Digitizing Analog Data

Data acquisition boards from seven manufacturers are examined from a hardware point of view. Their specific performance characteristics help a user select a suitable board for a given application.

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Data acquisition boards occupy an unusual niche in personal computer applications. They bridge the gap between the software world and the physical world of continuous data. It is this interface to the real world, rather than the programming of these cards, that is the focus here. Although the software is important in reducing the time to bring a card up and accomplish a given task, no amount of clever programming can make up for fundamental analog hardware instrumentation errors and defects.

The cards reviewed are not test and measurement grade instruments—they provide only a foundation for measurement. The user must add circuitry to accurately and nonintrusively accomplish monitoring and control functions. Also note that although a wide range of data acquisition systems exist that reside in external boxes, this review covers only internal products. The companies represented are Burr-Brown, Data Translation, IBM, Metra-Byte Corporation, Scientific Solutions, Strawberry Tree Computers, and Western Telecomputing, each with one or more boards. (See table 1 for a summary of the products reviewed and their basic features.) None of the manufacturers provided sufficient information to determine the accuracy of its data acquisition card for an application, nor did any offer guidance for determining a system's overall accuracy.

The standard architecture for a typical data acquisition board is shown in figure 1. The analog input signals are sent through to the analog-to-digital (A/D) converter via conditioning circuits that permit the collected data to be output as required. After some precautions involving grounding, attention is turned to the analog input channel, then the remainder of the I/O.

Grounding considerations for instrumentation work are an important aspect in the design of any system. Normally, the analog ground for the measurement system is isolated from the power-line ground; however, none of the boards reviewed did so. All of their analog and digital I/O grounds are connected to each other and to the power line ground inside the PC. Thus, the user must exercise considerable caution in interfacing to apparatus or sensors that also may have a power-line ground connection in order to prevent any hazards or ground loop currents.

It is not unusual, especially with heavy current consumption devices (motors, ovens, etc.) operating from the power line, to have a substantial potential difference, on the order of volts, across two power-line receptacles. Misapplication obviously could seriously damage all the attached equipment.

Differential inputs should be used unless a sensor is completely isolated from any power-line ground to avoid ground-related problems. Even so, the analog ground must be connected to stay within the input differential common mode limits. (More information on this is available in the references listed at the end of this article.)

Input protection. The first stage of the data acquisition board should be the

PHOTOGRAPH • JOHN LEI

TABLE 1: *Summary of Basic Features*

	BURR-BROWN					DATA TRANS.
	20001 C-2	**20002**	**20019**	**20003**	**20006**	**DT2801-A**
A/D CHARACTERISTICS						
A/D type[a]	N/A	2	2	N/A	N/A	2
Resolution (bits)	N/A	12	12	N/A	N/A	12
Accuracy (bits)	N/A	N/S	N/S	N/A	N/A	0.05% overall
Speed (conv./sec)	N/A	25,000	87,000	N/A	N/A	27,500
No. of channels						
Differential	N/A	8	None	N/A	N/A	8
Single-ended	N/A	16	8	N/A	N/A	16
Input ranges (volts)	N/A	+/−5, +/−10 0 to 10 Gains = 1, 10 100, 1,000	+/−2.5, +/−5, +/−10, 0 to 5, 0 to 10	N/A	N/A	+/−1.25, +/−2.5, +/−5, +/−10, +1.25, +2.5 +5, +10
D/A CHARACTERISTICS						
No. of D/A on board	N/A	N/A	N/A	2	2	2
Resolution	N/A	N/A	N/A	12-bit	16-bit	12
Range (volts)	N/A	N/A	N/A	+/−5, +/−10 0 to 10	+/−5, +/−10 0 to 10	+/−2.5, +/−5, +/−10, +5, +10
Number of parallel I/O channels	32	None	None	None	None	16
TIMER/COUNTER CHARACTERISTICS						
Type	None	None	None	None	None	Int. only
No. of channels	N/A	N/A	N/A	N/A	N/A	N/A
No. of bits	N/A	N/A	N/A	N/A	N/A	N/A
Realtime clock	None	None	None	None	None	None
Terminal box[f]	N/A	C	C	C	C	D (on PCB)
Supports ASYST	Yes	N/A	N/A	N/A	N/A	Yes
Supp. Lab Tech Note.	Yes	N/A	N/A	N/A	N/A	Yes
Other	Motherbd.	Module	Module	Module	Module	On-board 8742

N/A = Not applicable; N/S = Not supplied.

[a] Type 1 = integration; type 2= successive approximation.

[b] Can be used for voltage or frequency.

[c] 16 output (28 LSTTL loads), 16 input (LSTTL)

[d] 32-bit, 1.023 MHz input; 16-bit, DC-2 MHz input.

[e] 100 KHz input may be used for voltage or frequency.

[f] Type A = plastic box with mini-screw clamp connectors.

Type B = ribbon cable headers.

Type C = printed circuit board with mini-screw clamp connectors.

Type D = barrier terminal strip.

Type E = with thermocouple compensation.

[g] Unshielded cable, screw terminals.

[h] 19-inch rack mount.

input protection circuitry. Accidents *do* happen, so attention should be given to this important element. This is especially true in industrial environments where sensors can cross paths with power circuits. Most manufacturers of data acquisition boards rely solely on the small measure of protection offered by the multiplexer (typically the Harris 508A or 506A). It can withstand continuous ±20 V (volts) over its power supply voltages. (The typical supply voltage used is ±15 V). It also gives superior electrostatic discharge protection, up to 5 or 6 KV (kilovolts).

Three of the reviewed boards did offer external protection: IBM protects to ±30 V, Strawberry Tree to ±50 V, and the MetraByte DASCON 1 to 120 V RMS (root mean square) continuous.

Multiplexers. This next input stage presents an analog channel to the subsequent signal processing circuitry. Ideally, a multiplexer should look like a straight piece of wire between the output and the chosen input. These devices can exhibit extremes in performance.

Multiplexers can produce temperature-dependent offset voltages in the microvolt range, but this affects only those systems with high gain (greater than 1,000). They have a nasty habit of dumping leakage current, typically in the 100-pA (picoampere) range, into (or out of) the analog input. However, if the PC's expansion slots are filled, the temperature inside the box can rise dramatically, with a resultant increase in leakage current—the amount can double every 10 degrees centigrade.

These devices also present a changing capacitive load on an analog input line when they switch from the on condition to the off. This charge-injection effect dumps (or extracts) a packet of charge onto the input. Up to 150 pC (picocoulombs) of charge can suddenly appear on the input, which causes a voltage spike of magnitude $V = Q/C$ (C is the capacitance on the input line).

For example, if an input line has a low 50 pF (picofarads) of capacitance associated with it, a 150-pC charge dump will cause a 3-V spike. The spike will decay, the time constant for which depends upon the source resistance. If it is low—less than 1 KΩ (kilohm)—no problems result, because the spike will have disappeared before the sample-and-hold grabs the voltage. But, if the source resistance is high, the sample-and-hold grabs the input voltage plus a fraction of the spike. The user must be aware of the source resistance, input channel capacitance, and charge injection to be sure the sample-and-hold is triggered after the spike has decayed to an acceptable level.

Although often not explicit in data sheet or manual, the specifications for the data acquisition boards assume a zero input impedance. The user must calculate the errors produced by the application's nonzero input impedance and apply them to the system accuracy.

IBM	METRABYTE			SCIEN. SOL.	STRAWBERRY TREE		WEST.TEL.
BOARD	**DASCON 1**	**DASH 8**	**DASH 16**	**LAB MASTER**	**ACPC-14-16**	**ACPC-16-16**	**ICIS**
2	1	2	2	2	1	1	1
12	12 + sign	12	12	12	14	16	12
N/S	0.01% +/−1 bit	0.01% +/−1 bit	0.01% +/−1 bit	+/−0.025%	11	11	12
15,000	30	30,000	35,000	30,000	2.5 (variable)	200	10
4	4	None	8	8	16	16	16[b]
None	None	8	16	16	None	None	None
0 to 10, +/−5, +/−10	+/−2.0475	+/−5	0 to 1, 0 to 2, 0 to 5, 0 to 10, +/−0.5. +/−1, +/−2.5, +/−5, +/−10	0 to 10, +/−10	0.05, 0.5, 10, +/−0.025, +/−0.25, +/−5	0.05, 0.5, 10, +/−0.025, +/−0.25, +/−5	+/−0.01, +/−0.1 +/−1, +/−10
2	2	None	2	2	2	None	8
12-bit	12	N/A	12-bit mult.	12-bit	8-bit	N/A	12-bit (opt.)
0 to 10, +/−5, +/−10	N/S	N/A	N/S	N/S	N/S	N/A	+/−10
16[c]	12	7	8	24	16	16	24
Two[d]	None	8253-5	8253-5	9513	None	None	82C53
1 per timer	N/A	3	3	5	N/A	N/A	16
32, 16	N/A	16	16	16	N/A	N/A	—[e]
None	1	None	None	None	1	1	1 in software
D (shielded)	A	A	A	B	E[g]	E[g]	D[h]
Yes	No	No	Yes	Yes	No	No	No
Yes	No	Yes	Yes	Yes	No	No	No
I/O mapped only	N/A	Half-card	N/A	Input expans. (14, 16-bit), I/O or memory mapped	Expansion by adding cards	Expansion by adding cards	On-board 80C85, opt. battery

A wide range of data acquisition boards is available for different applications. Applications requiring conversion rates from 2.5 to 87,000 conversions per second can be accommodated. A variety in the number and type of input channels is offered.

Multiplexer isolation between channels at DC (direct current) to 1 KHz (kilohertz) is high—typically greater than 100 dB (decibels)—but this deteriorates rapidly as the frequency of the signal increases. The isolation also depends upon the impedance seen by the on channel. The user need not worry if all inputs are driven by low impedance sources. He should be cautious if an application requires digitizing not only high-level signals in the tens of kilohertz range, but low-level signals as well. The feed-through from the deselected high-level signal can cause significant errors in the low-level reading. Good practice indicates that all unused analog channels are terminated to analog ground.

The Harris 508A is used on many of the reviewed boards (table 2 lists the significant components used). It is a particularly good choice, but by no means perfect. Its strength is that in the face of overvoltages and static discharge it comes through like a trooper. A second nice feature of the 508A is that if a deselected channel experiences an overvoltage condition, it does not affect the present on channel.

An input multiplexer is not used in some applications. To achieve this and yet preserve the time relationship between various analog inputs, some boards use a *sample-and-hold* amplifier for each channel desired. The sample-and-holds are strobed simultaneously. A back-end multiplexer then allows the A/D conversion to occur sequentially to complete the data acquisition. None of the reviewed boards were designed for this configuration, although it is possible to use some of the Burr-Brown modules as a back-end multiplexer.

Instrumentation amplifier. An IA performs two functions: it converts a differential input to a single-ended output, and it supplies gain. In most situations, the IA input specifications determine the input characteristics of the data acquisition board. Its voltage offset and offset voltage drift contribute directly to the overall offset specification. Its input bias current (and bias current offset) often limit the maximum source resistance for the application. The common mode rejection ratio (CMRR) is also an offset-producing phenomenon. Theoretically, if the plus and minus inputs of an IA are tied together and raised a volt, no change should be evident in the output. In reality, the IA will convert that common mode signal to an input offset, and amplify it by its gain. A 60-dB CMRR means that the IA will develop a 1-mV (millivolt) input voltage offset when both inputs are raised 1 V. CMRR will decrease with frequency (starting at about 10 Hz) at a rate of approximately 20 dB per decade. The higher the CMRR, the better chance the data acquisition board has of combating common mode and ground induced noise.

For low sampling rates, the AC (alternating current) performance of the

TABLE 2: *Summary of Significant Components Used*

	BURR-BROWN					DATA TRANS.
	20002	**20019**	**20003**	**20006**	**20017**	**DT-2801-A**
INPUT STAGES						
Input circuitry protection	None	None	N/A	N/A	None	None
Multiplexer type	BB MPC8S^b	BB MPC8S^b	N/A	N/A	None	Harris 508A
Instrumentation amplifier type	Burr-Brown PGA-200AG	None	N/A	N/A	Burr-Brown INA 102AG	3 PMI-OP-15
Sample-and-hold type	National LF389A	Teledyne TP4866	N/A	N/A	National LF398A	National LF398A
Sample-and-hold capacitor (pF)	1,000	100	N/A	N/A	1,000	1,000
A/D type	Harris 574KD	Burr-Brown ADC84KG	N/A	N/A	N/A	AMD2504, LT311, AD565
A/D reference	On 574KD	On ACD84KG	N/A	N/A	N/A	On D/A Con.
Input amplifier type^c	S and D	S	N/A	N/A	D	S and D
OUTPUT STAGES						
D/A converter type	N/A	N/A	Burr-Brown DAC11A	Burr-Brown DAC709K	N/A	AD7545LN
Output amplifier type	N/A	N/A	On DAC811A	On DAC709K	N/A	LM258

[a] *Series resistor with diode clamp.* [b] *Harris 508A look-alike.* [c] *S = single-ended; D = differential.*

IA can be neglected. For sampling rates in excess of a few hundred hertz, however, the AC limitations can play an often unexpected role.

Foremost is the brick-wall limitation of slew rate. The output of the IA cannot traverse a signal step faster than it can slew. Assuming a simple sine wave input, the slew rate for the signal is given by the equation

$$\text{slew rate} = 2\pi F V_{pp}$$

where *F* is the sine's frequency and *Vpp* is the peak-to-peak voltage. Suppose that the IA on a data acquisition board can slew at 0.5 volts per microsecond and the user needs to determine the highest frequency sine wave that he can digitize, yet make maximum use of the A/D full-scale range (±10 V). In this case, the frequency would be:

$$F = \frac{\text{slew rate}}{2\pi\ \text{Vpp}} = 3.978\ \text{KHz}$$

Signal frequencies higher than this will be greatly distorted and erroneous measurements will result.

The next fundamental limitation is that of finite bandwidth, which can cause two measurement errors. The first limitation is the response time of the IA to a change in the input signal. Assuming a first order system, the time that it will take for the output to settle within a specified error is given by

$$t = \frac{-\ln(\text{err})}{2\pi\ \text{Fo}}$$

where *err* is the error and *Fo* is the −3-dB bandwidth of the IA at the gain of interest. Suppose that the IA has a −3-dB bandwidth of 10 KHz at a gain of 100. The time it will take the IA to settle to within 1 LSB (least significant bit) for a 12-bit converter will be:

$$t = \frac{-\ln(1/2^{12})}{2\pi\ 10^3} = \frac{-\ln(2.4 \times 10^{-5})}{2\pi\ 10^3}$$

$$= 169\ \text{microseconds}$$

As gain increases, IA bandwidth decreases, and longer acquisition times will be necessary. Sampling before the IA has settled can result in significant errors.

The second bandwidth limitation effect is even more insidious. Remember that a −3-dB bandwidth frequency is the frequency at which the IA gain is 30 percent down from its DC gain. This decrease in gain begins far before the −3-dB point and can materially affect surprisingly low frequency measurements. Reconsider the IA example above, with the gain of 100 and the −3-dB point at 10 KHz. Suppose the user wants to digitize the highest frequency signal he can, yet retain 1 LSB (at 12 bits) amplitude accuracy after the A/D stage. The maximum frequency at which the data acquisition board would be able to do this is 221 Hz; although the arithmetic is straightforward, table 3 shows results from similar calculations.

This simplified analysis using only first order behavior is negated by certain components that also demonstrate some second order frequency responses. The Precision Monolithics, Inc. (PMI) AMP-01, as it is used by MetraByte, has a nasty peak in its frequency response at low gains that makes accurate use past a few kilohertz impossible.

An anti-aliasing filter should be present at this point; however, none of these boards takes this precaution. Aliasing occurs when a signal is sampled at a rate less than twice the signal's frequency (this sampling rate limit is called the Nyquist rate). This error causes a high-frequency input signal, after conversion, to appear to the CPU at the output as a lower frequency signal. The user must take care that signals with a significant frequency content that is above one-half of the sampling rate not get through to the remainder of the system. An anti-aliasing filter at this position in the circuit averts the problem.

Sample-and-hold amplifier. Most data acquisition boards use *successive approximation* A/D converters for speed and versatility, making necessary a sample-and-hold amplifier. The successive approximation converter requires that the input voltage remain constant throughout conversion. The sample-and-hold acquisition time adds to the overall conversion throughput time directly. Sample-and-hold accuracy also depends upon the input signal slew rate. The manufacturers' data sheets provide graphs that show the possible error for sample frequencies.

In systems without an instrumentation amplifier, the input characteristics of the sample-and-hold dominate the overall system input specifications.

Analog-to-digital. The A/D converter is the last stop for the input analog volt-

IBM	METRABYTE			SCIEN. SOL.	STRAWBERRY TREE		WEST. TEL.
BOARD	**DASCON 1**	**DASH 8**	**DASH 16**	**LAB MASTER**	**ACPC-14-16**	**ACPC-16-16**	**ICIS**
+/−30 V[a]	+/−120 V RMS[a]	None	None	None	+/−50 V[a]	+/−50 V[a]	None
AD7502K	CD4052	Harris 508A	Harris 508A	Harris 508A	CD4052	CD4052	Harris 506A
S/H TL064	Opt. LM363D	None	PMI AMP-01	3 PMI-OP-15	LM308	LM308	AD524AD
Analog Dev. AD583KD	N/A	LF398	LF398	LF398A	N/A	N/A	N/A
2,200	N/A	4,700	2,200	1,000	N/A	N/A	N/A
AD674AKD	Teledyne 7109	Harris 574AJD	Harris 674AJD	AMD2504, LT311, AD565	LM331	LM331	ADVF32KN
On 574AKD	LM329BZ	On 574AJD	On 574AJD	On D/A Con.	LM399	LM399	AD584JH
D	D	S	S and D	S and D	D	D	D
AD7545KN	ADDAC80N CBI-V	N/A	AD7548KN	ADDAC80Z CBI-V	DAC0800LN	N/A	AD390JD
AD644KH	On ADDAC80N	N/A	OP-07D	On ADDAC80Z	LM324	N/A	On AD390JD

The reference for the A/D converter is obtained from different components. Some boards use the reference available from the A/D circuitry; others use an industry standard such as an LM399. The input protection on these boards is not really sufficient.

age signal. The successive approximation A/Ds usually are packaged in a single 24- or 28-pin DIP and are monolithic or hybrid in construction. Most incorporate the successive approximation register, D/A converter, voltage reference, comparator, and interface circuitry in the same package.

A sample-and-hold amplifier, followed by a successive approximation A/D converter, is very susceptible to noise. When confronted with it, these devices perform poorly, randomly sampling and converting the peaks and valleys of the noisy signal. Software can smooth the output data somewhat.

The *integrating A/D* converter is an alternative to successive approximation. Although slower, this A/D provides superior noise rejection and, in many cases, higher resolution. It is the A/D of choice, particularly in applications requiring high sensitivity—less than 100 mV (millivolts) full scale. MetraByte, Strawberry Tree, and Western Telecomputing offer boards that feature integrating A/D converters.

Reference. The *reference* sets the overall channel accuracy and stability for the A/D. Its time and temperature drift affect accuracy directly. Some boards use the reference available in the A/D converter itself. Others use off-the-shelf references, such as National's LM399. Strawberry Tree is the only manufacturer to specify time-related drift.

Bus control and interface. Data may be obtained from the analog conversion channel by polling the A/D converter until a conversion-complete signal has been received, then having the CPU read the data. Note that in the IBM PC, reading the data requires a minimum of two fetches for A/D resolutions greater than eight bits. Interrupts are sometimes used to signal the CPU that the A/D has valid data. The fastest method of obtainment is to use a DMA channel to grab the data directly from the data acquisition card and put it appropriately in memory. This, of course, requires the least amount of time from the CPU.

Analog output. An *analog output channel* consists of a reference, a D/A (digital-to-analog) converter, and an output amplifier. Some companies combine all three components into one package—for example, the industry workhorse, output voltage Analog Devices DAC80. The typical ranges are ±5 V, ±10 V, and 0 to +10 V. Output current is limited to 5 mA (milliamperes).

None of these boards supplies output protection other than short circuit current limit. The D/A converter will be destroyed if the output comes into contact with, for example, an external 18-V power supply. The IBM and Data Translation boards provide the proper compensation around their output amplifiers to tolerate up to 0.5-microfarad capacitive loads. The D/A converters on most other boards will oscillate with a few thousand picofarads of load capacitance, especially when forcing negative voltages. Even a few hundred picofarads of capacitance can cause ringing, and the attendant long settling times that this can produce.

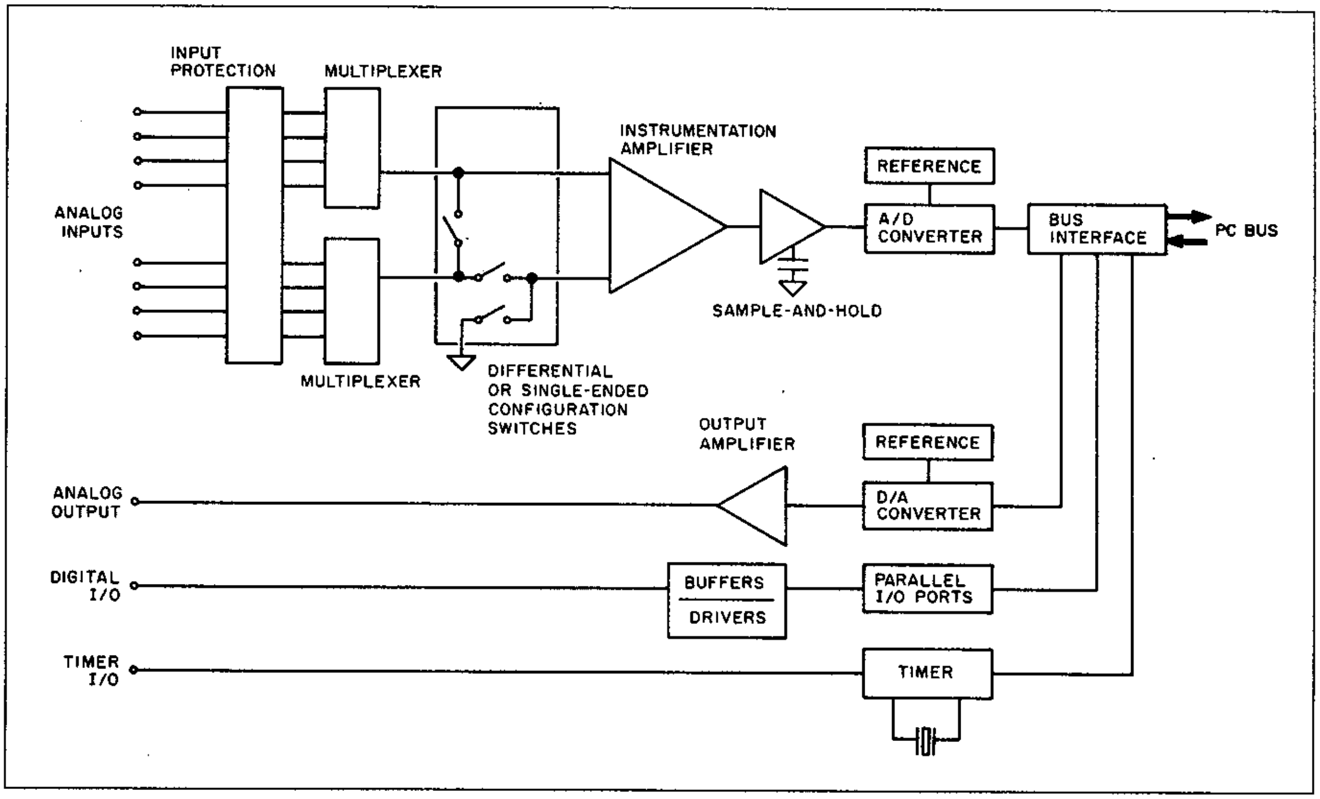
Shielding the D/A converter outputs is just as important as shielding the analog inputs. Although the D/A converter output resistance is low at DC (usually in the range of 0.1 ohms or less), the output impedance increases by a factor of 10 for each decade of frequency above 10 Hz. The D/A converter is powerless against interference from RF (radio frequency) sources, which is more common than users might suspect. Typically the RF comes down the unshielded D/A converter output and into its amplifier. It is rectified by nonlinearities in the input stage and ap-

TABLE 3: *Maintaining Signal Accuracy*

Required accuracy	1%	1LSB	1LSB	1LSB	1LSB	1LSB
Resolution of A/D (in bits)	any	8	10	12	14	16
−3dB ratio	7.0	11.3	22.6	45.2	90.5	181.0
1/−3dB ratio	0.143	0.088	0.044	0.022	0.011	0.006

The decrease in gain of the Instrumentation Amplifier occurs before the −3-dB point. This effect should be considered to ensure that signal fidelity is maintained throughout the system. As an example of reading this table, to maintain frequency fidelity within one percent of the maximum, frequency should be no greater than 14.3 percent of the instrumentation amplifier's −3-dB gain point.

FIGURE 1: *Block Diagram of a Typical Data Acquisition System*



The design of each stage of the board has a significant effect on its overall performance. The reviewed boards did not supply all aspects of this ideal situation. For example, the conversion time off the S/H contributes directly to the total throughput.

pears as a spurious DC offset voltage. The D/A converter output changes as a result of this phenomenon, and may be hundreds of millivolts away from what the user has programmed. It even may change in relation to the user's proximity to the output (because of resultant changes in the RF field).

Parallel and timer I/O channels. Parallel I/O is usually limited to the industry-standard 8255, or a couple of TTL (transistor-to-transistor logic) latches. Many manufacturers supply termination boards with optoisolated conversion for AC voltage sense and control, or relays for digital control of user-supplied sense and control circuitry.

Timers are most often of the 8253 type: three 16-bit counter/timers in a package. They are typically used for timing A/D conversions, for the counting of external inputs, or for the generation of pulse widths. A realtime clock is of marginal use, excepting those applications that require unattended operation.

Several boards have their I/O connectors (both analog and digital) sprinkled across them. It is quite a task to connect the multiplicity of cables and thread them. When the cables are connected and threaded through the cable opening, many invectives are generated. More importantly, stringing unshielded digital I/O cables across the top of sensitive analog circuitry is asking for trouble. The better data acquisition boards (IBM, Data Translation, MetraByte) have a single connector at the proper end. The user simply installs the board and hooks up his cable.

The cable or cables also contribute to the characteristics of the analog I/O. Unshielded ribbon cable adds approximately 14 pF per foot of capacitance to the I/O line, shielded cable about 25 pF per foot. The user must be aware of the length of the I/O cables and of the added capacitive load they provide.

A final consideration regarding I/O cables applies to all of the boards except IBM's: when the user connects the I/O cables to the data acquisition board, he nullifies precautions the PC manufacturer took to keep RFI (radio frequency interference) and EMI (electromagnetic interference) inside its covers. For example, if he hooks up three-foot I/O cables, the PC becomes a broadband radio station with a three-foot antenna. The user must be aware of relevant FCC regulations and take appropriate measures to curb interference.

Calibration. The user should calibrate the data acquisition board upon its arrival. Another calibration should take place after one month, then yearly. The bulk of time-related drift occurs within the first 1,000 hours. Calibration usually requires equipment unavailable to the average user. For 12-bit systems, a DC voltage calibrator with overall accuracy better than 60 ppm (parts per million) is mandatory. This, used in conjunction with a 5½-digit DVM (digital volt meter), should be sufficient.

Many of the boards will require recalibration should the A/D or D/A ranges be changed or the instrumentation amplifier gain altered. A prudent measure for any set-up is to dedicate two of the analog input channels for autozero and autocalibration. Software then can provide the necessary correction. The autozero channel simply connects to analog ground, thereby measuring the channel offset. The autocalibration channel connects to a known reference (a user could design his own based on an aged LM399 from National) for calculating the overall channel gain. Both time- and temperature-related accuracy dependencies can be corrected using this technique.

Software. Three software-related items should be available with each board. First, the instructions should show how

TABLE 4: *Summary of Electrical Characteristics*

	BURR-BROWN			DATA TRANS.	IBM
	20002	**20019**	**20017**	**DT2801-A**	**BOARD**
INPUT RESISTANCE (Ohms)	10^9	10^6	10^{10}	10^8	10^8
INPUT CAPACITANCE (pF)					
Channel on					
Single-ended	50	25	N/A	100	N/A
Differential	30	N/A	20	100	200
Channel off	5	5	20	10	200
OFFSET VOLTAGE	Trim	Trim	Trim	Trim	Trim
OFFSET VOLTAGE CHANGE WITH TEMPERATURE CHANGE (ppm/degree C)					
All gains	—	+/−15	—	+/−20	+/−24
Gain=1	+/−110	—	2	—	—
Gain=10	+/−20	—	6	—	—
Gain=100	+/−20	—	50	—	—
Gain=1,000	+/−20	—	500	—	—
INPUT BIAS CURRENT (nA)	+/−30	+/−300	+/−50	+/−20	+/−300
INPUT BIAS OFFSET CURR. (nA)	+/−30	N/A	+/−2.5	+/−20	+/−300
GAIN CHANGE WITH TEMPERATURE CHANGE (ppm/degree C)					
All ranges (min/max values)	+/−75	+/−30	+/−10 to +/−30	+/−35	+/−32
Linearity (percent)					
All gains	—	+/−0.01	—	<0.01	<0.02
Gain=1	+/−0.04	—	+/−0.03	—	—
Gain=10	+/−0.04	—	+/−0.03	—	—
Gain=100	+/−0.05	—	+/−0.05	—	—
Gain=1,000	+/−0.065	—	+/−0.1	—	—
COMMON MODE REJECTION RATIO (DC) (dB)					
All gains (min/max value)	80/106	N/A	70/90	80	72
CHARGE INJECTION (pC)	10	10	N/A	10	150

[a] *When 50-mV channel selected. 10^9 Ohms.*
[b] *Isolated from inputs by 100-KΩ resistors.*
[c] *Except 50-mV range, when it is +/−10 ppmm/degree centigrade.*
[d] *Effects swamped by 0.01-microfarad capacitor at input.*

TABLE 5: *Summary of Digital-to-Analog Characteristics*

	BURR-BROWN		DATA TRANS.	IBM
	20003	**20006**	**DT2801-A**	**BOARD**
ACCURACY	Trim	Trim	Trim	Trim
RESOLUTION	12	16	12	12
FAULT PROTECTION	No	No	No	No
MAX. LOAD CAPAC. (nF)	0.5	0.5	500	500
OFFSET DRIFT WITH TEMP. (ppm/degree C)	+/−60	+/−10	+/−30	+/−24
GAIN DRIFT WITH TEMP. (ppm/degree C)	+/−80	+/−25	+/−30	+/−35

[a] *Maximum variation is within the overall accuracy specification of 10 percent.*

to interface to the board at the lowest software level; that is, all of the ports the board uses for control and I/O should be discussed thoroughly, and examples should be provided.

Second, software drivers that provide functions for access by a reasonable number of high-level languages should be included. Of course, the user should be sure a particular language is supported before purchase.

Third, the package should include a menu-driven control program that would enable the user to perform some simple tasks to ensure the board's function independent of the rest of the system. This would serve two purposes: as an initial check when the user first obtains the board and as a debugging aid in interfacing to the real world.

None of the manufacturers supplies all three elements. For that matter, none seems to offer *complete* software control over its hardware. Range changes, gain changes, and measured quantity (voltage, current, or resistance) were, for the most part, set by switches or jumpers on the data acquisition board inside the PC. No read-back capability is included for determining the resultant board configuration. In a dedicated use, where the board configuration is set for good upon installation, this is not a problem. In general use, however, or when more than one user is involved, each user must check the position of all jumpers and switches.

Technical assistance. All of the manufacturers except IBM provided prompt telephone technical assistance. The representatives seemed capable of handling all software-related questions. However,

METRABYTE			**SCIEN. SOL.**	**STRAWBERRY TREE**		**WEST. TEL.**
DASCON 1	**DASH 8**	**DASH 16**	**LAB MASTER**	**ACPC-14-16**	**ACPC-16-16**	**ICIS**
10^{10}	10^{10}	10^{9}	10^{8}	200,000[a]	200,000[a]	10^{7}
N/A	25	50	100	N/A	N/A	N/A
25	N/A	30	100	10,000[b]	10,000[b]	55
10	5	5	10	10,000	10,000	5
Autozero	Trim	Trim	Trim	See text	See text	Autozero
Autozero	+/−10	+/−12	+/−20	See text	See text	Autozero
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
1	100	10	+/−20	10	10	+/−100
1	N/A	2	+/−20	1	1	+/−35
+/−25	+/−25	+/−25	+/−35	+/−100[c]	+/−100[c]	+/−100
+/−0.01	+/−0.02	+/−0.02	<0.01	+/−0.04	+/−0.04	+/−0.01
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
60	N/A	90	80	50/110	50/110	70/110
10	10	10	10	—A	—[d]	10

The manufacturers' specifications quote the input characteristics of the board for a zero input impedance. The actual value should be recalculated for the nonzero value of a given application. The change injection value for the IBM board is comparatively high. The voltage offset and voltage drift with temperature are not specified separately for the Strawberry Tree boards.

METRABYTE			**SCIEN. SOL.**	**STRAWBERRY TREE**		**WEST. TEL.**
DASCON 1	**DASH 8**	**DASH 16**	**LAB MASTER**	**ACPC-14-16**	**ACPC-16-16**	**ICIS**
Trim	N/A	Trim	Trim	10%	10%	0.1%
12	N/A	12	12	8	8	12
No	N/A	No	No	No	No	No
0.5	N/A	0.5	0.5	0.5	0.5	0.3
+/−10	N/A	+/−5	10	—[a]	—[a]	10
+/−30	N/A	+/−10	30	—[a]	—[a]	10

The D/A output characteristics show a variation in the maximum load capacitance that can be applied without ringing.

only a few could provide answers when the inquiries turned to analog circuitry, specifications, or interfacing.

INTERNAL ACQUISITION

Some of the manufacturers represented here offer more than one data acquisition product or combination of elements. As mentioned previously, tables 1 and 2 capsule the boards' basic features and significant components, respectively. In addition, table 4 summarizes their electrical characteristics, and table 5 lists their D/A attributes.

Tests were conducted using an Electronic Development Corporation DC Voltage Calibrator, with an overall accuracy to within 20 ppm, a Keithley 191 5½-digit DVM, and a Hewlett-Packard 3320B Frequency Synthesizer. All tests were conducted at room temperature and nominal humidity.

Burr-Brown. The Burr-Brown modular system occupies at least 1½ card slots; in most cases, 2 slots are required. It is the most flexible system, offering a range of modules and termination boards. (See photo A.)

Although only the motherboard interfaces to the PC edge connector, the daughterboards hang over enough so as not to allow another card to be plugged in. The motherboard is sparse: its only components are two 82C55 parallel I/O ports, a DC-to-DC converter (+5 to ±15 V), and some TTL logic gates; and it is memory-mapped. Connectors across the top of the motherboard accommodate three data acquisition daughterboards in a mix-and-match approach, for hardware customization. Each daughterboard is 3.9 inches

TABLE 6: *IA BW Limit of 20002 Module*

GAIN	1% ACCURACY	1 LSB ACCURACY
1	71.0 KHz	11.0 KHz
10	21.0 KHz	3.3 KHz
100	4.3 KHz	663.0 Hz
1,000	342.0 Hz	53.0 Hz

The limited BW in the IA section of this Burr-Brown module limits the sampling frequency. This, coupled with the low slew rate of the IA, gives a worst-case limit of 3.2KHz.

TABLE 7: *IA BW Limit of 20019 Module*

GAIN	1% ACCURACY	1 LSB ACCURACY
1	43.0 KHz	6.6 KHz
10	4.3 KHz	663.0 KHz
100	427.0 KHz	66.0 Hz
1,000	43.0 Hz	6.0 Hz

This Burr-Brown module also has a limited BW. Because the IA cannot be bypassed, this places a limit on the maximum signal frequency that can be accurately collected to 1.6 KHz.

square and contains an identifier that can be read by software for a simple installation. One nice design feature of this system: the motherboard and all daughterboards are of four-layer construction. This greatly attenuates PC-induced noise.

The motherboard reviewed (20001C-2) comes with 32 digital I/O ports. The digital I/O lines provide normal LSTTL input and output drive levels. Another motherboard is available without this option (20001C-1). Injudiciously, the digital I/O connectors are located at the far end of the board, and the nonshielded cables that connect them to the outside world must travel across each of the analog modules. This increases the amount of digital noise pickup by these modules. Although installation of the modules into the motherboard and motherboard into the PC is easy, the routing of more than one shielded I/O cable through the back panel is cumbersome. All of the termination panels were of simple printed circuit boards, and mounted on standoffs. Each had sufficient area for supplementary interface circuitry.

Seven Burr-Brown modules were reviewed. Three others are available: a trigger alarm module that can initiate conversions, a digital I/O board, and the 20021, which provides eight channels of analog output by multiplexing a single D/A converter.

The 20002 Analog Input Module is a 16-channel, single-ended or eight-channel differential input 12-bit A/D system. The input multiplexers are Burr-Brown's version of the Harris 508 (BB MPC8S). An instrumentation amplifier (Burr-Brown PGA200) gives programmable gains of 1, 10, 100, and 1,000. It is followed by a National LF398A sample-and-hold that feeds a Harris 574AKD 12-bit A/D converter. The total conversion time for a given signal ranges from 40 microseconds for a single channel to 83 microseconds for multiple successive channels when using unity gain. A gain of 1,000 requires slowing the overall conversion time to 753 microseconds. Total conversion time increases as the gain increases due to the necessary settling time in the instrumentation amplifier. Note that although the offset can be trimmed to zero for each gain, appropriate compensation must be made in the software (or a channel must be designated for autozero) if more than one gain range is used. Tests revealed that the gain does not have to be tweaked between ranges, because the gain inaccuracy is only 0.02 percent on each range. The A/D range can be changed by jumper for −5 to +5 V, 0 to +10 V, and −10 to +10 V.

Offset voltage drift is 100 ppm per degree centigrade (approximately ½ LSB) for unity gain. This improves dramatically, to 20 ppm, for the other gain ranges. The linearity inaccuracy of the programmable gain amplifier showed a loss of about two bits of the A/D resolution. Users should note with caution that the high bias current shown with testing could cause significant measurement errors even with small source resistances. On the gain-of-1,000 range, a 1.6-KΩ source impedance displayed an offset of 1 percent of the range. Even though this module's I/O cable is shielded, tests showed ten counts of noise on the gain-of-100 range and four counts of noise on a gain of 10. This is a good argument for not using higher gains inside the PC in conjunction with successive approximation converters.

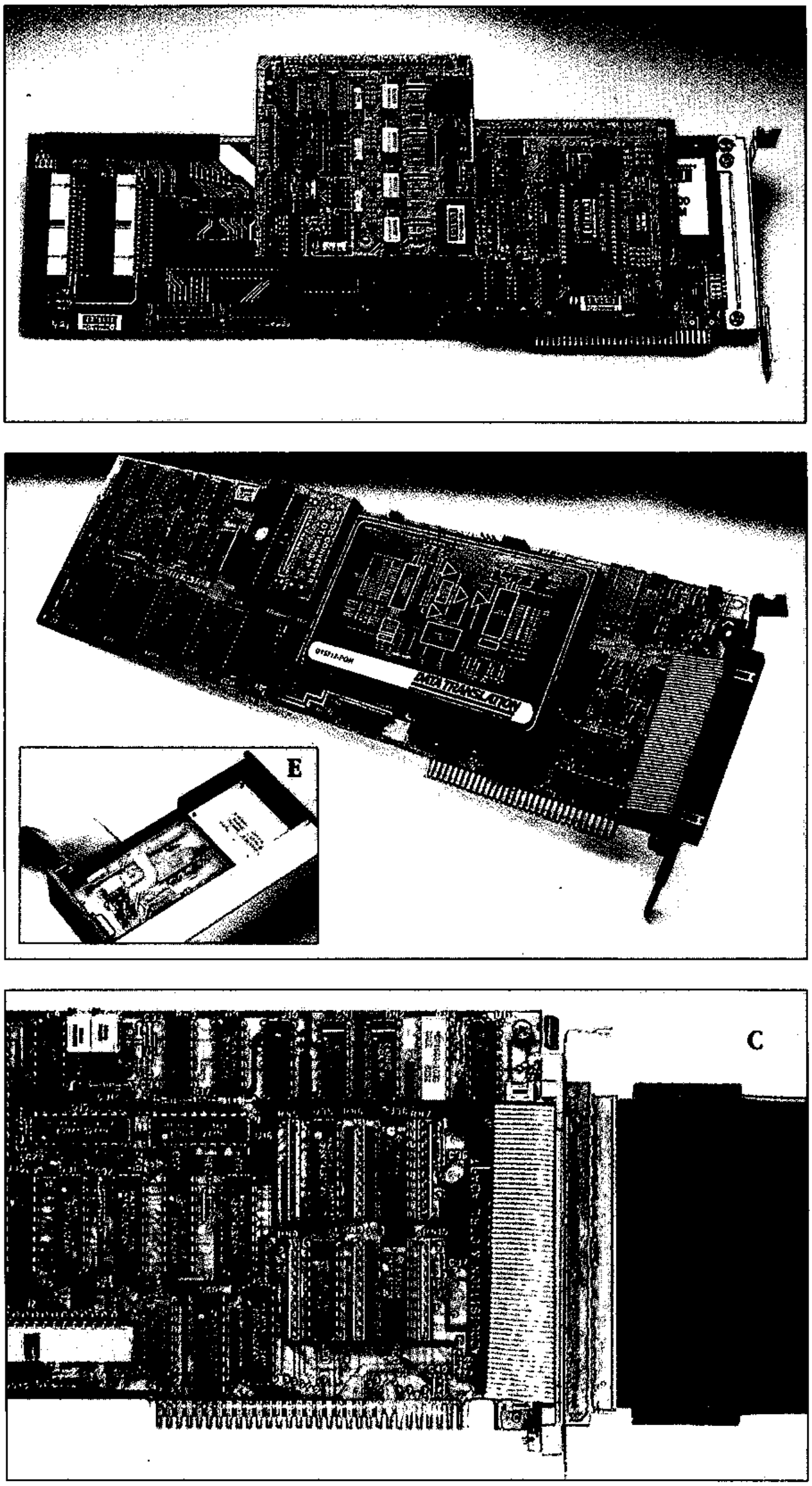
The module is capable of converting a single channel in 31 microseconds. However, testing showed that the limited bandwidth in the instrumentation amplifier limits the maximum conversion frequency (see table 6). In addition, the relatively sluggish slew rate of the instrumentation amp (0.4 V per microsecond) limits the maximum signal frequency for a full range input (20 V peak to peak) to 3.2 KHz.

The 20005 Analog Input Expansion Module, which consists of four Harris 508A multiplexers, is configurable to give an additional 32 single-ended or 16 differential input channels. Input capacitance ranges from 5 pF off channel to 30 pF on. Input leakage current is below 100 pA for both on and off conditions; however, the user should remember that this will double every 10 degrees centigrade.

Providing a means to grab four channels of data simultaneously without the accompanying time skew is the 20017 Sample-and-Hold Module. Each of the four National LF398A sample-and-holds is preceded by a Burr-Brown INA102G instrumentation amplifier. Gains of 1, 10, 100, and 1,000 are available by jumper selection. The user must recalibrate when changing gains because the tested gain inaccuracies range from 0.1 percent to 0.75 percent. Nonlinearity is worst on the gain in the 1,000 range: 0.1 percent. The input bias current is ±50 nA (nanoamperes)—which puts it on the high side. The low bandwidth of the instrumentation amplifiers severely limits the maximum frequency that the module may accurately acquire (see table 7).

Unfortunately, bypassing the instrumentation amplifiers and feeding the signal directly into the sample-and-holds is not possible. The abysmal slew rate of the instrumentation amplifiers limits the maximum signal frequency for a full range input (20 V peak to peak) to 1.6 KHz.

The 20019 High Speed Data Acquisition Module sports a fast monolithic sample-and-hold (Teledyne Philbrick 4866) followed by a 10-microsecond conversion time A/D (Burr-Brown ADC84KG). The input is multiplexed by a Harris 508A providing eight single-ended input channels. The input resistance was measured as 1 MΩ (megohm) and the bias current was 100 nA, as the manufacturer specifies. This definitely is a module for use with low source impedances for high-frequency applications. Throughput can be as high as 87,000 samples per second. Both gain and offset drift are generally negligible. The 2-MHz gain bandwidth of the sample-and-hold permits 1 LSB accuracy to 44 KHz. Gain and offset should be readjusted if the jumpers are configured



The modular system of the Burr-Brown product (photo A) enables the user to create configurations for specific applications. The addition of these modules makes the board overhang the adjoining slot such that it is not possible to put in another card. In photo B, the Data Translation module that contains the A/D converter is apparent on the data acquisition board. This module also is used by Scientific Solutions (photo E inset), but on the LAB MASTER, the module is in the external connection box, not on the main board. In photo C, the shielding of the cable on the IBM configuration extends onto the board, making a true shielded system. None of the other boards has this essential feature. This board's I/O connector is at the logical end so that analog signal lines do not cross circuitry unnecessarily.

PHOTOGRAPHS • DAVID ARKY

for an alternate range—those available are ±2.5 V, ±5 V, ±10 V, 0 to +5 V, and 0 to +10 V full scale.

Burr-Brown's 20003 and 20006 are Dual D/A Converter Analog Output Modules with 12- and 16-bit resolution, respectively. The 20006, however, is accurate and monotonic in nature over a 14-bit range because it uses a Burr-Brown DAC709. Its drift is in the range of a few LSBs per degree centigrade. On the 20003, the temperature drift of the Burr-Brown DAC811 is negligible. The user must not load the output with more than 500 pF of capacitance (cable plus load) in order to prevent ringing and possible oscillation. Both modules can force 0 to 10 V, −5 to +5 V, and −10 to +10 V, jumper selectable. Output current is limited to ±5 mA. Both modules require recalibration when changing ranges.

The 20007 Counter/Timer/Pulse Generator Module supplies four general purpose, 16-bit counter/timers and a flexible rate generator with an output frequency of from 0.002 Hz to 2 MHz. All inputs and outputs are TTL compatible. This device also can serve as a useful time base generator for A/D modules on the same motherboard. The module is built around two 8254 counter timer chips that use an 8-MHz crystal as their main time base.

One price the user pays for modular flexibility is the amount of flipping necessary in using the documentation—from the software section, to the information on the motherboard, then back to the details on a particular module, and finally to the description on the termination panel. Even so, the information is clearly written. Each module manual provides sufficient information for the user to write low-level drivers. Burr-Brown supplies an 8½-by-11 binder that accommodates the separate information packets.

The company's software interface consists of high-level support routines for BASIC, C, and Turbo Pascal. Moreover, sufficient information is provided on the lower-level mechanisms of interfacing to these drivers to make it possible to use them with assembly language. The 22 support routines share common ancestry, which makes it convenient for the user who programs in multiple languages. He must be careful, however, to load the correct driver for the language in use. This is accomplished by running the appropriate program one time upon powering up. The manual includes six sample programs in each of the three supported languages, with excellent documentation.

Technical questions are fielded by an apparently knowledgeable and energetic staff. Burr-Brown was one of the few manufacturers that could provide answers to analog-related questions.

Data Translation. An Intel 8742 helps to control the Data Translation data acquisition board: the DT2801-A exhibited the fewest design flaws of the products reviewed and its performance was quite acceptable. A total of 16 single-ended or eight differential 12-bit analog input channels, two 12-bit analog output channels, and 16 parallel I/O lines are packed onto the card. A variety of analog input options are available by changing the analog input module. The reviewed board contains Data Translation's DT5712-PGH module with four programmable gains: 1, 2, 4, and 8 (see photo B); the DT5712 module itself is a shielded enclosure for the A/D, an excellent precaution. (More on the DT5712 module is provided in the discussion of Scientific Solution's system.)

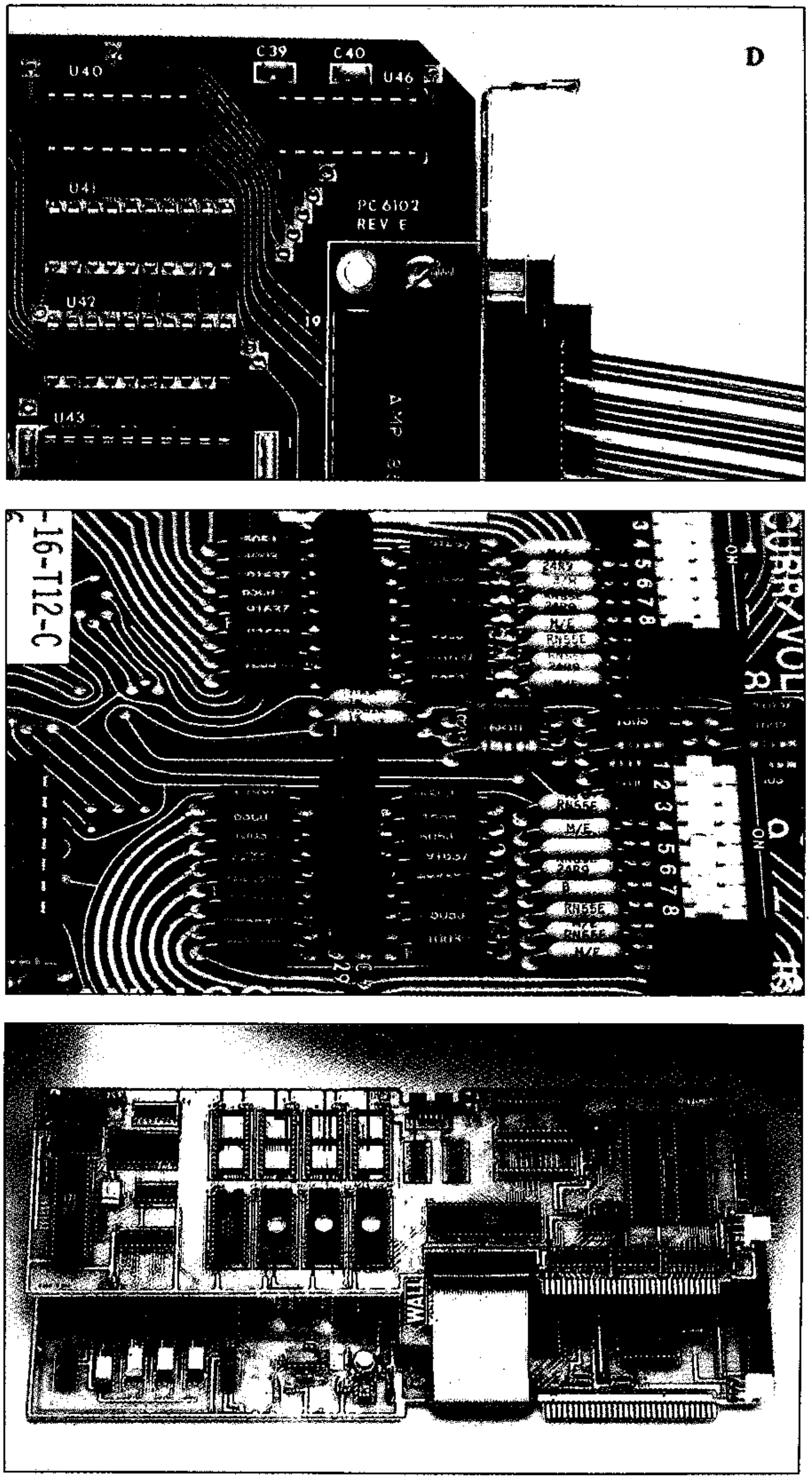
The maximum throughput to memory was specified as 27,500 samples per second. Overall input accuracy is ±0.05 percent for any gain, and gain and offset drift with temperature is negligible. Tests showed that the high bandwidth of the limited gain instrumentation amplifier provides for accurate performance up to the Nyquist rate (13 KHz).

Tests also revealed that the D/A channels are compensated for capacitive loads to 0.5 microfarads. As usual, changing the range requires recalibration. Drift in offset and gain is roughly 1 LSB per 10 degrees centigrade.

The board installs easily. The three-foot unshielded ribbon cable connects to the card and the terminal printed circuit board, mounted on rubber feet. The terminal card brings out the signals to barrier strip screwdriver connections. Space is provided for an optional cold junction sensor. This is of limited value, however, because no isothermal plate is present to keep the sensor at the same temperature as the connections.

Two manuals are packaged with the board. The first details hardware aspects, low-level programming, and programming in BASIC. The second is the user manual for the PCLAB machine language routine library; it provides high-level functions for BASIC, C, FORTRAN, Turbo Pascal, and assembly language. Neither manual has an index, and page flipping becomes the rule; however, the information is complete and clearly written.

The lowest level of programming requires sending a command byte followed by optional parameter bytes to



The MetraByte DASH 16 board (photo D) has a four-layer construction with excellent ground planes around the components. This is a simple and effective method of reducing noise that is not employed by all of the manufacturers reviewed. The disc ceramic capacitors that are used on the Strawberry Tree Acquisition Board in photo F are a surprising design choice. Their temperature stability is not really suitable for this type of application. The Western Telecomputing board pair (photo G) does not have a solder mask, an unusual and substandard printed-circuit board fabrication omission. This set is designed for a slightly different purpose than the other boards reviewed. It can be used in unattended mode for applications with a slow conversion rate (meteorological, for example).

the on-board microprocessor; the board implements 16 pseudocommands. The high-level functions are condensed into a series of these low-level commands to the 8742. In every case, a brief time delay takes place between when the command is sent and when the board has been configured by the 8742. Time-sensitive measurements should take this into account and use hardware initiation of tasks whenever possible. Direct access to the A/D, D/A, digital I/O, and timer functions is not possible.

As is the case with all of the boards, programmed data transfers of more than 2,000 per second require turning off the PC's time of day clock so that the CPU can orchestrate the data transfer without interference.

Data Translation offers technical assistance, but it seems limited. Analog questions that could be researched in the company's better-than-average specifications were handled easily. Tougher questions present a challenge.

IBM. The IBM Data Acquisition Board offers four differential channels of 12-bit analog input, two channels of 12-bit output, 32 parallel I/O lines (16 input and 16 output), and an Intel 8253 for counter/timer applications. Conversion from A/D to memory is specified as 15,000 conversions per second.

This was the only board reviewed that maintained shielding from the printed circuit board to the terminal box (see photo C); however, the connecting cable is not keyed, so the user must trace to the terminal box to locate pin 1 on the cable and properly attach it to the connector on the data acquisition board edge. Aside from this, installation is easy. The terminal box is a printed circuit board with barrier strip screwdriver connections inside a sheet metal box. The data acquisition board itself has a four-layer design, but there is little evidence of ground planes around the analog circuitry.

Each of the four differential input channels is protected by 10-KΩ input resistors and diode clamps to the supplies. The Analog Devices 7502 multiplexer is followed by a Texas Instruments TL064 buffer amplifier before feeding an AD583K sample-and-hold that doubles as the differential amplifier. The 7502 gave the highest charge injection of all the boards reviewed: 150 pC; the system's overall accuracy was within 1 LSB, 0.025 percent; and input bias current was measured as high as 300 nA, which is rather large.

IBM's four input channels are too few for general purpose use. If an application calls for autocalibration and autozeroing, the user is left with only two input channels. Recalibration is necessary when changing (by dip switch) between the ranges of 0 to +10 V, −5 to +5 V, and −10 to +10 V.

The two D/A channels are constructed from 12-bit Analog Devices AD7545KN D/A converters followed by AD644KH operational amplifiers. The reference for each channel is stolen from the A/D converter. Output ranges are 0 to +10 V, −5 to +5 V, and −10 to +10 V, and require recalibration when changed. IBM does compensate its output amplifiers to accommodate capacitive loads to 0.5 microfarads.

Two 34-pin ribbon cable connectors located on the board for IBM's expansion bus will accommodate data acquisition products that are as yet unreleased. The package includes a well-documented software manual and a fine hardware technical reference manual. IBM has included a full schematic and a generally excellent discussion of circuit operation.

> *IBM's board maintains shielding from the printed circuit board to the terminal box; but the connecting cable is not keyed, so the user must do some tracing.*

IBM supplies 15 functions for use with BASIC, C and FORTRAN. A device driver, included for loading at boot time, requires only a simple addition to the user's CONFIG.SYS file. The functions share a common heritage, so changing from language to language goes very smoothly. The technical manual provides information to enable the user to write his own low-level drivers.

Requesting technical information from IBM was difficult; it involved a local dealer and the representatives answering at the IBM information number. In the end, the answers supplied were incorrect or not to the point.

MetraByte Corporation. Three of this company's data acquisition cards were considered. All three have 37 pin-D connectors for connection to the outside world, making their installation easy, and all three are I/O mapped, with the address selectable by DIP switch. An unshielded ribbon cable connects the card to a plastic terminal box which contains binding posts and some auxiliary circuitry mounting space.

The half-card DASH 8 accepts eight single-ended analog input channels through its Harris 508A multiplexer. A National LF398 performs the sample-and-hold and a Harris 574AJD A/D converts the data. It is permanently configured for a −5 to +5 V range. Conversion time of the A/D is a maximum 35 microseconds, and its overall accuracy is specified as 0.034 percent. Acquisition time of the sample-and-hold typically is 15 microseconds. Its input current was rather high at 100 nA maximum, and its gain and offset voltage drift are negligible. The sampling error is slightly larger than for other boards. For example, at an input slew rate of 0.002 V per microsecond, it is 1 bit. If the input is a 10-V peak-to-peak signal at 32 Hz, the sampling error will be an additional bit.

The board also contains eight bits of I/O (four input and four output) and an 8253 counter timer (three 16-bit channels), and it can interrupt the PC on INT 2 through 7, jumper selectable.

The DASH 16 full-size card gives 16 single-ended or eight differential input channels to its 12-bit A/D (Harris 674AJD), two D/A channels, parallel I/O of four lines each input and output, and a three-channel, 16-bit timer/counter (Intel 8253). Conversions may take place at a rate of 35,000 per second on a single channel. The board has a four-layer construction with excellent ground planes (see photo D) surrounding the analog input section.

The card's multiplexers are the ever-popular 508A, and the sample-and-hold is National's LF398. Its acquisition time and sampling error are the same as that for the DASH 8.

The DASH 16 has switch-selectable gains of 0.5, 1, 2, 5, and 10, although the board requires calibration when gain is changed. The instrumentation amplifier is PMI's AMP-01, which yields ranges from ±0.5 V to ±10 V bipolar and +1 V to +10 V unipolar. Gain peaking of the lower gains is quite noticeable in the 10 KHz range (see the comment below in the discussion of the EXP 16). The user should not expect better than 1-percent accuracy for frequencies above 5 KHz. Its data transfers from A/D to memory can be programmed or under DMA control; its overall accuracy at DC is 0.034 percent.

Input current was measured as 10 nA. The specifications showed that the gain drift and nonlinearity are negligible. Offset voltage drift can be as high as ½ LSB per degree centigrade.

The D/A channels are 12-bit Analog Devices AD7548KN followed by PMI OP-07s; loading the outputs with more than a few hundred picofarads is not recommended. A unique feature of this board is that the input to the D/As can be either an on-board reference voltage for normal output voltage generation or a user-supplied signal. This could be used as an AC signal amplitude control, for example. Both gain and offset drift with temperature are negligible.

MetraByte's DASCON 1 is the low-frequency (30 conversions per second) integrating A/D cousin of the above two boards. Each of the four input channels is protected to 120 V RMS and multiplexed by a CD4052. Full-scale input voltage is ± 2.0475 V. The A/D is a Teledyne 7109, 12-bit A/D, and sign converter. Its accuracy is 0.034 percent. Gain and offset drift are negligible and input current is 1 nA maximum. The reference is a National LM329BZ.

Two of the input channels are configurable as RTD (resistance temperature detector) inputs, with built-in 1-mA current source. The other two channels may accept optional National LM363 instrumentation amps for gains of 10, 100, and 1,000. Input current then increases to a maximum of 10 nA. Instrumentation amplifier gain cannot be trimmed (except to within 1.5 percent); the user will need to calibrate with a known voltage and handle compensation in the software. Offset voltage can be trimmed, but it can drift a maximum of 10 LSB per degree centigrade. The common mode voltage range is on the low side: −2.7 to +3.8 V.

The board is made complete with a battery-backed realtime clock, 12 bits of parallel I/O, and two D/A channels (Analog Devices ADDAC80NCBI-V). Light capacitive loading (less than 1,000 pF) is recommended. As with the other boards, the D/A converters require recalibration if their range is changed.

The EXP 16 is a 16-analog-input expansion interface PC board that can be daisy-chained and is mounted on standoffs. It can be used with the DASH 8 or the DASH 16. Although a thermal sensor is present on the 4.7-by-8-inch board, it is not in intimate thermal contact with the terminal blocks. The board contains two Harris 506A multiplexers and a PMI AMP-01 instrumentation amplifier. Eight switch-selectable gains from 0.5 to 1,000 configure the overall gain for all channels. Gain and offset will have to be tweaked whenever the gain range is changed. Settling time to 0.01 percent varies from 12 microseconds for low gains to 50 microseconds for a gain of 1,000. The PMI AMP-01 gain versus frequency is adequately controlled for all except unity gain. In that case, the user should be cautious if the frequency of the input signal exceeds 10 KHz. The PMI AMP-01's frequency response has a 5-dB peak at 100 KHz. In fact, signals at 10 KHz showed three-percent peaking relative to a 1-KHz signal. The board is delivered with 8-Hz filters on all input channels; the filters consist of a 10-KΩ resistor from each of the inputs, which are bridged by a 1-microfarad capacitor. Each channel on the board requires a 170-millisecond settle time to 1 LSB.

Nonlinearity of the PMI AMP-01 is nearly nonexistent, as is gain and offset voltage drift, except for the gain 1,000 range. There, the offset voltage drift can be ½ LSB per degree centigrade.

The documentation on all three data acquisition boards is clear and well presented. MetraByte goes so far as to offer assistance, albeit limited, on interfacing and grounding applications. The only omission is an adequate referencing of the programs on the accompanying disk. As it is, the user must load and list each one, and read the comments, to find out what each program does.

The LAB MASTER outputs are not protected and supply only 5 to 10 mA of output current. When loaded with a few thousand picofarads of capacitance, they oscillate.

Compared to other documentation, the EXP 16 manual is shockingly inadequate. MetraByte installed 8-Hz filters on all channels, yet the specifications call for the board to be without filters. No instructions are included for removing the filters (which requires desoldering), and the user must trace circuitry on the board to determine which components require removal.

BASIC was the language of choice with these products. The drivers are loaded using either a BASIC program called LOADCALL or by placing a standard header at the beginning of each applications program. The interface to the drivers is accomplished through BASIC CALL statements. All three cards interface to BASIC in the same way. The DASH 8 and DASH 16 provide 17 high-level commands, the DASCON 1 provides 10. Sufficient information is provided to interface to the cards with user-supplied low-level software. Source code is available for the drivers, permitting the user to interface to other languages. BASIC programs were included for thermocouple linearization and for graphing results of data logging. The source code is accessible for all routines.

MetraByte's technical assistance was minimal in dealing with analog-related questions, but response time was good.

Scientific Solutions. The Scientific Solutions LAB MASTER, previously known as the Tecmar LAB MASTER, was reviewed by *PC Tech Journal* in March 1984 (see "Digital-to-Analog, Analog-to-Digital," Peter G. Aitken, p. 104). The basic board that fits inside the PC accommodates the 24 parallel I/O lines (an Intel 8255), the counter/timer, and the two D/A channels. An unshielded ribbon cable connects the data acquisition board to an external sheet-metal-and-plastic box that contains the A/D section. Connections to the A/D are made at ribbon cable connector headers.

The A/D in the outside box reviewed is a 12-bit Data Translation DT5712 module capable of 30,000 conversions per second (see photo E). The module contains a straightforward successive approximation A/D converter built around an AMD 2504 successive approximation register, an Analog Devices 565 D/A, and a Linear Technology 311 comparator. The input multiplexers are Harris 508As, and the instrumentation amplifier is built around PMI OP-15 operational amplifiers. The IA is followed by a National LF398A sample-and-hold. The PMI OP-15 consists of precision BIFET (bipolar and field-effect transistor on the same IC) operational amplifiers with bias current in the picoampere range; leakage current of the input multiplexer, however, brings the input bias current at the module inputs up to the nanoampere level.

Potentiometers are situated on the module for adjustment of offset and full scale gain, but the manual does not address the subject of calibration.

The D/A converters on the board are Analog Devices DAC80s. These 12-bit converters are industry workhorses that consist of a conventional voltage reference, a resistor ladder, current switches, and an output amplifier. The outputs are not protected (other than the output amplifier short circuit current limiting) and can supply only 5 to 10 mA of output current. When loaded with a few thousand picofarads of capacitance, they produce undesirable oscillation. As with all of the reviewed boards, the oscillation occurs more readily when the D/A converter is forcing a negative voltage. This is caused by the output amplifier. Conventional operational amplifiers use lateral PNP transistors in their output stages for swinging down to the negative supply. These PNPs have low bandwidth (ft) and decrease the phase margin of the overall amplifier when they are active. Both D/A converters require recalibration when the ranges are changed. Ranges can be changed only by on-board jumpers.

The counter timer used (AMD 9513) is probably the best available all-purpose timer for general laboratory applications. Enormously versatile (to the point of confusion), this device can handle nearly any rate or frequency output transducer or counting and timing needs the user may have.

The manual covers the LAB MASTER in all of its forms, including the 14- and 16-modular converters that can replace the 12-bit module. The material was confusing to follow in setting up the system, and the manual was just as difficult to use when looking up information. Programming help consisted of several brief, but very helpful low-level BASIC examples printed in the manual. No disk accompanied the board.

Installing the LAB MASTER requires only a screwdriver, and routing the single unshielded cable to the A/D box through the back panel is easy. Space gets a little tight, however, as the parallel I/O, timer/counter I/O, and D/A converter I/O cables are connected and routed through the back.

The Scientific Solutions technical representatives had difficulty answering analog-related questions outside of the company's published specifications.

Strawberry Tree Computers. Two boards from Strawberry Tree were reviewed. The 14-bit resolution version (ACPC-14-16-T12-A-C) provides 16 analog input channels, 16 bits of digital I/O, or two channels of poorly supported analog output. The 16-bit card (ACPC-16-16-T12-A) drops the two analog output channels and is otherwise the same as the 14-bit card. Each card carries a battery-backed realtime clock.

Testing of both cards revealed that the best specified accuracy is only 0.04 percent, which is a little better than 11 bits, and this is only for the 50-mV and ±25-mV ranges. All other ranges for the boards are accurate to only 1 percent (approximately 7 bits). Current ranges have 1.5 percent basic accuracy; the sense resistor is 10 ohms.

The analog channels are protected to 50 V continuous and 150 V intermittent. The digital I/O channels are nonprotected MOS, although the terminal box can accommodate additional circuitry for protection; the terminal box also provides 7407 buffers for the digital outputs. Two of these boxes are required to bring out all 16 analog and 16 digital I/O channels.

Input resistance for the on channel is 1,000 MΩs for the 50-mV and ±25 mV ranges, but this drops to 200 KΩs when the channel is deselected; the resistance is 200 KΩs for all other ranges. Input current is not specified although it typically will run about 10 nA. Each input channel has a slow filter that consists of two 100-KΩ resistors and a 0.01-microfarads disc ceramic capacitor. The user should take normal precautions to guard against overvoltages in order to prevent dielectric absorption problems with the disc ceramics (see photo F). This dielectric absorption effect was achieved on the review board. Input common mode range is ±8 V.

> *The program for the Strawberry Tree boards is the best reviewed; the user can select analog scale factors, units, or ranges easily.*

These cards include the best reference tested: a National LM399 comes to the terminal box unbuffered. Its connection requires great care.

The A/D converter is a departure from the predominant successive-approximation types. It is an integrating voltage-to-frequency converter built around National's LM331. Resolution and conversion time can be traded off to meet special signal requirements.

The analog input section is optimized for thermocouple inputs. As general A/D inputs, the variation in input impedance and crosstalk between channels acts as a limitation to their instrumentation capabilities.

Although the cards' accuracy specifications are not good, resolution was verified at 14 and 16 bits. Temperature drift specifications are not broken out separately between drift and offset. On the 50-mV ranges, drift is 10 ppm per degree centigrade; on all other ranges, it is 100 ppm per degree centigrade.

These boards can experience a problem when the analog input goes over range. The displayed value may decrease, then go negative on a positive overload. This is especially hazardous in control loops, because it amounts to positive feedback. Also note that input scanning and conversion injects 10-mV spikes of approximately 1-microsecond duration into the inputs.

The analog outputs are ±10 percent accurate. They consist of Analog Devices DAC08 D/A converters, followed by National LM324s. Software support for these two output channels is minimal. The outputs are unprotected and, when loaded with more than a few thousand picofarads, they oscillate.

The manual, which is quite clear, contains the best discussion of interfacing different transducers to the card among the products reviewed. It is one of two manuals that gives a full schematic for the card and terminal box.

The software is excellent for most straightforward data acquisition and control applications. In addition, it is not copy protected. Full source code is available for the BASIC program, as well as for the device drivers on the 14-bit card. The device driver source code is not available for the 16-bit card. The software hooks are well documented and can be incorporated easily into a user's own BASIC program.

Thermocouple linearization is given for types J, K, W, R, A, E, B, G, C, and D. The cards' best accuracy is 0.7 degrees centigrade using an E-type.

The data acquisition and control program supplied with the Strawberry Tree card is very complete and the best reviewed. The user can set the clock; select analog scale factors, units, and ranges; specify channel and I/O names; set alarms on analog or digital I/O; and do some simple control loops. Data logging to disk and/or printer is included. The display of analog input voltages shows resolution down to the nanovolt range, which can be mildly irritating. No provision is made for easily changing the number of displayed digits. Another glitch was that over-range signals can produce in-range readings. The user must be aware of this to prevent positive feedback loops when the product is used in a control system.

Installation of the card with two terminal boxes is abysmal: weaving the four unshielded ribbon cables to four disperse connectors is nearly impossible with only one slot open in the PC. It is highly recommended that the user remove the adjacent card before attempting this installation.

Layout in the terminal box is very convenient, especially for the analog inputs. They connect to terminal posts mounted in a massive anodized aluminum plate for isothermal contact. The plate has a temperature sensor embedded in the bottom for thermocouple cold junction compensation.

The Strawberry Tree technical assistance was good. The representatives provided accurate information and were knowledgeable about analog circuitry.

Western Telecomputing Corporation. The ICIS two-board set is a unique departure from the other boards covered in this review—a data acquisition system designed primarily for unattended monitoring of meteorological or pollution events (see photo G). Because of this, conversion times are rather slow (10 to 100 conversions per second).

This system also was the only one reviewed that permitted battery backup to allow it to keep acquiring data after power to the PC had been withdrawn.

The two boards are connected to a 19-inch rack-mount termination panel with a 64-conductor unshielded ribbon cable. The boards tested were supplied without solder mask, an unusual and substandard printed-circuit board fabrication omission. Two Harris 506A multiplexers provide 16 differential input channels. Two sockets were left open for an additional 16 input channels. Inputs can be either voltage or frequency. Frequency inputs are counted by an 82C53 and stored in on-board memory; they are controlled by an on-board CMOS microprocessor, an 80C85.

Voltage inputs are routed to one of four instrumentation amplifiers (AD524AD), selectable by software. The amplifiers provide gains of 1, 10, 100, and 1,000. Gain coefficients are stored by the control program to gauge gain inaccuracy, obviating the need for potentiometers. The A/D is built around a voltage-to-frequency converter (Analog Devices VFC32KN) and AD584JH reference. The frequency is counted over a 10- or 100-millisecond period and stored as described above. The effect is that of an integrating A/D converter with excellent noise rejection.

The overall accuracy of the system is 12 bits when the conversion time is 100 milliseconds. Offset voltage is autozeroed periodically by the microprocessor. The gain nonlinearity is less than 100 ppm, and its temperature stability is excellent, with the exception of the 1,000-gain range, which is 100 ppm per degree centigrade.

The realtime clock requires the connection of the external battery backup because it operates in software on the 80C85. Eight D/A converters (two each of Analog Devices AD390JD quad D/A converter) may be installed for 12-bit resolution voltage output.

The accompanying documentation is disappointing. The manual fails to present clearly the necessary information. Locating specific items is further frustrated by the lack of an index.

Western Telecomputing includes what it calls DMS (for Data Monitoring System) in compiled BASIC. DMS is an all encompassing set-up, configuration, debugging, and unattended data logging software package. Menu driven, this software aids the user in quickly setting up the desired configuration and logging in data. Conversions from raw data to engineering units can use built-in linearization with up to a sixth degree polynomial. The system automatically computes and records maximums, minimums, averages, and standard deviation. It also permits timed control of the digital I/O lines. (The source code for this program is not included.)

The primary language link for this product is BASIC. A driver is installed at boot time and is accessed by BASIC CALL instructions; however, the manual's discussions of the 28 high-level commands are inadequate, and the manufacturer's technical support may be necessary to their use. Fortunately, during telephone conversations, the representatives seemed knowledgable.

FITTING THE SYSTEM

It is, of course, understood, that one board cannot satisfy the entire range or even a wide range of measurement needs. The nature of continuous real world data requires that the user tailor the measurement system to a specific problem. For unattended battery-backed operation, for example, the Western Telecomputing set fits the bill and is highly recommended, having been designed specifically for that application. For low-signal-level transducers, predominantly thermocouple, one of the Strawberry Tree boards is a good choice; they are not recommended, however, for general purpose use, especially for voltages above 100 mV.

The price for a particular configuration of data acquisition board also varies according to the specific application. A minimum configuration system can be purchased for as little as $500, but the nature of these products allows many different sized systems to be set up with correspondingly varying prices. The prices for the reviewed boards range from around $500 to $2,300.

For general applications, the Data Translation board is the best bet, encompassing the finest all-around features, excellent documentation, and good software support. It requires only one slot in the PC and installs easily. This board may not be perfect, but neither are these products as a whole.

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