Thermocouple Data System

Bustec Production Ltd.

- Up to 322 Thermocouple channels
- Differential inputs on all channels
- Cold junction termination
- Open Thermocouple detection
- 100 sample/second/channel sustained sample rate *(typical) (800 samples/second/ch max)*
- 0.4°C temperature measurement accuracy
- Data sampling derived from single clock
- IEEE-1394 (Firewire) based Slot-0 Controller providing large block throughput to 14 Mbytes/second
- PCI IEEE-1394 Interface to Windows NT or Linux computer
- Periodic (6 mo) calibration with user supplied DVM for international standards tractability

Figure 1: Typical thermocouple data system features

1. Introduction

Bustec VXI products provide a highly modular approach to data acquisition. A *typical* data acquisition system configuration for thermocouples is presented in this paper, however the system can be easily configured for a wide range of applications with requirements for a variety of sensors and sampling rates.

The configuration as presented, is capable of acquiring data from up to 322 thermocouples and is capable of being expanded with additional modules. A *typical* sample rate for thermocouple applications of 100 Hz is illustrated, however the system is capable of substantially higher per channel sample rates. The ADC subsystem is capable of per channel sample rates of 1000 samples/second/channel with 24 active channels per ADC card (3411-AA).

Isothermal panels are provided for terminating groups of up to 23 thermocouples per panel. Each isothermal panel includes four National Semiconductor LM35

precision temperature sensors. The output of these sensors are averaged to determine the isothermal panel temperature (cold junction temperature). The average of the four temperature sensors are read as a separate 24th channel along with the thermocouple voltages. Through the use of four temperature sensors the overall accuracy of the cold junction temperature measurement is improved by a factor of two over the single sensor accuracy.

2. Typical System Features

The features of a *typical* system configuration are summarized in Figure 1. Features such as the sample rate per channel are *typical* values. The illustrated system is capable of per channel sample rates of 4000 samples/second when scanning all 24 channels on a 3411 ADC card. The channel count can be adjusted in groups of 23 channels plus Isothermal panel cold junction to meet a wide range of needs.

3. System Configuration

The components for a typical 322 channel VXI-based data acquisition system are illustrated in Table 1.

3.1. Configuration Considerations

3.1.1. VXI Mainframe

In the configuration illustrated two single-width VXI modules (3150 ProDAQ Mother Boards) are required to accommodate 14 3411 ADC Function Cards. Each ADC Function Card provides 23 thermocouple channels plus cold junction monitoring channel for a total of 322 thermocouple channels. In addition a Slot-0 controller is required. Thus the mainframe must provide a minimum of three VXI slots. For most applications it is good practice to allow for some additional expansion. In this case we have chosen the Agilent (HP) 4-slot VXI mainframe which provides one open VXI expansion slot.

3.1.2. VXI Slot-0 Controller/Firewire/PCI Computer Interface

The VXIbus Standard requires a special controller located in Slot 0 of each mainframe. This controller is responsible for generation of the mainframe-wide 10 MHz clock and bus arbitration as well as a number of system startup services. A variety of

Table 1: 322 Channel Thermocouple System Components

Qty	Part No.	Description	Typ. Cost	Total
		VXI I/O Components		
2	3150-AA	ProDAQ Mother Board VXI Modules *(accommodates up to 8 ProDAQ cards per 3150)*	$ 4200	$ 8400
14	3411-AA	24-ch Thermocouple ADC ProDAQ card	$ 1750	$ 24,500
2	3201-AA	Voltage Ref 3150 Mother Board plug-in	$ 410	$ 820
2	3901-AA	Voltage Reference Monitor ProDAQ card	$ 310	$ 620
		Signal Cond. Chassis components		
1	5010-AA	Signal Conditioning Chassis	$ 750	$ 750
1	5111-AA	110V Power supply (see note)	$ 515	$ 515
14	5310-AA	Isothermal Panel 23-ch plus reference 0.4°C accuracy	$ 615	$ 8,610
		Analog I/O Cabling		
14	8010-AB	50-pin SCSI Shielded Pr. Cable 1m	$ 130	$ 1,820
		VXI-Mainframe, Slot-0 & Computer Interface		
1	E8408A	Agilent 4-Slot VXI Mainframe	$ 2,200	$ 2,200
1	E8491B	Agilent IEEE-1394 Slot-0 Controller	$ 2,070	$ 2,070
1	E8491B 001	Agilent OHCI-Based IEEE-1394/PCI Card	$ 520	$ 520
1	E8491-61603	Agilent FireWire Cable, 4.5m (cable included with E9481B)	—	—
		Software Support		
1		3150 VXI*Plug& Play* Driver	—	—
1		3411 VXI*Plug& Play* Driver	—	—
1		Slot-0 Interface Driver	—	—
		Approximate Total System Cost		$ 50,825
		Approximate Cost per channel		$ 158
		Approximate Cost per channel (VXI I/O Modules & Signal Cond. only)		$ 143

Note: Prices in USD are for illustration purposes and are subject to change

Slot-0 controllers are available. In general Slot-0 controllers fall into two categories:

Intelligent Slot-0 Controllers: These controllers include an embedded processor and typically an ethernet network port for communications with other networked systems and a SCSI port for local storage. They typically require an embedded operating system and application software. These controllers are frequently used in control applications where rapid response to sampled data is needed as well as some high speed data acquisition applications where data is stored locally on disk. They can also used in some data acquisition applications where it is possible to process, buffer and reduce the data volume sufficiently that worst case network latencies do not result in loss of data before it can be moved over the network and archived.

Slot-0 *Slave* Controllers: These controllers typically do not include any user programmable processors but rather depend on some form of high speed link to a full-featured computer system. Application software on the main computer system initiates data transfers between the computer and a VXIbus I/O module via the high speed link and the slave Slot-0 Controller. The high speed link typically supports multiple slave controllers. These controllers are most widely used in data acquisition applications where data is acquired and buffered at the mainframe level and transferred in relatively large blocks to the main computer system for analysis and archival. They are also used in control applications where somewhat longer response intervals are acceptable. In general these controllers are considerably less expensive than those with embedded processors. They allow the user to take advantage of the better price/performance and flexibility offered by mass produced general purpose computer systems.

For this illustration we have chosen the Agilent Technologies E8491B IEEE-1394 Slot-0 controller and E8491B-001 OCHI IEEE-1394 PCI interface. IEEE-1394 (FireWire) provides a nice high speed serial interface that can be extended up to 72 meters allowing considerable flexibility in placing the VXI mainframe some distance from the main computer system as well as permitting connection of multiple mainframes on a single FireWire link. The E8491B Slot-0 and E8491-001 PCI Interface supports large block transfers at throughputs up to 12 Mbytes/second. The use of serial communications protocols provide several advantages:

- The VXI mainframe can be easily located some distance from the computer (up to 72 meters for FireWire). Parallel cables tend to be severely limited in length due to attenuation and less sophisticated drivers and receivers.
- Cables are generally much smaller diameter and much easier to handle than parallel bus cables. As a result they are less subject to failure.

- Serial communications protocols implement sophisticated error detection and recovery that is generally beyond the scope of parallel connections.

IEEE-1394 is a standard communications protocol with multiple vendors offering equipment that inter-connect using this standard. When connecting multiple devices on FireWire that is used in a data acquisition application one must insure that transfers between other devices does not block access to the data acquisition devices for sufficient time to cause a data buffer overrun.

3.1.3. 3150 ProDAQ Motherboard

For this configuration we have chosen the 3150-AA ProDAQ Mother Board which is a single-width VXI module that accommodates up to 8 option cards such as the 3411. Two 3150's are required to accommodate the 14 ADC 23-channel option cards that are needed as well as the Voltage Reference Monitor card for each 3150.

In this configuration 7-3411's and 1-3901 are configured in each 3150. Data buffering is provided by the 3150 mother board. Other optional features can be provided by the 3150 include:

Cold Junction Compensation: One channel of the 3411 is devoted to measuring the temperature of the Isothermal Panel (cold junction temperature). The 3150 can use this measurement to correct the thermocouple voltages.

Thermocouple Linearization: The 3150 can provide linearization for most thermocouple types including J, K, N, R, S, T using polynomial corrections.

Conversion to Engineering Units: The 3150 can convert thermocouple input voltages to engineering units (Celsius, Faharenheit).

Digital Filtering and Data Averaging: The 3150 can apply various digital filtering and averaging algorithms to the sampled data streams. The resulting data streams are filtered or averaged, decimated and buffered for output. The digital filter and decimation parameters are common to all channels on a 3150.

Limit Checking The 3150 can limit check one or more data channels and generating either a trigger on a selected VXIbus trigger line or an interrupt on a high or low limit violation.

Cold junction compensation, thermocouple linearization and engineering unit conversion are also options in the 3411 Plug & Play Instrument driver software that is supplied with the hardware and runs on the host computer.

An important consideration when using features such as engineering units conversion and digital filtering is that these operations convert the raw data from 16-bit integer format to 32-bit floating point values. This effectively doubles the amount of data that must be moved and eventually archived increasing both system throughput and data storage requirements. Also the fact that the conversion to engineering units is a non-linear operation that can complicate post acquisition analysis if any of the parameters used in original conversion are later found to be suspect. Finally the effects of digital filtering and decimation are not reversible. That is once a low-pass digital filter is applied to the data, information above the filters cutoff frequency is lost.

In many applications however these tools can be very effectively applied to acquiring critical information in a cost-effective manner.

Alternatively the system could be configured using the lower cost 3120 ProDAQ Motherboard however in this case one would likely have to use the more expensive 3411-AB for additional data buffering. The the cost of the extra FIFO buffering on 3411-AB cards and the 3120 is offset by the cost of the 3150 base card and 3411-AA with minimum FIFO buffering. The break even is at seven option cards with the extra FIFO buffering. In addition the 3150 provides the base for many additional features such as engineering units conversion, digital filtering, and limit checking.

3.1.4. 3411-AA 24-channel Thermocouple ADC

The 3411-AA *24-channel Enhanced ADC Function Card* provides 24-channels of low-level multiplexed differential input suitable for use with thermocouples. Features include:

- 24 Differential Channels
- 16-bit Resolution
- Accuracy <0.02% with optional Vref Source
- < 1 μV_{RMS} Noise
- Open Thermocouple Detection
- 20 kHz Maximum Aggregate sample rate *(see note)*
- Programmable Gain (1—1000) $\pm 10V$ to $\pm 10.0mV$ input span
- 2 kSample FIFO

Note: 20 kHz maximum sample rate is determined by a 51μ*sec settling time to 0.01%.*

3.2. Configuration Options

Several options exist to expand the number of channels:

1. Up to an additional 161 channels can be added by adding an additional 3150 and up to seven 3411s.
2. By replacing the 4-slot mainframe with a standard 13-slot mainframe a total of 12-slots are available for mounting 3150 VXI modules populated with 3411 ADC cards or other options.

3.2.1. Adding up to 161 channels

One slot is unused in the basic configuration. By adding one additional 3150 VXI Mother Board module it is possible to expand the channel count by up to 161 additional channels. Each group of 23 channels requires the components listed in the table below. When the 5010 Signal Conditioning Chassis is full at 16 5310-AA Isothermal Panel cards an additonal 5010-AA Signal Conditioning Chassis and 5111-AA power supply will also be required.

Qty	Part No.	Description	Typ. Cost	Total
1	3411-AA	24-ch Thermocouple ADC ProDAQ card	$ 1750	$ 1750
1	5310-AA	Isothermal Panel 23-ch plus reference 0.4°C accuracy	$ 615	$ 615
1	8010-AB	50-pin SCSI Shielded Pr. Cable 1m	$ 130	$ 130

3.2.2. Configurations Over 483 Channels

To configure systems with over 483 channels a larger mainframe or multiple mainframes are required. By using a standard 13-Slot mainframe in place of the 4-slot, up to twelve 3150s can be configured in the mainframe. At these densities some consideration must be given to the net throughput and the capabilities of the Slot-0 controller to move data as well as the computer to process and archive data. Data sampling rate and post processing by the 3150s can play important rolls in determining throughput requirements.

US Headquarters

Bustec, Inc.
17820 Englewood Dr. #14
Middleburg Hts. OH 44130
Tel: (440) 826 4156
Fax: (440) 826 4184
email: paul@bustec.com

European Headquarters:

Bustec Production Ltd.
World Aviation Park
Shannon, Co. Clare
Ireland
Tel: +353 61 707 100
Fax: +353 61 707 106
email: sales@bustec.ie

WEB Site: www.bustec.com