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PC-BASED DATA ACQUISITION INTERFACE AND EXPANSION SYSTEM

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ABSTRACT

A hardware interface and expansion system for PC-based data acquisition and control systems was developed for use within the Kansas State University Agricultural Engineering Department. The system, consisting of an interface box and analog input satellite boards, was designed to allow easy connection of sensors and to expand the original analog input capacity. The interface box's star topology analog bus and the satellite board's optional thermocouple temperature compensation circuitry and instrumentation amplifier support are discussed. A variety of applications using the technology are presented.
KEYWORDS. Instrumentation, Data acquisition, Sensors.

INTRODUCTION

Data collection and process control needs in both research and teaching programs, especially in agricultural engineering departments, are quite diverse. A data acquisition and control system used in a variety of research and instructional applications should meet the following hardware requirements to be effective:

1. Be adaptable and flexible enough to meet the needs of a wide variety of applications. Thus, it should be able to digitize analog input voltages, produce analog voltages, handle digital input and output signals, and provide general purpose counters.
2. Be computer based with all of its advantages (programmability for each specific application, on-line analysis of data for experiment control, reduction, or display, and disk-based data storage).
3. Be portable (all or a major part of the system).
4. Be able to interface easily to standard commercial sensors (load cells, flow meters, rpm sensors, accelerometers, thermocouples, etc.).

A general purpose system should also have a modular and reusable library of data acquisition and control interface routines to speed development of application software. Discussion of the software tools used with this system, however, are not presented here since the focus is on the hardware aspects of an interface and expansion system for PC-based data acquisition and control systems. The tool box philosophy used to develop the software tools used for interfacing with a variety of data acquisition hardware and sensors is discussed elsewhere (Wagner and Funk, 1989a).

A review of currently available PC-based data acquisition and control systems, at the time the data acquisition expansion system was conceived (fall, 1984), found them to lack the necessary interfacing and expansion facilities required to easily connect a variety of sensors and control equipment. This lack of "plug-ready" capability for PC-based systems prompted the design and development of an interface box and satellite expansion board system. However, since the development of the interface box, analog bus expansion system, and satellite boards, vendors have improved their offerings.

The interface box and satellite board designs presented here are for a specific PC-based data acquisition and control system, but the concepts have been applied to other systems as well. A variety of applications which incorporate PC-based systems using the hardware interface and satellite expansion enhancements are described later. The success of these applications attest to how such systems can provide reliable, cost effective, and portable data acquisition and control solutions.

The hardware components of the PC-based data acquisition and control units discussed here consist of:
1. LabMaster*† data acquisition and control system,
2. interface box and analog bus expansion system, and
3. satellite expansion boards.

The LabMaster is briefly described first, to present the basic capabilities of the specific system used during development of the interface and satellite expansion system. The technical descriptions and functions of the interface box and analog input satellite board follows. Finally, a summary of various applications which incorporate these ideas is presented.

LABMASTER

The data acquisition and control functions are performed by a PC-based LabMaster system. The LabMaster consists of two printed circuit boards, a mother board containing the digital logic that plugs into an 8-bit

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* The use of tradenames in this publication does not imply endorsement of the products named.

† Marketed originally by Tecmar, Inc., Solon (Cleveland), OH, but later purchased by Scientific Solutions, Inc., Solon (Cleveland), OH.

PC bus expansion slot, and a daughter board that contains the analog input circuitry. A 50-pin cable is used to carry signals between the two boards. This two board concept allows utilization of different analog to digital converters and isolation of analog input signals from the digital PC bus.

The LabMaster system‡, provides the following components for data acquisition and control:

1. Three, 8-bit digital TTL-level ports that can be configured as either inputs or outputs through software control.
2. Five, 16-bit counters that can be programmed to provide a real-time clock, count external signals, generate output control frequencies, construct 32-bit counters, etc.
3. Two, 12-bit digital to analog converters that can be jumper configured for a variety of output voltage ranges.
4. A daughter board containing 12-bit resolution, 40-kHz, programmable gain analog to digital channels configured as eight differential inputs.

The PC-based LabMaster system meets all but one of the listed requirements for a portable, cost effective, general purpose data acquisition and control system. Like other PC-based systems, the LabMaster does not provide "plug ready" facilities for connecting a variety of sensors to the system. Therefore, an interface box and satellite boards were designed and built to provide that "plug ready" capability to the LabMaster system.

Interface Box

An interface box was designed and built to house the LabMaster daughter board and optional DC power supplies. Cabling carries all the signals for the data acquisition and control functions on the LabMaster mother board to the interface box. This allows full access to the LabMaster's capabilities at the interface box (fig. 1).

1. The top of the interface box contains a breadboard area for custom signal conditioning and prototyping.
2. Front panel access to the digital to analog channels, counters, TTL-level I/O ports, and analog to digital channels are provided via screw and push-in connectors for quick connection of sensors and other external devices.
3. Screw connectors also are provided to access the optional ±15 volt and +5 volt DC power supplies housed within the interface box. These power supplies are used to provide power for sensors, customized interfaces, and the interface box expansion circuitry. A jumper block, figure 2, is provided to select between DC power sources available from the microcomputer power supply or those that could be contained within the interface box. This allows the interface box to be constructed at a lower cost if sensor power requirements can be met with the microcomputer's power supply and if this power source does not adversely affect the sensor signals.
Figure 2 shows the power supply jumper block configured for using the interface box power supplies. If it is desired to use the microcomputer power supplies, relocate the jumpers from the top row to the bottom row. Note that analog ground (AGND) and digital ground (DGND) have been separated to improve noise immunity.
4. An 8255A programmable interface adapter on the LabMaster mother board provides 24 digital lines that can be used unbuffered as outputs or inputs. Output line buffering is available from non-inverting 74LS465 TTL digital buffer chips on the interface box. The lines are available at the interface box for individual connection to sensors and control devices or together as a unit through a single connector to obtain readings from digital encoders, etc.
5. Each of the five counters provided by the LabMaster AM9513 System Timing Controller chip contains a source input, gate input, and a counter output signal. Each of these signal lines can be buffered with 74LS465 or similar TTL digital buffer chips for protection of the AM9513 chip. A frequency output line is also available on the AM9513 and is also buffered at the interface box. All lines are available individually for connection of sensors or control devices to the interface box.
6. The two DAC80 12-bit digital to analog converter latched outputs are available for connection to

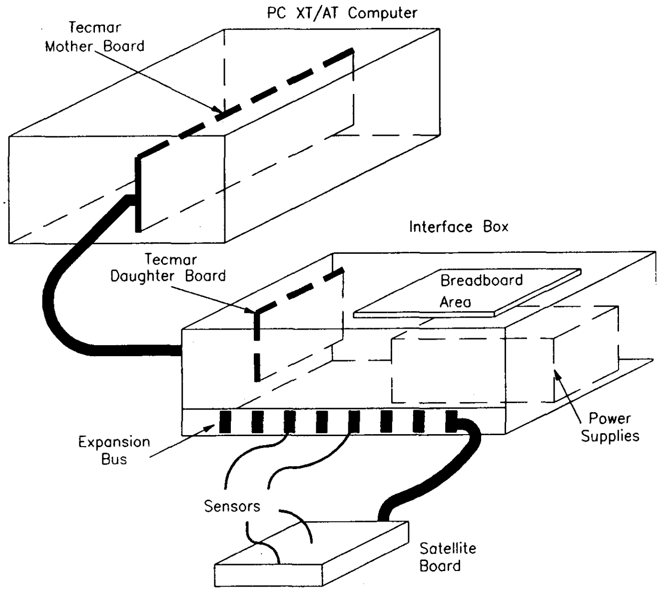

Figure 1–PC-based data acquisition and expansion system.

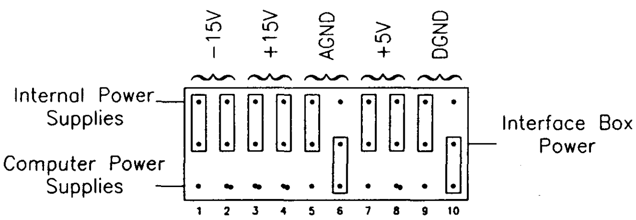

Figure 2–Interface power supply jumper block.

‡ System as configured in the Agricultural Engineering Department. Scientific Solutions offers many options and variations of the LabMaster.

external devices at the interface box. Both of the DACs are buffered with a standard (Texas Instruments TL062) op amp configured as a noninverting unity gain amplifier with a ±15 volt power source. However, in higher performance applications than used to date, such as servo-motor controllers, a buffering op amp with higher slew rate characteristics than the TL062 would be required.

7. A star topology, analog bus expansion system is available at the interface box. Sensors can be plugged into the bus connectors for direct access to any of the eight original, differential input configured, channels. Satellite expansion boards may also be connected to increase the analog input channel capacity of the system.

   The LabMaster daughter board contains eight address lines that can be used to multiplex additional analog input channels into the analog to digital converters. A 4028B CMOS binary-to-octal decoder chip on the interface box is used to decode three of the address lines into eight channel select lines. Pullup resistors are used to handle incompatibilities between the three TTL-level address lines and the CMOS decoder chip inputs (Horowitz and Hill, 1983, pg. 385). Each of these signal lines is used to select an analog input channel on the LabMaster daughter board. The remaining address lines are made available on the analog expansion bus and can be decoded by the satellite expansion boards. A summary of the signals available on the analog expansion bus for each of the eight, 14-pin connectors is provided in Table 1 and includes: 1) high and low analog channel inputs with their respective individual channel select line, 2) five additional address lines used for decoding the possible 32 channels on each satellite board, 3) +5 volt and ±15 volt DC power lines, and 4) digital, analog, and shield grounds.

Analog Input Satellite Boards

Analog input satellite expansion boards can be attached to the interface box via any of the eight analog expansion bus connectors. These satellite boards can provide a total of four banks of eight(differential or single-ended input) channels for up to 32 total analog input signals. Thus, a total of eight satellite boards can provide up to 256 analog input channels per LabMaster system.The satellite board is a circuit board containing a channel decoder, multiplexers, sensor input screw connectors, and configuration jumper blocks (fig. 3). The board may be configured with an on-board temperature reference circuit for thermocouple temperature compensation and/or an instrumentation amplifier for increased signal noise immunity.

The satellite boards not only provide expansion capability to the system, but also promote the "plug ready" sensor interface concept. Analog sensors for a laboratory demonstration or research experiment can be connected to an analog input satellite board. The satellite board can then be made a permanent part of the setup. Only a 14-pin cable is necessary to connect the satellite board to the data acquisition system.

The satellite expansion board was designed to be used economically in a variety of applications. Low cost systems can be constructed for a large number of analog inputs by eliminating components that are not necessary for a given application. Optional components include the instrumentation amplifier, the reference temperature circuit, and unused multiplexers (MUX). If single-ended inputs are used, a dip header can replace the low channel input MUX. The design also accommodates the mounting requirements of both embedded applications and portable data acquisition systems. This flexibility allows the board to be tailored to each specific application, thus, reducing the cost of instrumenting facilities that may be used only a few times each year.

TABLE 1. Description of analog expansion bus

Pin no	Signal	Description
1	CH+	Channel input signal (Hi)
8	CH–	Channel input signal (Lo)
2	SGND	Shield ground
9	AGND	Analog ground
3	+15V	+15 volt DC
10	DGND	Digital ground
4	–15V	–15 volt DC
11	+5V	+5 volt DC
5	MA2	Address line
12	MA4	Address line
6	MA1	Address line
13	MA3	Address line
7	MA0	Address line
14	MCS	Analog channel select

Board Configuration

Several jumper options are contained on the analog input satellite board. These jumpers provide the following functions:

Channel address decode configurations. A five-pin jumper block, located at J1S in figure 3 and shown schematically in figure 4, provides channel address decoding capability. A CMOS 14555B dual binary to one-of-four decoder/demultiplexer can be used to decode the four possible satellite channel banks.

A single jumper across two pins in any one of the four positions (A, B, C, or D) provides the following configuration options:

A. Bank 0 select (BCS0) line is tied to +5 volts. Therefore, the first eight channels are always enabled. No decoder is necessary for this option.

B. The channel select (MCS) line, from the analog expansion bus, is tied to the bank 0 select (BCS0) line. Bank 0, the first eight channels, is enabled when the channel select line is high. No decoder is necessary for this option.

C. The decoder enable (DE) line is tied to the channel select (MCS) line. When the channel select line is high, one of the four banks is selected and enabled based on the status of the input lines MA3 and MA4. A decoder must be installed on the satellite board to use this option.

D. The decoder enable (DE) line is tied to +5 volts and one of four banks is always enabled. When the channel select line is high, one of the four banks is selected based on the status of the input lines MA3 and MA4. A decoder must be installed on the satellite board to use this option.

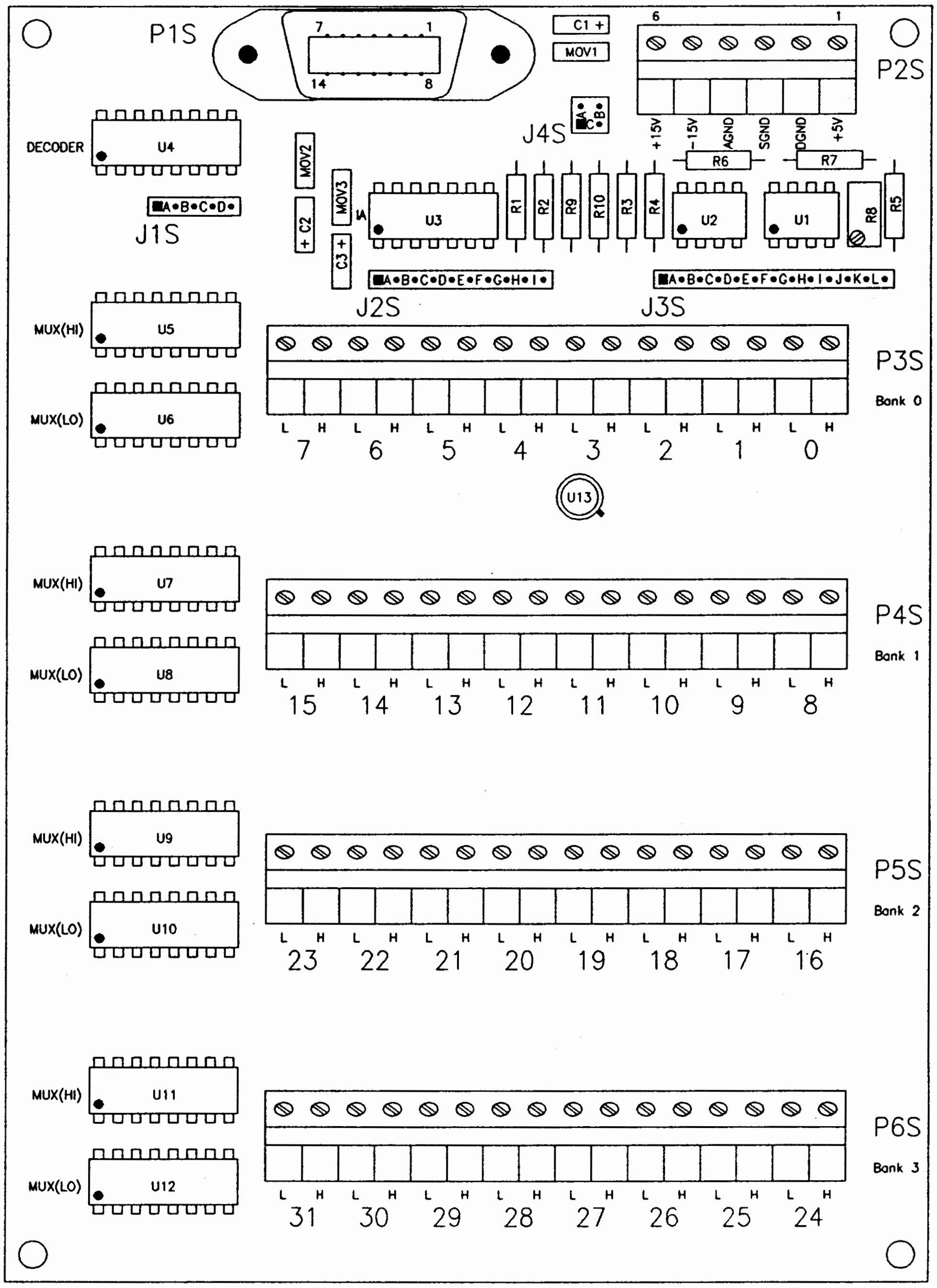

Figure 3–Satellite expansion board layout.

Board output and instrumentation amplifier configurations. A 10-pin jumper block, located at J2S in figure 3 and shown schematically in figure 5, provides configuration of the satellite board outputs and of an optional instrumentation amplifier (Burr Brown INA101).

Table 2 provides a summary of the possible configurations available, as discussed below.

A. Single-ended analog inputs with no instrumentation amplifier installed (Case a1 and a2 in Table 2). MUX+ must be connected to CH+, and MUX- must be connected to analog ground or biased to analog ground through resistor R2. MUX- must also be connected to CH-. A dip header connecting all the low channel inputs to MUX- may be installed in place of the MUX(LO)multiplexer for these single-ended input configurations.

B. Differential analog inputs with no instrumentation amplifier installed (Case b in Table 2). MUX+ must be connected to CH+ and MUX- must be connected to CH-.

C. Single-ended analog inputs with the instrumentation amplifier installed (Case c1 and c2 in Table 2). MUX+ must be connected to IA+, and MUX- must be connected to IA-. In addition, CH- must be connected to analog ground, and CH+ must be connected to IA_{out}. The MUX- signal must be connected to analog ground by inserting a zero ohm resistor at R2 or biased to analog ground through resistor R2. A dip header connecting all the low channel inputs to MUX- may be installed in place of the MUX(LO) multiplexer for single-ended input configurations.

D. Differential analog inputs with the instrumentation amplifier installed (Case d in Table 2). MUX+ must be

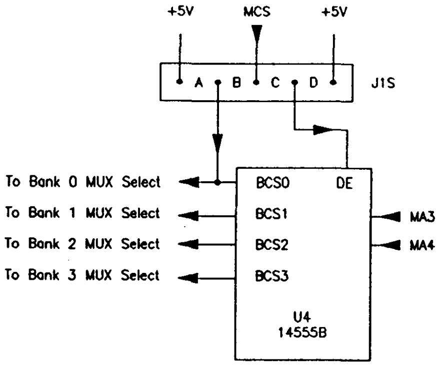

Figure 4–Channel address decode jumper block.

connected to IA+, and MUX- must be connected to IA-. In addition, CH- must be connected to analog ground, and CH + must be connected to IA_{out}.

In any of these cases that utilize the INA101 instrumentation amplifier, the user must install resistor R1 to set the gain§. A precision gain resistor R1 should be selected with a low temperature coefficient for best results. Also, note that removing the resistor, i.e., R1 = ∞, from the circuit results in unity gain.

Ground and power configurations. A four-pin jumper block, located at J4S in figure 3, provides configuration of the satellite board grounds. Table 3 provides a summary of the possible configurations available. In addition to the ground configuration jumper, a connector (P2S in figure 3) provides access to the analog expansion bus power supplies and board grounds.

Zero, temperature, and/or voltage reference configurations. A 13-pin jumper block, located at J3S in figure 3 and shown schematically in figure 6, provides for zero, temperature, and voltage reference inputs at selected satellite channels.

Table 4 provides a summary of the possible configurations available as discussed below.

Channel 0: Two jumpers can connect both inputs of channel 0 to analog ground producing a zero offset reference channel. The two jumpers must be placed at locations J and L. If no jumpers are installed at these locations, channel 0 may be used as a normal analog input channel.

Channel 1: Two jumpers can connect the channel 1 inputs to an on-board temperature reference circuit. A jumper at location H connects the CH1+ input to the low temperature reference output (TC_LO 40μV/° C) line. A jumper at location G connects the CH1+ input to the high temperature reference output (TC_HI 10mV/° C) line. A jumper at location E connects the CH1- input to analog ground. If jumpers are installed at either locations E and H or E and G, channel 1 can be used as a temperature reference channel on the satellite board. If no jumpers are installed at these locations, channel 1 may be used as a normal analog input channel.

Channel 2: Two jumpers connect both inputs of channel 2 across a user-defined, voltage divider network

§ Burr Brown IC Data Book, Vol 33: 3-11.

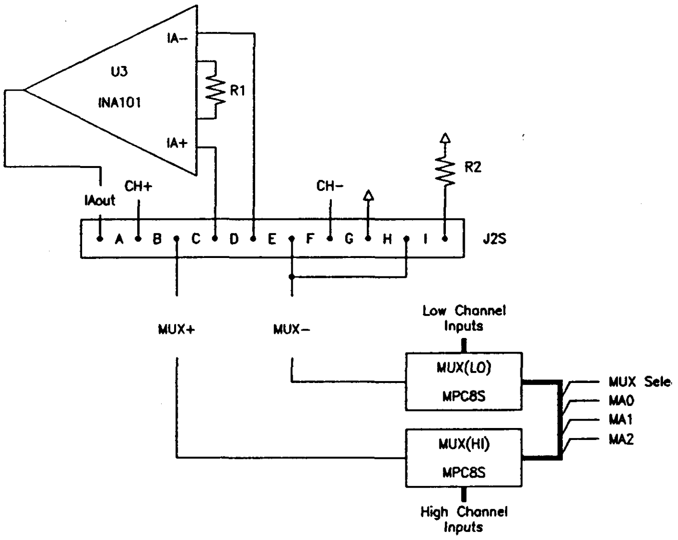

Figure 5–Board output and instrumentation and amplifier jumper block.

to obtain a signal derived from a precision +2.5V reference. This voltage reference can be used to compute the overall gain of the system. Jumpers must be placed at locations A and C and two precision resistors installed at R9 and R10. The voltage reference signal obtained in this configuration is given by equation 1. Also, note that by removing resistor R10 and installing a jumper in place of resistor R9, i.e., R10 = ∞ and R9 = 0, gives a reference voltage of 2.5 volts:

$$V_{ref} = 2.5\ V \frac{R10}{(R9 + R10)} \qquad (1)$$

where

$$R9 + R10 > 5k\Omega.$$

If no jumpers are installed at these locations, channel 3 may be used as a normal analog input channel.

Temperature Reference Circuit

The temperature reference circuit developed for the satellite board consists of an AD1403 precision +2.5V DC reference, an AD590 two-terminal temperature transducer, a TL062 amplifier, and several resistors (Wagner et al., 1989b). A schematic of the circuit is shown in figure 7.

To summarize the design of the temperature reference circuit, two outputs are provided for use in thermocouple temperature compensation. The high gain output, TC_HI, provides a voltage output with a temperature coefficient of

TABLE 2. Summary of instrumentation amplifier configuration

Case no	Inst. amp installed	J2S jumpers	R2 installed	Description
a1	No	B,F,H	No	single-ended inputs
a2	No	F,F,I	Yes	single-ended inputs & biased to gnd
b	No	B,F	No	differential inputs
c1	Yes	A,C,E,G,I	Yes	single-ended inputs (R2=0Ω)
c2	Yes	A,C,E,G.I	Yes	single-ended inputs & biased to gnd
d	Yes	A,C,E,G	No	differential inputs

TABLE 3. Summary of ground configuration

Case no	J4S jumpers	Description
1	none	all grounds sepaarated
2	A	DGND connected to AGND
3	B	SGND connected to AGND
4	C	SGND connected to DGND
5	A,B	all grounds connected

10mV/° C. The low gain output, TC_LO, provides a voltage output with a temperature coefficient of 40μV/° C.

APPLICATIONS

PC-based data acquisition and control systems have been used in several research projects and numerous teaching demonstrations within the Agricultural Engineering Department at Kansas State University. A brief description of several applications is presented in order to demonstrate the flexibility and versatility of these data acquisition systems.

INSULATION PERFORMANCE

Laboratory classes use a PC-based data acquisition system to measure temperatures at 18 locations in a "hotbox" constructed specifically for educational purposes. The hotbox is used to investigate the differences in insulating properties between various building materials. Each wall is constructed of different common building materials such as plywood (with and without insulation), corrugated tin, and double pane glass. A heat source is located in the center of the hotbox. Thermocouples are used to measure temperatures inside, outside, and at various interfaces and surfaces. All thermocouples are connected to an analog input satellite board that remains permanently installed on the hotbox. Thus, only the 14-line cable is needed to connect the hotbox to the data acquisition system's interface box.

SOIL DYNAMICS - TOOL REACTIONS

A PC-based data acquisition system has been interfaced to a tillage tool/traction device dynamometer that operates on a rail system over a 15 m (50 ft) soil bin. The tillage tool dynamometer is instrumented with six load cells to provide the three components of force and their respective moments acting on the tillage tool. The load cells were connected to an analog input satellite board mounted on the carriage dynamometer frame. Again, only the 14-line cable is needed to connect the tillage tool dynamometer to the data acquisition system's interface box.

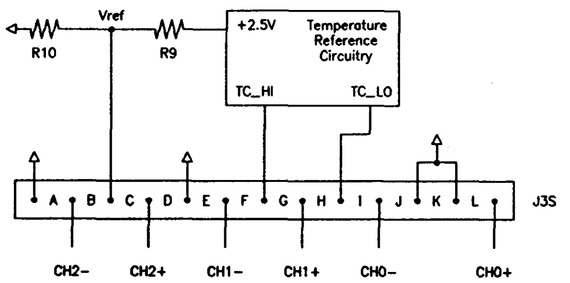

Figure 6–Zero, temperature, and voltage reference jumper block.

TABLE 4. Summary of zero, temperature, and voltage reference configurations

Chan no	J3S jumpers	Description
0	J,L	zero voltage reference
1	E,H	temperature referrence (40 μ V/ ° C)
1	E,G	temperature reference (10mV/ ° C)
2	A,C	user defined voltage reference

AERODYNAMIC DUST SEGREGATION TESTER FOR LIVESTOCK FEED

The relative "dustiness" of various livestock feeds is measured with an experimental dustiness measurement device controlled by a PC-based data acquisition system (Heber and Martin, 1988). Feed samples are placed in the top of a tube mounted vertically in a support stand. The amount of material that falls through the tube during a specified time interval is then measured. 110 VAC relays open and close valves mounted at each end of the tube. These relays are controlled with the LabMaster TTL-level digital outputs.

ELECTRIC POWER CONCEPTS AND ELECTRIC MOTOR TESTING

An instrumented electric motor dynamometer test facility has been constructed for teaching and research use (Wagner et al., 1989c). The facility is used to demonstrate the concepts of power factor, motor efficiency, running motor torque, starting torque, and power to students (Slocombe et al., 1988). Research use of the facility currently encompasses testing of livestock confinement ventilation fan motors (Cole et al., 1988). The electric motor dynamometer facility demonstrates how a PC-based data acquisition system can also be used in a permanent installation.

COMBINE YIELD SENSOR

A PC-based data acquisition system and interface box were installed in a commercial combine. The data acquisition system was used to obtain field data from an experimental grain flow sensor (Wagner, 1988). The system was interfaced to four load cells, a proximity rpm sensor, the combine's internal analog travel speed signal, and two accelerometers. The system was powered with a 12 VDC to 110 VAC inverter. This research project shows how a PC-based system can be used in applications that require some degree of portability without modifications to the data acquisition system.

WHEAT HARDNESS TESTER

A PC-based data acquisition system was used during initial development of Kansas State University's wheat hardness tester. The data acquisition system was used to obtain force data from a load cell at constant time intervals using an analog input channel and to read an absolute position encoder with 16 TTL-level digital input lines.

SOIL TEMPERATURE PROFILE

This application shows the expansion capability of PC-based data acquisition systems and how the interface and

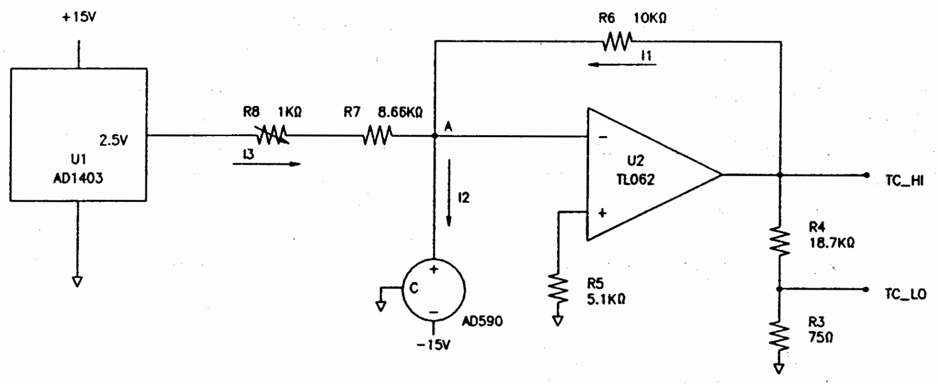

Figure 7–Temperature reference circuit.

satellite expansion system can be extended beyond a specific data acquisition system.

A PC-based data acquisition system was used to measure surface, soil, and ambient air temperatures under a variety of seeding conditions (Thierstein et al., 1985, 1986). This system differs from the other applications in that an ADC-1[||] data acquisition system was used. The system utilized four analog input satellite boards (same satellite boards presented and discussed here) to obtain readings from 84 thermocouples. The field plots spanned a 76 m (250 ft) transect with satellite boards being connected to the ADC interface box with up to 30.5 m (100 ft) cables. The ADC data acquisition system communicated with a computer using a serial interface. Approximately 305 m (1000 ft) separated the computer from the ADC-l unit.

Class Demonstrations and Laboratory Assignments

A variety of uses have been found for the PC-based data acquisition systems for instructional use besides those previously mentioned. None of these required a dedicated system and most could not justify a great deal of setup time to demonstrate individual course concepts. However, the flexibility of PC-based systems allows the instructor to easily provide reinforcement of the concepts studied in the class through laboratory demonstrations and assignments. Two examples are an instrumented internal combustion engine and a mechanical vibration resonance device.

The instrumented engine and dynamometer were used to obtain data for students to perform a laboratory assignment on engine heat balance. Exhaust, engine block, crankcase oil, inlet and outlet coolant, and ambient air temperatures were measured as well as engine torque and speed, coolant flow, air flow, and fuel flow rates. All of the sensors were connected to an analog input satellite board.

The mechanical vibration resonance device consists of an unbalanced rotating mass that is powered with a variable speed electric motor. The frame containing the unbalanced mass is pivoted on one end and supported with coil springs on the other end. Rotating the unbalanced mass causes the frame to vibrate on the spring supported end. The unit has been instrumented with a linear potentiometer to measure the displacement of the frame and an accelerometer to measure acceleration. The students determine accelerations analytically and compare their calculated results with the experimental data.

[||] Remote Measurement Systems, Inc. Seattle, WA.

Summary

Data collection and process control needs in the Agricultural Engineering Department at Kansas State University are quite diverse and vary greatly in the time of utilization. These needs have been met primarily with commercially available PC-based data acquisition and control systems enhanced by a unique interface and expansion system. These systems handle a wide variety of analog inputs, produce a range of output voltages, include digital signal input and output capabilities, and provide general purpose counters for time-based measurements and control. In addition, these systems provide a cost effective, portable solution to instructional laboratory assignments and research projects with a "plug ready" capability that easily interfaces a wide variety or sensors with a minimum of effort.

PC-based data acquisition systems have been used successfully in a variety of applications. These diverse applications range from research projects in electric motor testing, environmental effects of dust, grain yield measurement, wheat hardness determination, and soil temperature profiles to laboratory assignments in insulation performance, soil/tool dynamics, electric power concepts, IC engine efficiency, and mechanical vibration.

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