided from an external source. With jumpers, the user can select which crossing-polarity will cause a high or low alarm output and interrupt. Deadband (hysteresis) of ±50mV to ±1V may be enabled for each channel. MACSYM can read any channel's status at any time.

Control applications include temperature, pH, compressors, heaters, and tank-level maintenance. Price of the SPA01 is \$650. ▶

V/I CONVERTER Resistor-Programmable 2B23 Is 1500-Volt Isolated



Model 2B23 † is a voltage-to-current converter/current transmitter with ±1500-volt peak input-to-output isolation and pin-programmable choice of 4-to-20mA or 0-to-20 mA output. It can drive grounded or floating loads of up to 800Ω. Any full-scale input span, from 100mV to 10V, can be set by the selection of one external resistor.

Applications include analog signal transmission, transient-voltage protection, and ground-loop elimination in industrial instrumentation, process control, and remote data-acquisition. Because it meets the requirements of ISA Standard 50.1 on isolated current-loop transmission, the 2B23 may serve as a transmission link between such system elements as computers, controllers, actuators, recorders, and indicators.

To assure high reliability in harsh environments, the device meets the requirements of IEEE Std. 472-1974 for Transient Voltage Protection (SWC). Its isolation barrier will withstand continuous common-mode voltage of ±1500V peak and 1500V rms at 60Hz for 60 seconds.

The 2B23 operates over a wide range of single-supply voltages (+14V to +28V) and provides isolated loop power, eliminating the need for an external dc/dc converter.

It will operate at temperatures from -25°C to +85°C and is specified in two grades for operation from 0°C to 70°C. The 2B23K has nonlinearity of ±0.05% max, offset and span errors of ±0.1% max, and ±0.005%/°C max temperature coefficients of offset and span. Comparable max errors for the 2B23J are ±0.1%, ±0.25%, and ±0.01%/°C. Prices in 100s (K/J) are \$97/\$75. ▶

*Technical data for RTD01 and more than 30 other ADIO cards can be found in the free 64-page Databook, *Analog/Digital Input/Output for MACSYM Systems*
†For technical data, use the reply card.

ADI Division Fellow Named

Mike Timko



Michael P. Timko, most recently Manager of Computer-Aided Design, has been named a Division Fellow at Analog Devices Semiconductor, in recognition of his technical achievements and of his wide area of influence and visibility within the technical community. He reports to Jerald Fishman, Group Vice President—Components—and acting General Manager of Analog Devices Semiconductor.

Throughout his eleven years with Analog Devices, Mike has held a number of engineering positions. His most visible major contributions have been to design and development of the the AD590 current-mode temperature transducer, as advocate, project engineer, and co-inventor (with A. Paul Brokaw), and to the development of the AD574, the world's first self-contained μ P-compatible a/d converter on two chips in a single package (with Peter Holloway). Both major products were introduced in these pages in 1978. Among Mike's other contributions was his significant participation in the development of the AD521 IC instrumentation amplifier, introduced in 1975. All three of these products are documented in the *IEEE Journal of Solid-State Circuits* in papers co-authored by Mike.

In his new position, Mike will be working on design projects dealing with complex data-acquisition components, especially those employing technologies combining bipolar and CMOS (analog and digital) circuitry on a single VLSI chip.

He holds Bachelor's and Master's degrees in Electrical Engineering from M.I.T. He is also a member of Tau Beta Pi, Sigma Xi, and Eta Kappa Nu honor societies, and a Member (and active volunteer contributor to technical programs) of the I.E.E.E. He lives in Burlington, Massachusetts with his wife, Judy, and one son.

WHAT IS A DIVISION FELLOW?

Division Fellow is one of the highest levels of technical advancement within the divisions of Analog Devices. It is a part of the company's parallel-ladder program, which was established to distinguish highly competent technical individuals and provide them with long-term career growth within their technical disciplines without the need to assume management responsibilities. In addition to recognition for invention and technical creativity, the parallel ladder also stresses the important impact other roles, such as mentor, entrepreneur, and consultant can have on the company.

Fellows are recognized for their outstanding technical contributions to the company and for having exemplified unusual talents as innovators in their fields; for having acted as mentors to young technologists; for having demonstrated leadership in generating new business opportunities; and for having developed valuable industry and academic relationships for the company.

Mike is the fourth person to be named a Division Fellow. He joins Division Fellows A. Paul Brokaw*, Barrie Gilbert*, and Jack Memishian†—and Corporate Fellow Ivar Wold‡.

*See *Analog Dialogue* 14-1, 1980.

†See *Analog Dialogue* 14-3, 1980.

‡See *Analog Dialogue* 16-1, 1982.

MORE AUTHORS (Continued from page 2)

Richard Quinn (page 12) is a Senior Marketing Engineer with ADI's MACSYM division. Prior to that, he worked for ADI as corporate Marketing Analyst. Rich has a BSEE from Case Western Reserve University and an MBA from the Amos Tuck School of Business Administration. Before joining ADI, he worked for Gould as a marketing analyst and Reliance Electric as a control-systems engineer.



Dave Reynolds (page 7), Senior Marketing Engineer for Systems Interface Products at ADI, earned a BSEE at the University of Southern California, and both an MSE and MBA from the Moore and Wharton Schools at the University of Pennsylvania. He joined ADI as a Strategy and Systems Analyst, became an Operations Systems Analyst in ADI's Systems Components Division, then joined Marketing in July, 1981. He enjoys team sports and racquetball.



Alan Rich (page 16), a Senior Product/Test Development Engineer at Analog Devices Semiconductor, has a BSEE from Lowell Technological Institute and is studying towards an MSEE at Northeastern University. He was a test engineer at Western Electric for A/D telecommunications systems, a senior design engineer and I/O section manager for industrial interface products at Gould Modicon, and has consulted on a variety of systems. He enjoys marriage, his two children, restoring an old house, and gardening.



Bill Schueber (page 21) is a Systems Marketing Engineer with ADI's MACSYM group. Before this, he designed microprocessor-based controls for materials testing equipment. Bill has a BSEE from Columbia University, an MSEE from the University of Massachusetts, and is a Registered Professional Engineer. His hobbies include bicycling, photography, model railroading, and "just taking care of things around the house."



Scott Wurcer (page 3) is a Design Engineer at Analog Devices Semiconductor. A native of Milwaukee, Wisconsin, he graduated from the M.I.T. with a BSEE in June, 1973. While at M.I.T., he worked in the X-Ray Astronomy Group at the Center for Space Research. He has been employed at ADS since 1974, in various engineering positions. He is a Member of IEEE.



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 16, Number 3, 1982 - 28 pages) . . . AD7528: A Dual Monolithic DAC for All Reasons . . . Applying High-Performance Monolithic Fet-Input Op Amps . . . Use Your Personal Computer for Measurement and Control . . . Multitasking: The Key to Effective Measurement and Control . . . Improved Vector-Scan Displays Are Coming . . . De-glitching a Monolithic 16-Bit D/A Converter . . . Versatile Microprocessor-Based Meters for J-K-T-E-R-S Thermocouples (AD2050/AD2051) . . . Logarithmic Multiplying CMOS D/A Converter, 0.375 dB/Bit (AD7111) . . . New Software Package for LTS-2010 Linear IC Test Systems . . . High-Performance Hybrids for Data Acquisition (AD5210 and AD5240 ADCs) . . . Super-Performance Hybrid Op-Amp Families (AD380/AD381/AD382) . . . and these New-Product Briefs: Fast Track-Hold with 1.3-us max Acquisition Time for 20-V Step (HTC-0500) . . . 12-Bit, 5-MHz A/D Converter for MIL Applications (MOD-1205MB) . . . 12-Bit-Plus-Sign CMOS Monolithic Integrating A/D Converter (AD7552) . . . Low-Cost Precision 2.5-V IC Reference (AD1403/1403A) . . . 10-Bit Monolithic IC DAC (AD DAC100) . . . AC/DC and DC/DC Power: New Catalog Includes 18 New Supplies . . . Ultrafast Op Amps: AD3554 and HOS-050C . . . Test Subpicamp Bias Currents Automatically with LTS-2010 . . . Accurate Multi-Channel Thermocouple Measurements for MACSYM (STB03) . . . Analog and Digital Boards Increase uMAC System Capacity uMAC-4030, uMAC-4040 . . . Worth Reading: The Analog Devices 1982 Databook, ADI Authors in the Trade Press, Featured in MACSYMIZER . . . plus Editor's Notes, Authors, Potpourri, etc.

PRODUCT NOTES . . . Output impedance-vs.-frequency data is available for HOS-050 and HOS-100 op amps. Consult your local ADI component sales engineer. . . . Timer Testing: LTS benchtop IC test systems may be used for testing IC timers (555, 556) in TO5s, DIPs, and miniDIPs, using the LTS-0801 Socket Assembly and an appropriate DUT Board with the LTS-2200 ADC Family Board. The device program that accompanies each DUT Board allows for full dc parametric testing and for testing pulse widths of timer devices . . . Intrinsic Safety The 2B52 Isolated Thermocouple Transmitter and the 2B58 RTD Transmitter have been approved by Factory Mutual for intrinsically safe use in hazardous locations when used with intrinsic safety barriers in the recommended manner. Ask for the new data sheets that discuss intrinsically safe operation . . . Improved P.S. Range All AD2050 and AD2051 dc-powered microprocessor-based Thermocouple Meters shipped after 1 Oct 82 will work at dc voltages from +7.5V to +28V dc, up from +15V . . . AD OP-07 is now available in plastic. Consult your ADI component sales engineer for info . . . HDD Series DACs are now housed in ceramic completely interchangeable with earlier glass packages.

NEW PRODUCT AREA - DIGITAL SIGNAL PROCESSING . . . We have recently announced the first of a series of families of IC digital signal-processing components and subsystems. They will be discussed at length in the next issue of Dialogue . . . Products available include 16 x 16- and 8 x 8-Bit Digital Multipliers and Multiplier-Accumulators in DIP and flat pack configurations for commercial and military temperature ranges at competitive prices . . . Employing CMOS for power dissipation as low as 55mW for 8 x 8 and 175mW for 16 x 16-bit multiplier-accumulators, they are cool, reliable, and compatible in form, function, and pinout with the equivalent industry-standard devices. For data, use the reply card or call your nearby ADI Component Sales Engineer.

DATA SHEET UPDATE . . . If your AD7528 data sheet is dated 7/82 (on page 4), it's up-to-date and shows the reduced digital capacitances and correct timing specs for +5V and +15V operation. If it's an earlier version, we'll be happy to send you the new one . . . Locations of four mounting-hole centers for MOD-1005 a/d converter are 0.230" (5.84mm) from ends along line of pin centers and 0.215" (5.46mm) from sides . . . Now available from your ADI component sales engineer: a corrected circuit for using the 2B20 analog current transmitter in the 0-to-20mA mode, to replace Figure 4b of currently existing data sheets . . . Model 757 100-ratio amplifier: Figure 6 shows photodiodes in wrong orientation; correct forward direction for "N" version is toward common, away from input (vice versa for "P") . . . ADC1140, Figure 2: Use a 24.9-ohm, 1% resistor between pins 25 and 26 for nominal zero offset . . . DAS1152/1153: For bipolar operation (Figure 2), jumper REF OUT to ANA IN 2, not ANA IN 1 . . . AD390: Chip-select lines on pins 25, 26, 27, and 28 have two TTL loads; In Figure 6, the upper four (MSR) data lines should be driven at higher power - by a 74LS173 . . . DRC1745/1746: For the "L" option, the position of the +5 V supply pin is #31 . . . HDD-Series data sheet, "Typical Applications" section, Power-Supply Sensitivity: "1:" means a 1% change in power-supply voltage will cause a 1% change in full-scale output (much more palatable than the definition shown!) . . . 1982 DATABOOK, Volume I, Section 20: Outside diameter of H12A 12-pin metal-can package should read 0.6 (15.24) \pm 0.005 (0.127). Same error should be corrected in Outline Drawings section of individual combined data sheet for HOS-050,050A,050C.

NEW LITERATURE (Available upon request) . . . Analog/Digital Input/Output for MACSYM Systems - Signal Conditioning to Match Any Application, Catalog of MACSYM ADIO cards . . . "Isolation and Conditioning (Clean up Industrial Signals," by John Sylvan, reprinted from Electronic Design, April 29, 1982 . . . Three op-amp Application Notes: Applications of High-Performance BIFET Op Amps (by Don Travers), How to Select Operational Amplifiers, How to Test Basic Operational-Amplifier Parameters . . . Component Test System Technology, reprints of a series of four articles on testing A/D Converters, FET-input op amps, Instrumentation Amplifiers, and V/f Converters . . . Application Notes: A Cost-Effective Approach to Thermocouple Interfacing in Industrial Systems, by Steve Guinta, describing applications of the AD2050/2051 Thermocouple Meters; The AD7574 Analog-to-Microprocessor Interface, by Paul Toomey . . . "Instrumentation Amplifier Nears Input-Noise Floor," by Lew Counts and Scott Wurcer, reprinted from Electronic Design, June 10, 1982 - cover feature on the AD574 . . . MACSYMIZER (MACSYM users' Newsletter), Volume 2, Number 2, featuring Special Purpose Transducers, Plotter Sizes and Scaling, New Products, and Customer Service Notes . . . Component-Test Systems Product Catalog, June, 1982, on LTS testers, accessories, and supplies.

CONVERTERS CHARACTERIZED BY RADC/RBRA . . . The following information may be of interest to those of our readers who specify and purchase converters for applications in military equipment: According to the April 1982 RAC Newsletter, the Newsletter of the Reliability Analysis Center, a DoD Information Analysis Center operated by TIT Research Institute, MIL-M-38510 detail specifications for devices corresponding to members of the following Analog Devices d/a-converter families have been listed: 10-bit AD7520 and 12-bit AD7521, AD7541, AD562, AD563. The only converters previously covered by the JAN system were 8-bit DACs, the DAC08 and DAC08A . . . According to the Newsletter, members of the 5200 and 571 ADC families, and 565, 566, and 561 DAC families are being characterized, with anticipated 38510 specifications coming by the end of calendar 1982.

PATENT . . . The following U. S. Patent has recently been issued: 4,349,811, to A. Paul Brokaw, Digital-to-Analog Converter with Improved Compensation Arrangement for Offset Voltage Variations.

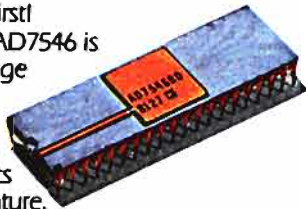
Innovative circuit design and advanced laser wafer trimming bring you the first monotonic, monolithic 16-bit DAC.

We made it first!

Our new AD7546 is a 16-bit, voltage output D/A converter

that's monotonic to 16 bits over temperature.

It features fast settling time (10 μ s to 1/2LSB), unipolar and bipolar operation, and low power consumption (50mW). It has an on-chip latch for easy μ P interface, and even an output deglitching switch synchronized to the latch-enable signal.



And we can deliver it!

By using a novel circuit design and our exclusive laser wafer trimming technology—the only proven way to cost-effectively manufacture ADCs and DACs—we've also made the AD7546 a real high-volume production component.

If you want the high reliability, compact size, and low cost (as low as \$19 in 100's) of a true monolithic 16-bit DAC, you want it from the recognized leader in IC converter technology.

For more information and the full specifications on this advanced new DAC, contact Don Travers or Doug Grant at (617) 935-5565, or write Analog Devices, Inc., P.O. Box 280, Norwood, MA 02062.

**The AD7546.
The First Monolithic
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