Owner'sGuide 0300172-03 Rev. D

SLC 500™ UNIVERSAL ANALOG INPUT MODULE

Thermocouple, RTD, Resistance, mV/V, mA

Catalog Numbers
1746sc-NI8u

SPECTRUM CONTROLS

Important Notes

1. Please read all the information in this owner’s guide before installing the product.

2. The information in this owner's guide applies to hardware series B and firmware version 2.0 or later.

3. This guide assumes that the reader has a full working knowledge of the relevant processor.

Notice

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Preface

Read this preface to familiarize yourself with the rest of the owner's guide. This preface covers:

- who should use this guide
- what this guide covers
- related Allen-Bradley documents
- terms & abbreviations you should know

Who Should Use This Guide

Use this guide if you design, install, program, or maintain a control system that uses Allen-Bradley Small Logic Controllers.

You should have a basic understanding of SLC 500 products. You should also understand electronic process control and the ladder program instructions required to generate the electronic signals that control your application. If you do not, contact your local Allen-Bradley representative for the proper training before using these products.

What This Guide Covers

This guide covers the 1746sc-NI8u universal analog input module. It contains the information you need to install, wire, use, and maintain these modules. It also provides diagnostic and troubleshooting help should the need arise.

Related Allen-Bradley Documents

Table A lists several Allen-Bradley documents that may help you as you use these products.

Table A. Related Allen-Bradley documents

Allen-Bradley Doc. No.	Title
1747-2.30	SLC 500 System Overview
SGI-1.1	Application Considerations for Solid State Controls
1770-4.1	Allen-Bradley Programmable Controller Grounding and Wiring Guidelines
1747-6.2	Installation & Operation Manual for Modular Hardware Style Programmable Controllers
1747-NI001	Installation & Operation Manual for Fixed Hardware Style Programmable Controllers
1747-6.4	Allen-Bradley Advanced Programming Software (APS) User Manual
1747-6.11	Allen-Bradley Advanced Programming Software (APS) Reference Manual
1747-6.3	Getting Started Guide for Advanced Programming Software (APS)
ABT-1747-TSG001	SLC 500 Software Programmers's Quick Reference Guide
1747-NP002	Allen-Bradley HHT (Hand-Held Terminal) User Manual
1747-NM009	Getting Started Guide for HHT (Hand-Held Terminal)
SD499	Allen-Bradley Publication Index
AG-7.1	Allen-Bradley Industrial Automation Glossary

To obtain a copy of any of the Allen-Bradley documents listed, contact your local Allen-Bradley office or distributor.

Terms & Abbreviations You Should Know

You should understand the following terms and abbreviations before using this guide.

A/D - Refers to analog-to-digital conversion. The conversion produces a digital value whose magnitude is proportional to the instantaneous magnitude of an analog input signal.

Attenuation – The reduction in magnitude of a signal as it passes through a system. The opposite of gain.

Channel – Refers to one of eight, small-signal analog input interfaces to the module's terminal block. Each channel is configured for connection to a thermocouple or DC millivolt (mV) input device, and has its own configuration and status words.

Chassis – See rack.

CJC - (Cold Junction Compensation) The means by which the module compensates for the offset voltage error introduced by the temperature at the junction between the thermocouple lead wire and the input terminal block (the cold junction).

Common mode rejection ratio (CMRR) - The ratio of a device's differential voltage gain to common mode voltage gain. Expressed in dB, CMRR is a comparative measure of a device's ability to reject interference caused by a voltage common to its terminal relative to ground.

Common mode voltage – The voltage difference between the negative terminal and analog common during normal differential operation.

Configuration word – Contains the channel configuration information needed by the module to configure and operate each channel. Information is written to the configuration word through the logic supplied in your ladder program.

Cut-off frequency - The frequency at which the input signal is attenuated 3 dB by the digital filter. Frequency components of the input signal that are below the cut-off frequency are passed with under 3 dB of attenuation for low-pass filters.

dB (decibel) – A logarithmic measure of the ratio of two signal levels.

Data word – A 16-bit integer that represents the value of the analog input channel. The channel data word is valid only when the channel is enabled and there are no channel errors.

Digital filter - A low-pass filter of the A/D converter. The digital filter provides high-frequency noise rejection.

Effective resolution – The number of bits in the channel data word that do not vary due to noise.

Full-scale error (gain error) – The difference in slope between the actual and ideal analog transfer functions.

Full-scale range (FSR) – The difference between the maximum and minimum specified analog values.

Gain drift – The change in full-scale transition voltage measured over the operating temperature range of the module.

Input data scaling - Depends on the data format that you select for the channel data work. You can select from scaled-for-PID or Engineering Units for millivolt, milliamp, thermocouple, RTD, or CJC inputs, which you must compute to fit your application's temperature or voltage resolution.

Local System - A control system with I/O chassis within several feet of the processor, and using 1746-C7 or 1746-C9 ribbon cable for communication.

LSB (least significant bit) – The bit that represents the smallest value within a string of bits. The "weight" of this value is defined as the full-scale range divided by the resolution.

Mulitplexer – A switching system that allows several input signals to share a common A/D converter.

Normal mode rejection (differential mode rejection) – A logarithmic measure, in dB, of a device's ability to reject noise signals between or among circuit signal conductors, but not between the equipment grounding conductor or signal reference structure and the signal conductors.

Module update time – See channel update time.

Remote system - A control system shere the chassis can be located several thousand feet from the processor chassis. Chassis communication is via the 1747-SN Scanner and 1747-ASB Remote I/O Adapter.

Resolution – The smallest detectable change in a measurement, typically expressed in engineering units (e.g. 0.15 °C) or as a number of bits. For example, a 12-bit system has 4096 possible output states. It can therefore measure 1 part in 4096. See also effective resolution.

RTD (Resistance Temperature Detector) - A temperature sensing element with 2, 3, 4, lead wires. It uses the basic characteristics that electrical resistance of metals increases with temperature. When a small current is applied to the RTD, it creates a voltage that varies with temperature. This voltage is processed and converted by the RTD module into a temperature value.

Sampling time - The time required by the A/D converter to sample an input channel.

Status word – Contains status information about the channel's current configuration and operational state. You can use this information in your ladder program to determine whether the channel data word is valid.

Step response time – The time required for the A/D signal to reach 95% of its expected, final value, given a full-scale step change in the output data word.

Update time – The time for the module to sample and convert a channel input signal and make the resulting value available to the SLC processor.

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Chapter 1

Module Overview

This chapter describes the universal analog input module and explains how the SLC controller reads thermocouple or millivolt analog input data from the module. Read this chapter to familiarize yourself further with your universal analog input module. This chapter covers:

- general description and hardware features
- an overview of system and module operation
- block diagram of channel input circuits

General Description

This module is designed exclusively to mount into Allen-Bradley 1746 I/O racks for use with Allen-Bradley SLC 500 fixed and modular systems. The module stores digitally converted thermocouple, RTD, millivolt (mV), volt (V), milliamp (mA), and CJC temperature analog data in its image table for retrieval by all fixed and modular SLC 500 processors. The module supports connections of up to eight channels of thermocouple, current or voltage inputs, OR four channels of RTD or resistance inputs and four channels of thermocouple, current or voltage inputs.

Input Ranges

The following tables provide compatibility information on the supported thermocouple types and their associated temperature ranges, the supported RTD types and their associated temperature ranges, as well as the millivolt, volt, milliamp and resistance input types supported by the NI8u module. To determine the practical temperature range of your thermocouple, refer to the specifications in appendices A and B. Detailed accuracy specifications for all input types can be found in appendix A.

Table 1.1 Thermocouple Temperature Ranges

Type	˚C Temperature Range	˚F Temperature Range
J	-210°C to 760°C	-346°F to 1400°F
K	-270°C to 1370°C	-454°F to 2498°F
T	-270°C to 400°C	-454°F to 752°F
B	300°C to 1820°C	572°F to 3308°F
E	-270°C to 1000°C	-454°F to 1832°F
R	0°C to 1768°C	32°F to 3214°F
S	0°C to 1768°C	32°F to 3214°F
N	0°C to 1300°C	32°F to 2372°F
C	0°C to 2315°C	32°F to 4199°F
CJC Sensor	-25°C to 105°C	-13°F to 221°F

Table 1.2 RTD Temperature Ranges

Type		°C Temperature Range	°F Temperature Range
Platinum (385)[1]	100 Ohm	-200°C to +850°C	-328°F to +1562°F
	200 Ohm	-200°C to +750°C	-328°F to +1382°F
	500 Ohm	-200°C to +850°C	-328°F to +1562°F
	1000 Ohm	-200°C to +850°C	-328°F to +1562°F
Platinum (3916)[1]	100 Ohm	-200°C to +630°C	-328°F to +1166°F
	200 Ohm	-200°C to +630°C	-328°F to +1166°F
	500 Ohm	-200°C to +630°C	-328°F to +1166°F
	1000 Ohm	-200°C to +630°C	-328°F to +1166°F
Copper (426)	10 Ohm	-100°C to +260°C	-148°F to +500°F
Nickel (618)	120 Ohm	-100°C to + 260°C	-148°F to +500°F
Nickel (672)	120 Ohm	-80°C to +260°C	-112°F to + 500°F

1=The digits following the RTD type represent the temperature coefficient of resistance (alpha, a), which is defined as the resistance change per Ohm per °C. For instance, Platinum 385 refers to a platinum RTD with a = 0.00385 Ohms/Ohm - °C, or simply 0.00385/ °C.

Table 1.3 Millivolt Input Ranges

-50 to +50 mV
-100 to +100 mV
-500 to +500 mV
-2.0 to +2.0 V
0 to +5.0 V
1.0 to +5.0 V
0 to 10.0 V
-10.0 to +10.0 V

Table 1.4 Current Input Ranges

4 to 20 mA
0 to 20 mA

Table 1.5 Resistance Input Range

0 to 3000 Ohms

All eight input channels are individually configurable for thermocouple, millivolt, volt, or milliamp input types. Channels 4 through 7 can be defined for RTD or resistance inputs, and then can be individually configured for a specific RTD or resistance type. Each input channel provides broken input, over-range, and under-range detection and indication, when enabled.

Hardware Features

The module fits into any single slot for I/O modules in either an SLC 500 modular system or an SLC 500 fixed system expansion chassis (1746-A2). It is a Class 1[1] module (uses 8 input words and 8 output words).

[1] Requires use of Block Transfer in a remote configuration.

The module utilizes two removable terminal blocks, that provides connections for the eight input channels. There are two cold-junction compensation (CJC) sensors that compensate for the cold junction at ambient temperature rather than at freezing (0°C). There are four current sources for supplying the RTD or resistance sensors. The module is configured through software, with jumpers used to define RTD, resistance, current or voltage input paths.

Table 1.6 Hardware Features

Hardware	Function
Channel Status LED Indicators	Display operating and fault status of channels 0-7
Module Status LED	Displays operating and fault status of the module
Side Label (Nameplate)	Provides module information
Removable Terminal Block	Provides electrical connection to input devices
Door Label	Permits easy terminal identification
Self Locking Tabs	Secure module in chassis slot

Diagnostic LEDs

The module contains diagnostic LEDs that help you identify the source of problems that may occur during power-up or during normal operation. Power-up and channel diagnostics are explained in Chapter 6, *Testing Your Module*.

System Overview

The module communicates with the SLC 500 processor and receives +5 Vdc and +24 Vdc power from the system power supply through the parallel backplane interface. No external power supply is required. You may install as many universal modules in the system as the power supply can support.

The first four input channels (0 through 3) can receive input signals from thermocouples, millivolt, volt, or milliamp devices. The last four input channels (4 through 7) can receive input signals from thermocouples, millivolt, volt, milliamp, or 2, 3 or 4-wire RTD or resistance devices. If RTD or resistance inputs are selected, channels 4 through 7 can be individually configured for the supported RTD or resistance types.

When configured for thermocouple input types, the module converts analog input voltages into cold-junction compensated and linearized, digital temperature readings. The module uses the National Institute of Standards and Technology (NIST) linearization tables based on ITS-90 for thermocouple linearization.

When configured for RTD input types, the module converts the analog input voltages into digital temperature readings, based on the alpha type, wire type, and ohms specified. The standards used are the JIS C 1604-1997 for the Pt 385 RTD types, the JIS C 1604-1989 for the Pt 3916 RTD types, SAMA RC21-4-1966 for the 10Ω Cu 426 RTD, DIN 43760 Sept. 1987 for the 120Ω Ni 618 RTD, and MINCO Application Aid #18 May 1990 for the 120Ω Ni 672 RTD.

When configured for millivolt, volt, milliamp, or resistance analog inputs, the module converts the analog values directly into digital counts. For those input types, the module assumes that the input signal is linear prior to input into the module.

System Operation

At power-up, the module checks its internal circuits, memory, and basic functions. During this time the module status LED remains off. If the module finds no faults, it turns on its module status LED.

After completing power-up checks, the module waits for valid channel configuration data from your SLC ladder logic program (channel status LEDs are off). After channel configuration data is transferred and channel enable bits are set for one or more channels, the module turns on its channel status LEDs. Then it continuously converts the inputs to the data format you selected for the channel.

Each time the module reads an input channel, the module tests that data for a fault, i.e. over-range, or under-range condition. If open-circuit detection is enabled, the module tests for an open circuit condition. If it detects an open-circuit, over-range, or under-range condition, the module sets a unique bit in the channel status word and causes the channel status LED to blink.

The SLC processor reads the converted thermocouple, RTD, resistance, millivolt, volt, or milliamp data from the module at the end of the program scan, or when commanded by the ladder program. After the processor and module determine that the data transfer was made without error, the data can be used in your ladder program.

Module Operation

The module's input circuitry consists of eight differential analog inputs, multiplexed into an A/D converter. The A/D converter reads the analog input signals and converts them to digital counts. The input circuitry also continuously samples the CJC sensors and compensates for temperature changes at the cold junction (terminal block). The module can be used with remote CJC sensor inputs. The sensors must be Analog Devices AD592CN temperature transducers. The module will not accept other CJC sensor inputs, and thermocouple inputs will not function properly if incorrect CJC sensors are used.

Module Addressing

The module requires eight words each in the SLC processor's input and output image tables. Addresses for the module in slot e are as follows:

I:e.0-7 thermocouple/mV/V/mA, RTD, resistance or status data for channels 0-7, respectively

O:e.0-7 configuration data for channels 0-7, respectively.

Compatibility with Thermocouple, Current, and Millivolt Devices & Cables

The module is compatible with the following standard types of thermocouples: B, E, J, K, N, R, S, T and C and extension wire. Refer to appendices B and C for details. The module is also compatible with a variety of voltage and current devices with an output of ±50, ±100 mV, +500mV, ±2V, 0-5V, 1-5V, 0-10V, ±10V, 0-20mA, and 4-20mA.

To minimize interference from radiated electrical noise, we recommend twisted-pair and highly shielded cables such as the following:

Table 1.7 Recommendations to minimize interference from radiated electrical noise

For This Type of Device	We Recommend This Cable (or equivalent)
Thermocouple Type J	EIL Corp. J20-5-502
Thermocouple Type K	EIL Corp. K20-5-510
Thermocouple Type T	EIL Corp. T20-5-502
Other Thermocouple Types	consult with EIL Corp or other manufacturers
mV, V, mA devices	Belden 8761, shielded, twisted-pair

Compatibility with RTD and Resistance devices and cables

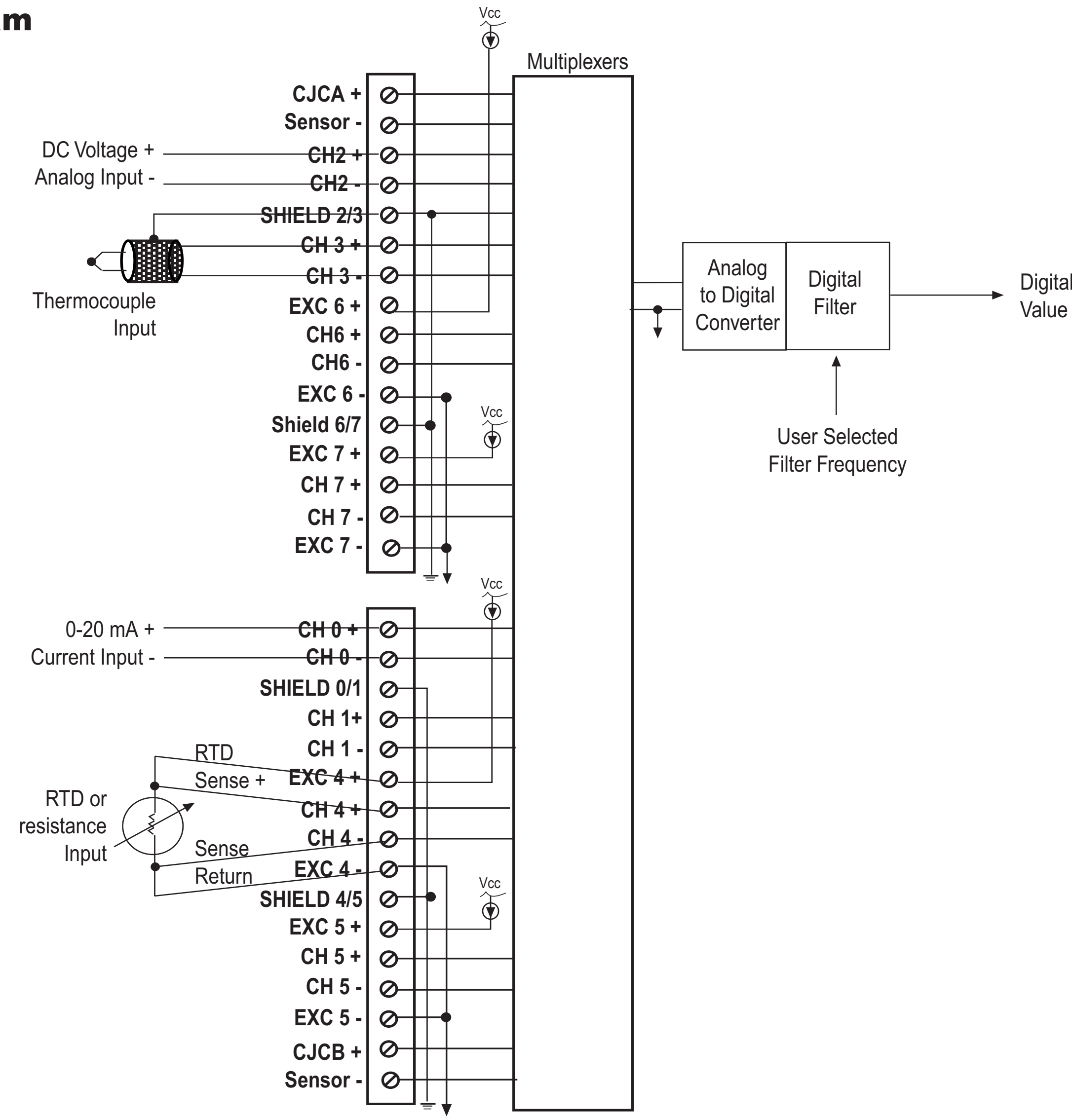
The module is compatible 100Ω Platinum 385, 200Ω Platinum 385, 55Ω Platinum 385, 1000Ω Platinum 385, 100Ω Platinum 3916, 200Ω Platinum 3916, 500Ω Platinum 3916, 1000Ω Platinum 3916, 10Ω Copper 426, 120Ω Nickel 618 and 120Ω Nickel 672 RTD types and 3000Ω resistance inputs, and 3 possible wire types (2 wire, 3 wire, or 4 wire). Each RTD input individually supports four input pins on the terminal block: one excitation current source (EXC+), one excitation current drain (EXC-), one sense positive (CH+) and one sense negative (CH-). Only those pins are connected that are required by the selected RTD or resistance wire type. For 2, 3, or 4 wire configurations, the module can support a maximum combined cable length associated with an overall cable impedance of 25 ohms or less without exceeding its input limitations. The accuracy specifications provided herein do not include errors associated with unbalanced cable impedance.

Since the operating principle of the RTD and resistance inputs is based on the measurement of resistance, take special care in selecting your input cable. For 2-wire or 3-wire configuration, select a cable that has a consistent impedance throughout its entire length. For 2-wire configurations, we recommend that you use *Belden #9501* (*or equivalent*). For 3-wire configurations, we recommend that you use *Belden #9533* (*or equivalent*) for short installation runs (less than 100 feet) or use *Belden #83503* (*or equivalent*) for longer runs (greater than 100 feet) and in high humidity environments.

Table 1.8 Cable Specifications

Description	Belden #9501	Belden#9533	Belden#83503
When used?	For 2-wire RTDs and potentiometers.	For 3-wire RTDs and potentiometers. Short runs less than 100 feet and normal humidity levels.	For 3-wire RTDs and potentiometers. Long runs greater than 100 feet or high humidity levels.
Conductors	2, #24 AWG tinned copper (7x32)	3, #24 AWG tinned copper (7x32)	3, #24 AWG tinned copper (7x32)
Shield	Beldfoil aluminum polyester shield w/ copper drain wire.	Beldfoil aluminum polyester shield w/copper drain wire.	Beldfoil aluminum polyester shield w/copper drain wire.
Insulation	PVC	S-R PVC	Teflon
Jacket	Chrome PVC	Chrome PVC	Red teflon
Agency Approval	NEC Type CM	NEC Type CM	NEC Art-800, Type CMP
Temperature Rating	80°C	80°C	200°C

Block Diagram



Chapter 2

Installing And Wiring Your Module

Read this chapter to install and wire your module. This chapter covers:

- avoiding electrostatic damage
- determining power requirements
- installing the module
- wiring signal cables to the module's terminal block

Electrostatic Damage

Electrostatic discharge can damage semiconductor devices inside this module if you touch backplane connector pins. Guard against electrostatic damage by observing the following precautions:

CAUTION

ELECTROSTATICALLY SENSITIVE COMPONENTS

- **Before handling the module, touch a grounded object to rid yourself of electrostatic charge.**
- **When handling the module, wear an approved wrist strap grounding device.**
- **Handle the module from the front, away from the backplane connector. Do not touch backplane connector pins.**
- **Keep the module in its static-shield container when not in use or during shipment.**

Failure to observe these precautions can degrade the module's performance or cause permanent damage.

Power Requirements

The module receives its power through the SLC-500 chassis backplane from the fixed or modular +5 VDC and +24 VDC chassis power supply. The maximum current drawn by the module is shown in the table below.

Table 2.1. Maximum current drawn by the module

5VDC Amps	24VDC Amps
0.120	0.100

When using the module in a *modular system*, add the values shown above to the requirements of all other modules in the SLC to prevent overloading the chassis power supply.

When using the module in a *fixed controller*, be sure not to exceed the power supply rating for the 2-slot I/O chassis.

Considerations for a Modular System

Place your module in any slot of an SLC-500 modular, or modular expansion chassis, except for the left-most slot (slot 0) reserved for the SLC processor or adapter modules.

Considerations for a Fixed Controller

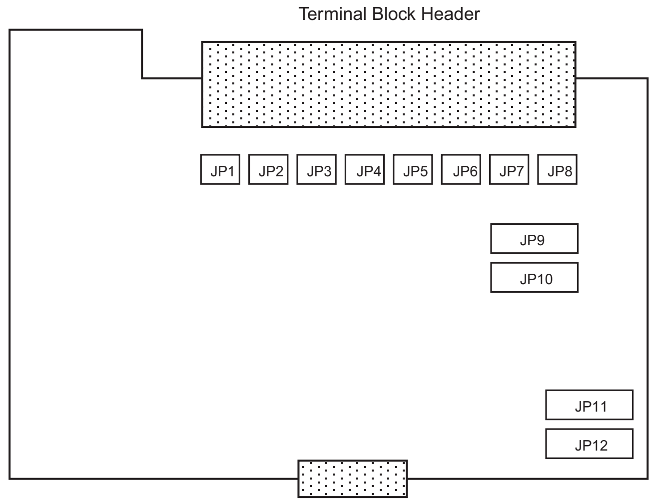
The power supply in the 2-slot SLC 500 fixed I/O chassis (1746-A2) can support only specific combinations of modules. Make sure the chassis power supply can support the NI8u and additional module power requirements.

Shunt Configuration

The 1746sc-NI8u module is a multi-purpose, multi-functional module, that is capable of supporting many different input types in a very small package. There are a few shunts on the board that allow the user to define input paths properly, which are imperative for the configuration control to allow proper utilization of the module. JP1 through JP8 supports the current input mode options of each of the inputs channels, 0 through 7, respectively. In order to define channels 4 through 7, JP9 and JP10, must be configured properly. JP11 is used at the factory and should not be modified. JP12 indicates whether or not RTD or resistance inputs are to be used in the configuration. The module is shipped with all current input shunts in place, and the remaining shunts installed for non-RTD or resistance inputs. The shunts are to be modified prior to installation of the module. Proper precautions for electrostatic handling should be followed. Small needlenose pliers may be used to configure the shunts, if needed.

ATTENTION: Never touch the module without being properly strapped and connected to ground. Electrostatic damage may result.

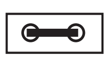
The following diagram shows the module outline defining the placement of the various shunts, looking at the primary side of the board, with the terminal block pointing up. A brief description of each follows.



JP1, JP2, JP3, JP4, JP5, JP6, JP7, and JP8 Setup

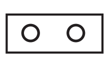
There are eight shunts corresponding to eight inputs, respectively, that exist to support the 0 to 20mA or 4 to 20mA current input selections. JP1 corresponds to channel 0, and JP8 corresponds to channel 7. The shunts of JP2 through JP7 follow for channels 1 through 6, respectively. These shunts are two pin headers that only need to be connected if a channel is to be configured for current input. If the channel is to be used for any other type (thermocouple, millivolt, voltage for channels 0 through 3, or thermocouple, millivolt, voltage, RTD, or resistance for channels 4 through 7), then the pins are to be left open and unconnected.

Current Input



Shunt in place

Non-Current Input



Shunt removed

JP11 Setup

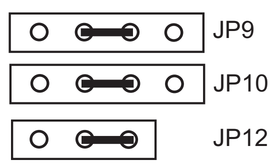
Located in the bottom right hand corner, JP11 should always have pins 1 and 2 connected as shown. This shunt is used during manufacturing of the module, and should never be moved by the user.

JP9, JP10, and JP12 Setup

The NI8u module supports up to four RTD or resistance inputs on channels 4 through 7. In order to properly support RTD or resistance inputs, JP9, JP10, and JP12 have to be configured correctly. The function of JP9 and JP10 is to define the input path for the channels 4 through 7. JP9 and JP10 are four pin headers toward the right side of the board, looking at the primary side of the board with the terminal block pointing up. JP12 is a three pin header on the very bottom right hand corner, below JP11.

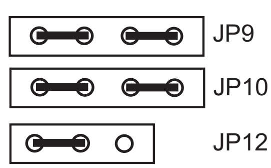
Setting For RTD or Resistance Inputs

The module will either support zero RTD or resistance inputs or four RTD or resistance inputs in channels 4 through 7. To properly configure JP9 and JP10 for RTD or resistance, set the shunts across pins 2 and 3 of the four pin headers. JP12 also needs to have pins 2 and 3 connected when RTD or resistance are to be used, as shown below.



Setting For Non-RTD or Resistance Inputs

If RTD and resistance inputs are not used, and channels 4 through 7 are to be defined as thermocouple inputs, current inputs, millivolt or voltage inputs, jumper pins 1 and 2 together, jumper pins 3 and 4 together, of JP9 and JP10, as defined below. JP12 also needs to have pins 1 and 2 connected when RTD and resistance inputs are not in use.



Selecting A Rack Slot

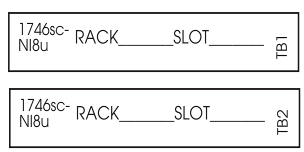
Two factors determine where you should install your module in the rack: ambient temperature and electrical noise. When selecting a slot for your module, try to position your module:

- in a rack close to the bottom of the enclosure (where the air is cooler)
- away from modules that generate significant heat, such as 32-point input/output modules
- in a slot away from ac or high-voltage dc modules, hard contact switches, relays, and ac motor drives
- away from the rack power supply (if using a modular system)

Remember that in a modular system, the processor always occupies the first slot of the rack.

Module Installation and Removal

When installing the module in a chassis, it is not necessary to remove the terminal blocks from the module. However, if the terminal blocks are removed, use the write-on label located on the side of the terminal blocks to identify the module location and type.



CAUTION

POSSIBLE EQUIPMENT OPERATION

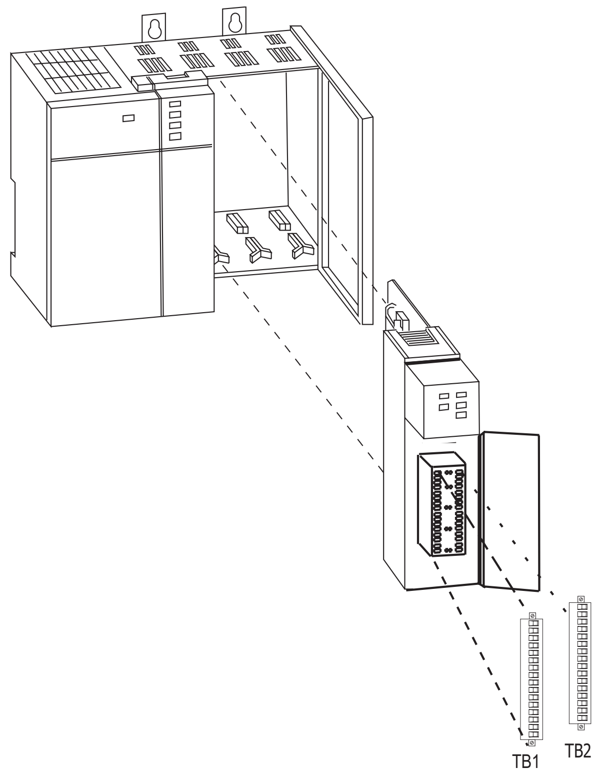
Before installing or removing your module, always disconnect power from the SLC 500 system and from any other source to the module (in other words, don't "hot swap" your module), and disconnect any devices wired to the module.

Failure to observe this precaution can cause unintended equipment operation and damage.

To insert your module into the rack, follow these steps:

1. Align the circuit board of your module with the card guides at the top and bottom of the chassis.

Figure 2.1. Module insertion into a rack



2. Slide your module into the chassis until both top and bottom retaining clips are secure. Apply firm even pressure on your module to attach it to its backplane connector. Never force your module into the slot.

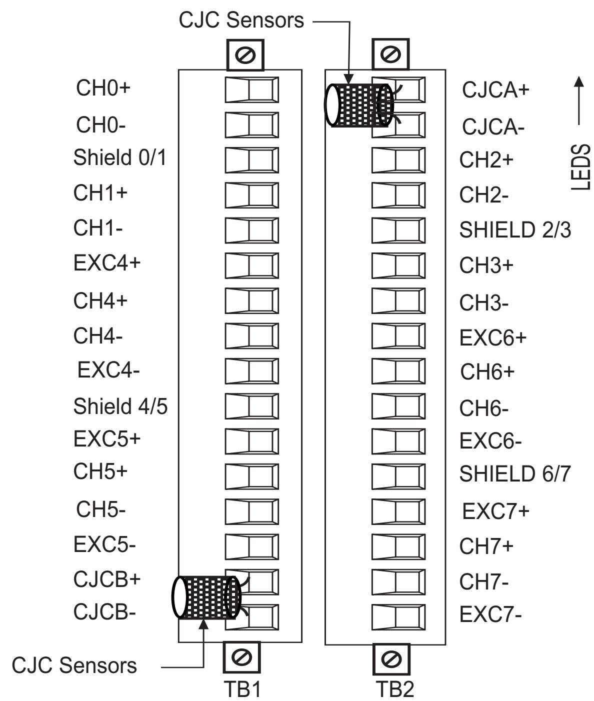
Cover all unused slots with the Card Slot Filler, Allen-Bradley part number 1746-N2.

Terminal Block Removal

To remove the terminal block:

Using a screwdriver or needle-nose pliers, carefully unscrew and then pry the terminal block loose. When removing or installing the terminal block be careful not to damage the CJC sensors.

Figure 2.2. Terminal block diagram with CJC sensors



CAUTION

POSSIBLE EQUIPMENT OPERATION

Before wiring your module, always disconnect power from the SLC 500 system and from any other source to the module.

Failure to observe this precaution can cause unintended equipment operation and damage.

Wiring Your Module

Follow these guidelines to wire your input signal cables:

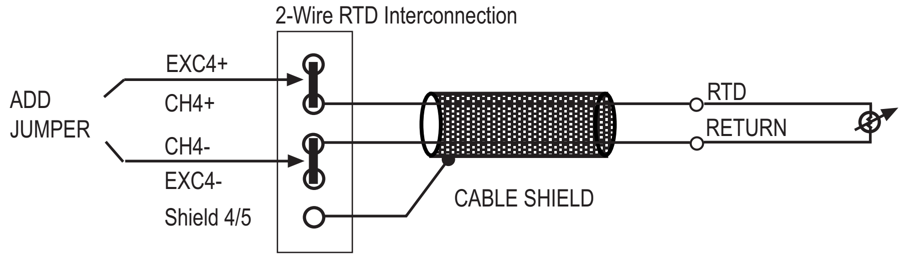
- Power, input, and output (I/O) wiring must be in accordance with Class 1, Division 2 wiring methods [Article 501-4(b) of the National Electrical Code, NFPA 70] and in accordance with the authority having jurisdiction.
- Peripheral equipment must be suitable for the location in which it is used.
- Route the field wiring away from any other wiring and as far as possible from sources of electrical noise, such as motors,

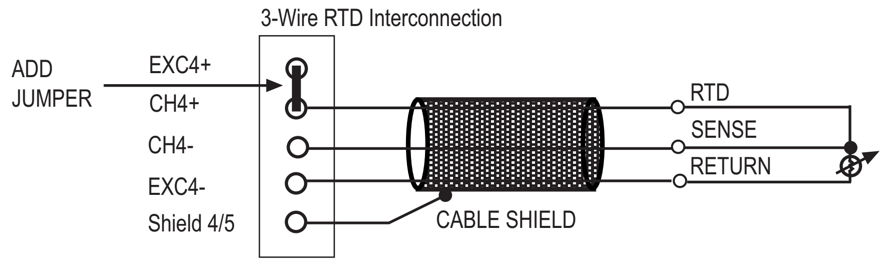
transformers, contactors, and ac devices. As a general rule, allow at least 6 in. (about 15.2 cm) of separation for every 120 V of power.

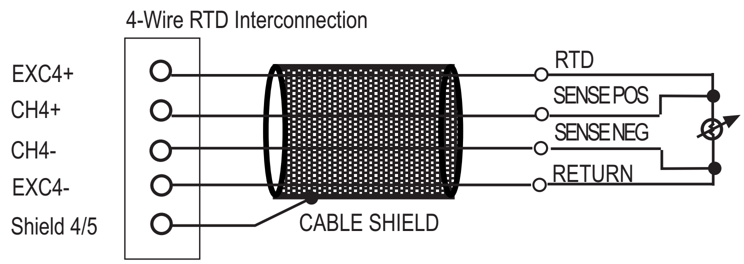
- Routing the field wiring in a grounded conduit can reduce electrical noise further.
- If the field wiring must cross ac or power cables, ensure that they cross at right angles.
- To limit the pickup of electrical noise, keep thermocouple, RTD, millivolt, and milliamp signal wires as far from power and load lines as possible.
- For improved immunity to electrical noise, use Belden 8761 (shielded, twisted pair) or equivalent wire for millivolt sensors; or use shielded, twisted pair thermocouple extension lead wire specified by the thermocouple or RTD manufacturer. Using the incorrect type of thermocouple extension wire or not following the correct polarity may cause invalid readings.
- There is one shield pin for every two input channels. All shields are internally connected, so any shield terminal can be used with any channel.
- Ground the shield drain wire at only one end of the cable. The preferred location is at the shield connections on the terminal block. (Refer to IEEE Std. 518, Section 6.4.2.7 or contact your sensor manufacturer for additional details.)
- Keep all unshielded wires as short as possible.
- To limit overall cable impedance, keep input cables as short as possible. Locate your I/O chassis as near the RTD or thermocouple sensors as your application will permit.
- Tighten screw terminals with care. Excessive tightening can strip a screw.
- Follow system grounding and wiring guidelines found in your SLC 500 Installation and Operation Manual.

Wiring RTD or Resistance Sensors to the NI8u Module

The NI8u module supports two, three, and four wire RTDs or resistance inputs connected individually to the module (channels 4 through 7), as shown in the figure below.







These are:

* 2-wire RTDs, which are composed of 2 RTD lead wires (RTD and Return)

* 3-wire RTDs, which are composed of a Sense and 2 RTD lead wires (RTD and Return)

* 4-wire RTDs, which are composed of 2 Sense and 2 RTD lead wires (RTD and Return).

In any RTD sensing system, it is important that the lead and sense wire resistances are matched as much as possible. The lead lengths, and their resulting impedances, must be matched and kept small to eliminate the introduction of connectivity errors. The 4-wire RTDs are the most accurate, with 2-wire RTDs being the most inaccurate. In 2-wire the lead resistance adds error to the resulting degree reading. With a 200µA current source, 1Ω of lead resistance adds 200µV, or 3.45°C error, with the 100Ω 385 alpha type. To gain an understanding of how lead resistance affects RTD readings, the µV/C for each RTD type is listed below. The current source is 200µA.

RTD Type	V/°C
100Ω Pt 385	58μV/°C
200Ω Pt 385	116μV/°C
500Ω Pt 385	290μV/°C
1000Ω Pt 385	580μV/°C
100Ω Pt 3916	68μV/°C
200Ω Pt 3916	136μV/°C
500Ω Pt 3916	340μV/°C
1000Ω Pt 3916	680μV/°C
10Ω Cu 426	4.3μV/°C
120Ω Ni 618	110μV/°C
120Ω Ni 672	130μV/°C

The accuracies specified for the NI8u RTDs do not include errors due to lead resistance imbalances.

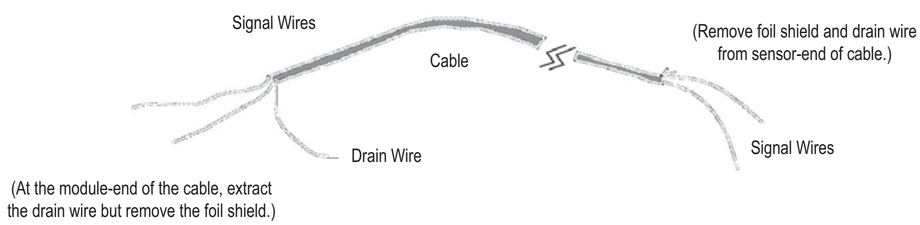
Important: To ensure temperature or resistance value accuracy, the resistance difference of the cable lead wires must be equal to or less than 0.01 ohms.

There are several ways to insure that the lead values match as closely as possible. They are as follows:

* Keep total lead resistance as small as possible, and less than 25 ohms.
* Use quality cable that has a small tolerance impedance rating.
* Use a heavy gauge lead wire which has less resistance per foot.

Preparing and Wiring the Cables

To prepare and connect cable leads and drain wires, follow these steps:



1. At each end of the cable, strip some casing to expose individual wires.
2. Trim signal wires to 5-inch lengths beyond the cable casing. Strip about 3/16 inch (4.76 mm) of insulation to expose the ends of the wires.
3. At the module-end of the cables (see figure above):

- extract the drain wire and signal wires

- remove the foil shield

- bundle the input cables with a cable strap

4. Connect pairs of drain wires together, Channels 0 and 1, Channels 2 and 3, Channels 4 and 5, Channels 6 and 7. Keep drain wires as short as possible.

5. Connect the drain wires to the shield inputs of the terminal block.

   Channel 0 and 1 drain wires to the shield 0/1 input pin

   Channel 2 and 3 drain wires to the shield 2/3 input pin

   Channel 4 and 5 drain wires to the shield 4/5 input pin

   Channel 6 and 7 drain wires to the shield 6/7 input pin

6. Connect the signal wires of each channel to the terminal block. Important: Only after verifying that your connections are correct for each channel, trim the lengths to keep them short. Avoid cutting leads too short.

7. Connect the chassis ground terminal/lug to the nearest chassis mounting bolt with 14 gauge wire. (Looking at the face of the module, the terminal/lug is near the terminal block and above power supply PS2 on the primary side of the PCB.)

8. At the source-end of cables from mV devices:

   - remove the drain wire and foil shield

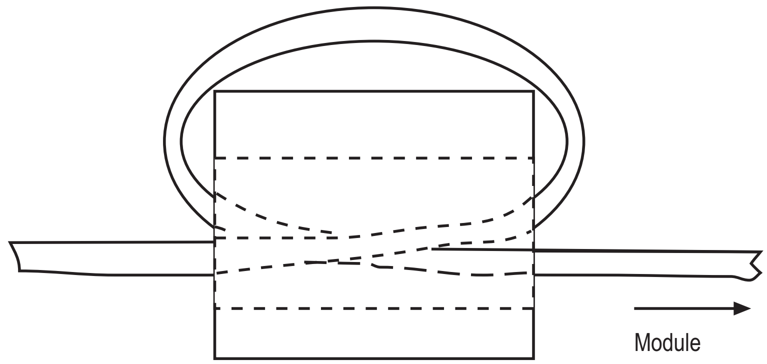
   - apply shrink wrap as an option

   - connect to mV devices keeping the leads short

Important: If noise persists, try grounding the opposite end of the cable, instead (Ground one end only.)

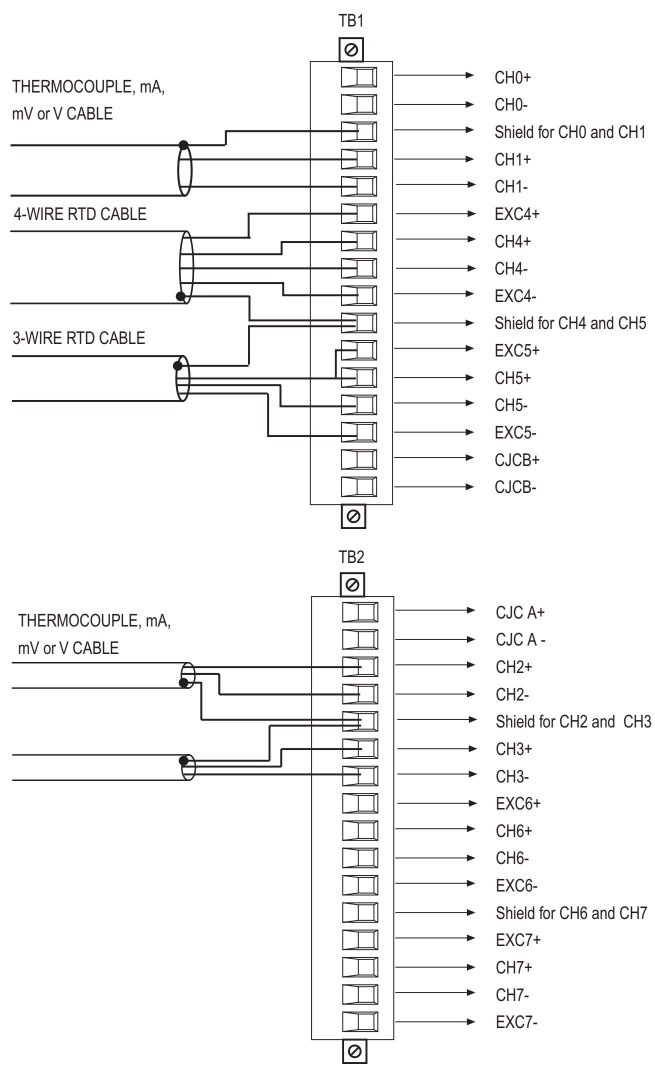
Important: For CE compliance, Ferrite EMI Suppressors are needed on each channel's terminal block connection. If remote CJCs are installed, shielded wire must be used and a Ferrite EMI suppressor is needed on each CJC input connection. The drain wire of the CJC cable must be connected to a shield connection at the module. Apply the suppressor close to the module terminal block, as shown below. A Steward Part 28B2024-0A0 or equivalent is recommended. The Steward 28B2024-0A0 has an impedance of 157Ω at 25 MHz, 256Ω at 100 MHz, and can accomodate one turn of wire.

Figure 2.3 Ferrite EMI suppressor for CE compliance



Note: Please refer to Appendix C for additional information on wiring and using grounded junction, ungrounded junction and exposed juction thermocouple types.

Figure 2.4 Terminal block diagram with input cable



The module also has a ground terminal TB1 which should be grounded to a chassis mounting bolt with 14 gauge wire.

Cold Junction Compensation (CJC)

CAUTION

POSSIBLE EQUIPMENT OPERATION

Do not remove or loosen the cold junction compensating temperature transducers located on the terminal block unless you are connecting remote CJCs to the module. Both CJCs are critical to ensure accurate thermocouple input readings at each channel. The module will not operate in thermocouple mode if a CJC is not connected.

Failure to observe this precaution can cause unintended equipment operation and damage.

To obtain accurate readings from each of the channels, the cold junction temperature (temperature at the module's terminal junction between the thermocouple wire and the input channel) must be compensated for. Two cold junction compensating sensors have been integrated in the removable terminal block. They must remain installed to retain accuracy. If remote CJC compensation is desired, the sensors at the terminal block must be removed and the external sensors wired to the CJCA and CJCB terminals. The remote CJC sensors must be Analog Devices AD592CN T0-92 style temperature transducer devices. The module will not function with any other CJC sensor connected.

Things To Consider Before Using Your Module

This chapter explains how the module and the SLC processor communicate through the processor's I/O image tables. It also describes the module's input filter characteristics. Topics discussed include:

- module ID code
- module addressing
- channel filter frequency selection
- Channel turn-on, turn-off, and reconfiguration times
- response to slot disabling

Module ID Code

The module ID code is a unique number assigned to each type of 1746 I/O module. The ID defines for the processor the type of I/O module and the number of words used in the processor's I/O image table.

With APS software, use the system I/O configuration display to manually enter the module ID when assigning the slot number during the configuration. Do this by selecting (other) from the list of modules on the system I/O configuration display and enter 3500, the ID code for the 1746sc-NI8u.

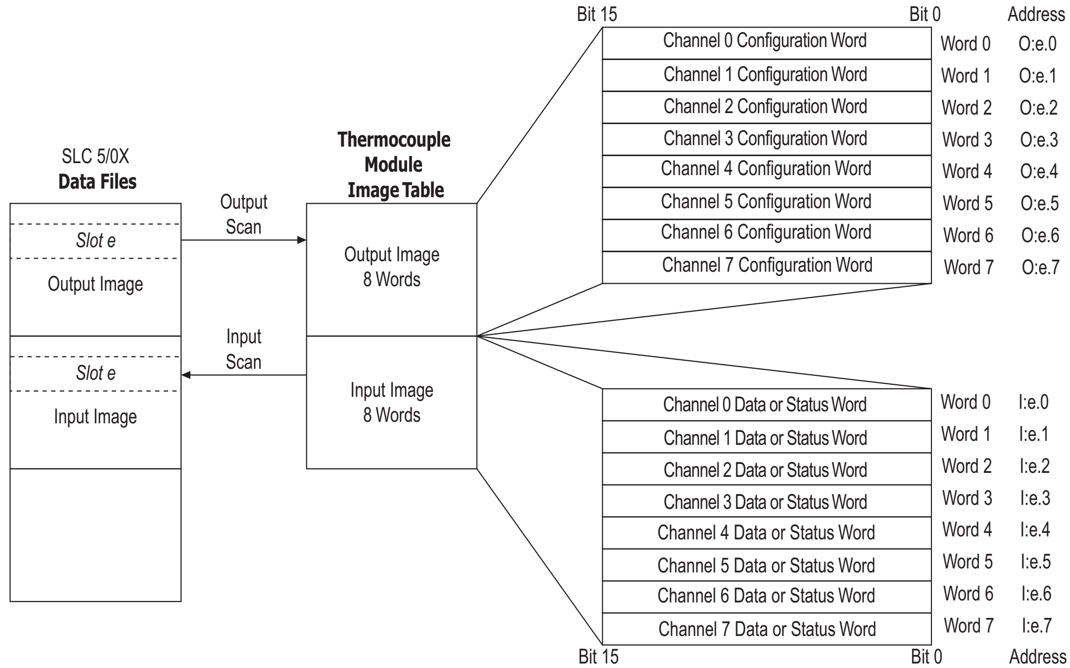
No special I/O configuration (SPIO CONFIG) is required. The module ID automatically assigns the correct number of input and output words.

If you are using different programming software package, refer to the documentation that came with your software.

Module Addressing

The following memory map shows you how the SLC processor's output and input tables are defined for the module.

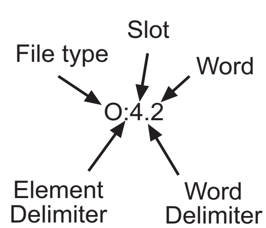
Figure 3.1 Image table



Output Image - Configuration Words

Eight words of the SLC processor's output image table are reserved for the module. Output image words 0-7 are used to configure the module's input channels 0-7. Each output image word configures a single channel, and can be referred to as a configuration word. Each word has a unique address based on the slot number assigned to the module.

Example Address - If you want to configure channel 2 on the module located in slot 4 in the SLC chassis, your address would be O:4.2.



Chapter 4, *Channel Configuration, Data, and Status*, gives you detailed bit information about the data content of the configuration word.

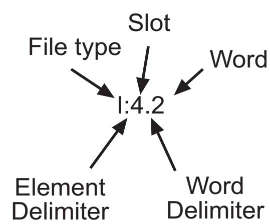
Input Image - Data Words and Status Words

Eight words of the SLC processor's input image table are reserved for the module. Input image words are multiplexed since each channel has one data word and one status word. The corresponding configuration word selects whether the channel status or channel data is in the input image word.

Status bits for a particular channel reflect the configuration settings that you entered into the configuration (output image) word for that channel. To receive valid status, the channel must be enabled and the module must have stored a valid configuration word for that channel.

Each input image word has a unique address based on the slot number assigned to the module.

Example Address - To obtain the status/data word of channel 2 (input word 2) of the module located in slot 4 in the SLC chassis use address I:4:2.



Chapter 4, *Channel Configuration, Data, and Status*, gives you detailed bit information about the content of the data word and the status word.

Channel Filter Frequency Selection

The universal module uses a digital filter that provides high frequency noise rejection for the input signals. The digital filter is programmable, allowing you to select from four filter frequencies for each channel. The digital filter provides the highest noise rejection at the selected filter frequency. The graphs to follow show the input channel frequency response for each filter frequency selection.

Selecting a low value (i.e. 10 Hz) for the channel filter frequency provides the best noise rejection for a channel, but it also increases the channel update time. Selecting a high value for the channel filter frequency provides lower noise rejection, but decreases the channel update time.

The following table shows the available filter frequencies, cut-off frequency, step response, and ADC effective resolution for each filter frequency.

Table 3.1 Cut-off frequency, step response time, and effective resolution (based on filter frequency)

Filter Frequency	Cut-Off Frequency	Step Response	ADC Effective Resolution
10 Hz	2.62 Hz	300 ms	20.5
50 Hz	13.1 Hz	60 ms	19.0
60 Hz	15.72 Hz	50 ms	19.0
250 Hz	65.5 Hz	12 ms	15.5

The step response is calculated by a 3 x (1/filter frequency) settling time.

Channel Cut-Off Frequency

The channel filter frequency selection determines a channel's cut-off frequency, also called the -3 dB frequency. The cut-off frequency is defined as the point on the input channel frequency response curve where frequency components of the input signal are passed with 3 dB of attenuation. All frequency components at or below the cut-off frequency are passed by the digital filter with less than 3 dB of attenuation. All frequency components above the cut-off frequency are increasingly attenuated, as shown in the graphs below.

The cut-off frequency for each input channel is defined by its filter frequency selection. The table above shows the input channel cut-off frequency for each filter frequency. Choose a filter frequency so that your fastest changing signal is below that of the filter's cut-off frequency. The cut-off frequency should not be confused with update time. The cut-off frequency relates how the digital filter attenuates frequency components of the input signal. The update time defines the rate at which an input channel is scanned and its channel data word updated.

Figure 3.2 Signal attenuation with 10 Hz input filter

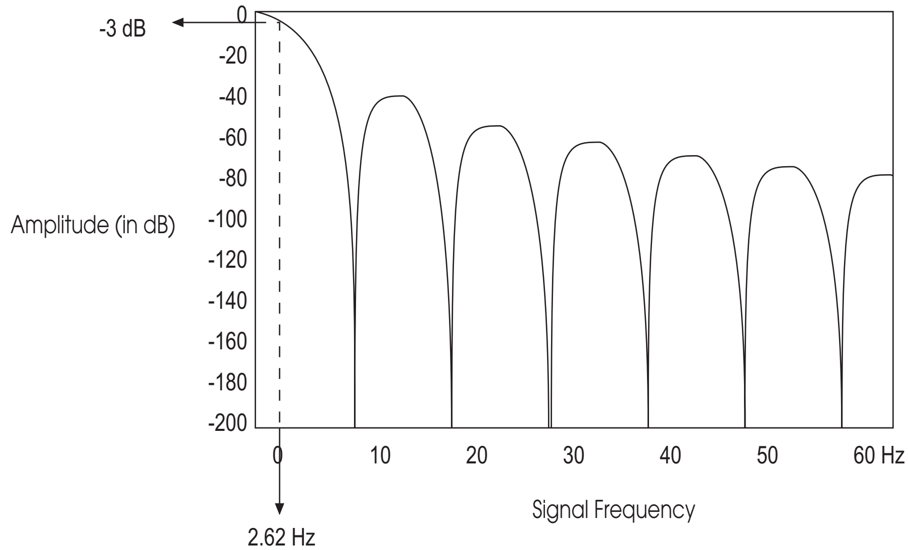


Figure 3.3 Signal attenuation with 50 Hz input filter

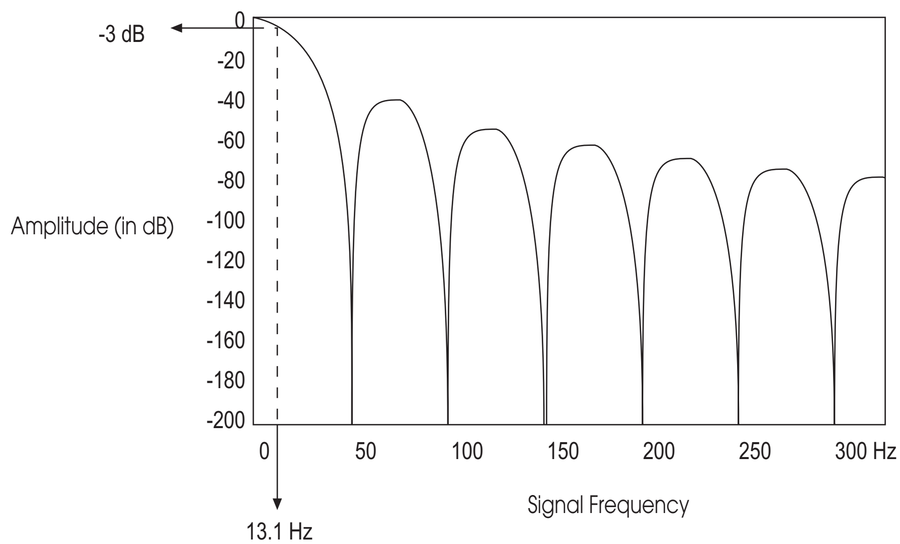


Figure 3.4 Signal attenuation with 60 Hz input filter

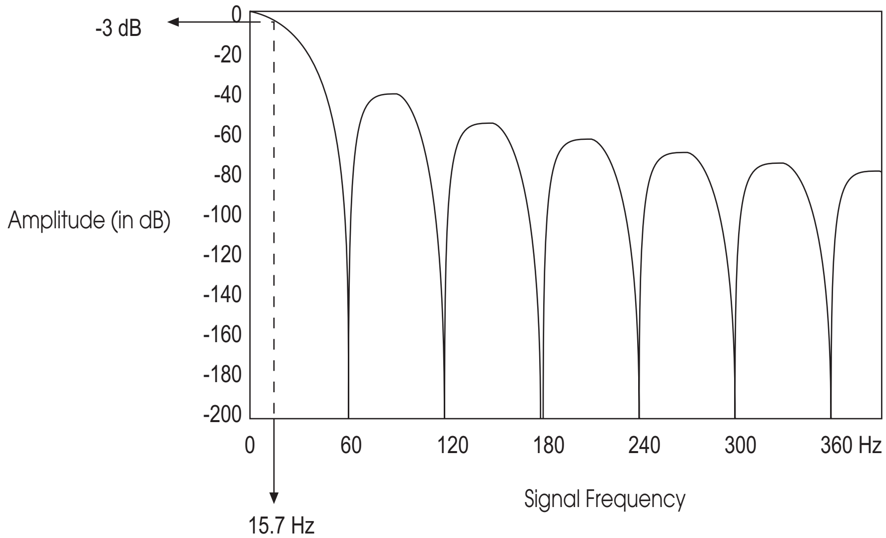
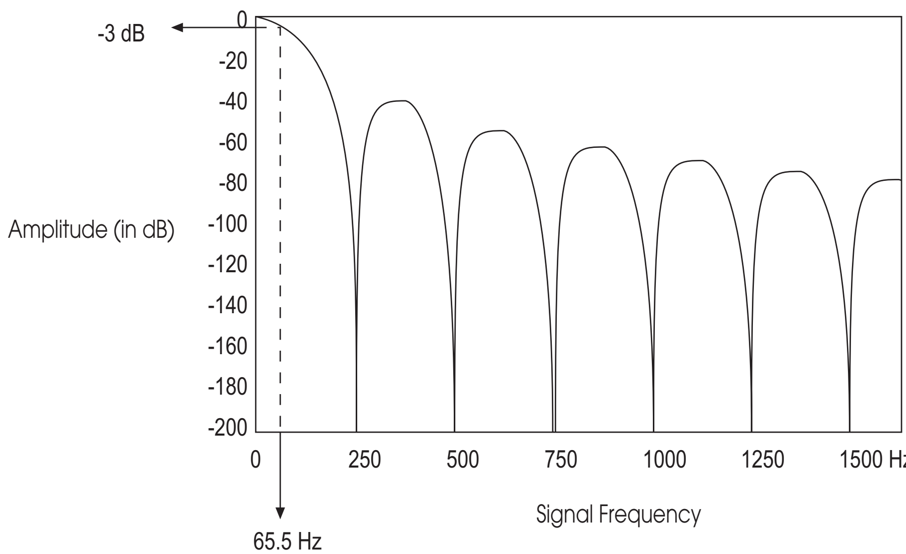


Figure 3.5 Signal attenuation with 250 Hz input filter

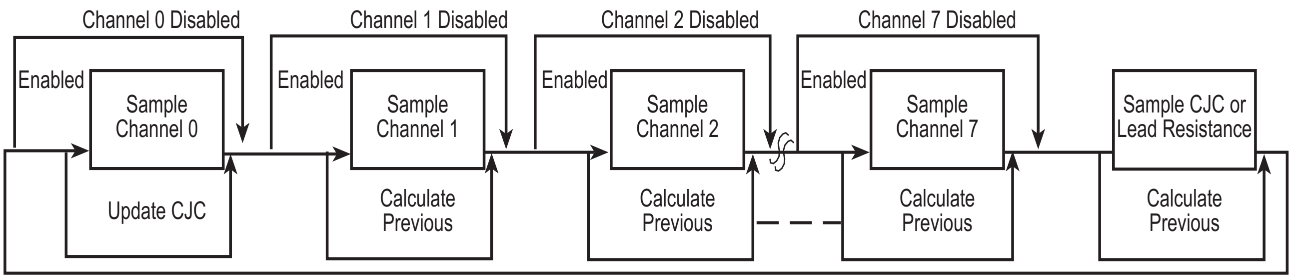


Channel Step Response

The channel filter frequency determines the channel's step response. The step response is time required for the analog input signal to reach 95% of its expected, final value given a full-scale step change in the input signal. This means that if an input signal changes faster than the channel step response, a portion of that signal will be attenuated by the channel filter. Table 6 shows the step response for each filter frequency.

Update Time

The universal module update time is defined as the time required for the module to sample and convert the input signals of all enabled input channels and make the resulting data values available to the SLC processor. It can be calculated by adding the sum of all enabled sample times, plus one CJC update time or one lead resistance update time.



The following table shows the channel sampling time for each filter frequency.

Table 3.2 Channel Sampling Time

Channel Sampling Time for Each Filter Frequency (all values ±1 msec)

Channel Sampling Time			
250 Hz Filter	**60 Hz Filter**	**50 Hz Filter**	**10 Hz Filter**
26 msec	64 msec	74 msec	314 msec

The times above include a settling time necessary between input channel readings.

In addition, on each module scan the module will sample either one CJC input or one lead resistance input if any enabled channel input type is a thermocouple, RTD, or resistance input. The CJC sampling time is 64 msec. The lead resistance sampling time is equal to the channel sampling time for that RTD. When both thermocouple inputs and RTD or resistance inputs are used, the module will alternate between sampling one CJC and one lead resistance.

The fastest module update time occurs when only one millivolt channel with a 250 Hz filter frequency is enabled.

Module update time = 26 msec

The slowest module update time occurs when eight channels, four thermocouples and four RTDs, each using a 10 Hz filter frequency, are enabled.

Module update time = 314 msec + 314 msec + 314 msec + 314 msec + 314 msec + 314 msec + 314 msec + 314 msec + 314 msec = 2.826 sec

Note: On alternate module scans, the 314 msec lead resistance sampling time would be replaced by a 64 msec CJC sampling time.

Update Time Calculation Example

The following example shows how to calculate the module update time for the given configuration:

Channel 0 configured for mV input at 250 Hz filter frequency, enabled
Channel 1 configured for mV input at 250 Hz filter frequency, enabled
Channel 2 configured for mV input at 50 Hz filter frequency, enabled
Channel 3 disabled
Channel 4 configured for RTD input at 50Hz filter frequency, enabled
Channel 5 through 7 disabled

Using the values from the table above, add the sum of all enabled channel sample times, plus one 50 Hz lead resistance update time.

Channel 0 sampling time	= 26 msec
Channel 1 sampling time	= 26 msec
Channel 2 sampling time	= 74 msec
Channel 4 sampling time	= 74 msec
Lead Resistance Sampling time	= 74 msec
Module update time	= 274 msec

Channel Turn-On, Turn-Off, and Reconfiguration Times

The time required for the module to recognize a new configuration for a channel is generally one module update time plus 1.865 msec per newly configured channel. If the filter frequency selected for the newly enabled, configured channel is new to the module, then auto-calibration will be performed following configuration recognition.

Turn-off time requires up to one module update time.

Reconfiguration time is the same as turn-on time.

Auto-Calibration

Auto-calibration is performed by the module to correct for drift errors over temperature. Auto-calibration occurs immediately following configuration of a previously unselected filter frequency for the particular input path. If all enabled channels have the calibration disable configuration bit set to zero, auto-calibration also occurs as a continuous cycle, where every two minutes all the required filter frequencies and input paths are calibrated. There are three input paths in the system to accommodate all the input options: a low voltage input path, a mid voltage input path, and a high voltage input path. The following table correlates input type to input path.

Input Type	Input Path
4 to 20mA	Mid
0 to 20mA	Mid
± 50mV	Low
± 100mV	Low
± 500mV	Mid
± 2V	Mid
0 to 5V, 1-5V	High
± 10V, 0-10V	High
All Thermocouple Types	Low
Pt 385 RTD, 100Ω	Low
Pt 385 RTD, 200Ω, 500Ω, 1000Ω	Mid
Pt 385 RTD, 100Ω	Low
Pt 385 RTD, 200Ω, 500Ω, 1000Ω	Mid
Cu 426 RTD, 10Ω	Low
Ni 618 RTD, 120Ω	Low
Ni 672 RTD, 120Ω	Low
CJC	Low
3000Ω Resistance	Mid

Each input path supports four different filter frequencies: 10Hz, 50Hz, 60Hz and 250Hz. The following table indicates auto-calibration time based on the input path, and the selected filter frequency.

Input Path	250Hz Filter	60Hz Filter	50Hz Filter	10Hz Filter
Low	181mS	384mS	435mS	1.85S
Mid	181mS	384mS	435mS	1.85S
High	96mS	208mS	238mS	1.03S

CJC sensors are acquired through the low voltage input path at 60Hz, to maximize the trade-offs between resolution and update rate.

Once every two minutes, the module calibrates one of the input path and filter combinations on successive scans until all input path and filter combinations that are used have been calibrated. During auto-calibration, the module scan time will increase by the auto-calibration time.

Auto-calibration can be disabled by placing a one in any enabled channel's auto-cal disable bit.

Response to Slot Disabling

By writing to the status file in the modular SLC processor, you can disable any chassis slot. Refer to your SLC programming manual for the slot disable/enable procedure.

CAUTION

POSSIBLE EQUIPMENT OPERATION

Always understand the implications of disabling a module before using the slot disable feature.

Failure to observe this precaution can cause unintended equipment operation.

Input Response

When a universal slot is disabled, the universal module continues to update its input image table. However, the SLC processor does not read input from a module that is disabled. Therefore, when the processor disables the universal module slot, the module inputs appearing in the processor image table remain in their last state, and the module's updated image table is not read. When the processor re-enables the module slot, the current state of the module inputs are read by the processor during the subsequent scan.

Output response

The SLC processor may change the universal module output data (configuration) as it appears in the processor output image. However, this data is not transferred to the universal module. The outputs are held in their last state. When the slot is re-enabled, the data in the processor image is transferred to the universal module.

Channel Configuration, Data, and Status

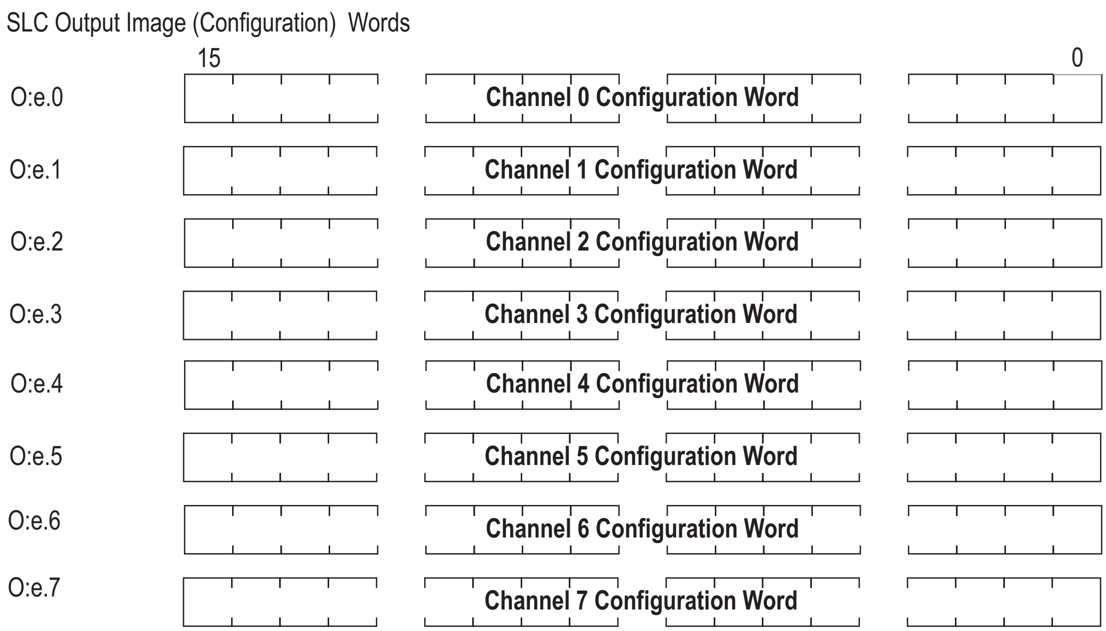
Read this chapter to:

- configure each input channel
- check each input channel's configuration and status

Channel Configuration

Channel configuration words appear in the SLC controller's output image table as shown below. Words 0-7 correspond to module channels 0-7.

After module installation, you must configure each channel to establish the way the channel operates (e.g., input type, temperature units, etc.). You configure the channel by setting bits in the configuration word using your programmer. We present bit descriptions next.



e = slot number of the module

The configuration word default settings are all zero. Next, we describe how you set configuration bits of a channel configuration word to set up the following channel parameters:

- type of thermocouple , RTD, resistance, mV, V, or mA input
- RTD or resistance type of 2-wire, 3-wire or 4-wire
- data format such as engineering units, counts, or scaled for PID
- how the channel should respond to a detected open input circuit, if applicable
- filter frequency selection
- temperature units in °C or °F
- whether the channel is enabled or disabled
- whether auto-calibration is enabled or disabled
- whether status or data information is selected for the module's input image table.

Channel Configuration Procedure

The channel configuration word consists of bit fields, the settings of which determine how the channel will operate. This procedure looks at each bit field separately and helps you configure a channel for operation. Refer to the chart on the following page and the bit field descriptions that follow for complete configuration information.

1. Determine which channels are used in your program and enable them. Place a one in bit 0 if the channel is to be enabled. Place a zero in bit 0 if the channel is to be disabled.

2. Determine the input device type (thermocouple, RTD, resistance, mV, V, or mA) for a channel and enter its respective 5-digit binary code in bit field 1-5 of the channel configuration word. Remember that only channels 4-7 support the RTD and resistance options. Make sure that the shunts are set accordingly for the input types specified.

3. Select a data format for the data word value. Your selection determines how the analog input value from the A/D converter will be expressed in the data word. Enter your 2-digit binary code in bit field 6-7 of the channel configuration word. Not all data formats apply to all

input types. Check table 11 to make sure you selected a valid combination.

4. Determine the desired state for the channel data word if an open circuit condition is enabled and detected for that channel. Enter the 2-digit binary code in bit field 8-9 of the channel configuration word. Not all input types support open circuit detection. Review the “Open Circuit State” description on page 43 to verify applicability.

5. If the channel is configured for thermocouple inputs, RTD or the CJC sensor, determine if you want the channel data word to read in degrees Fahrenheit or degrees Celsius and enter a one or a zero in bit 10 of the configuration word. If the channel is configured for a mV, V, mA, or resistance analog sensor, enter a zero in bit 9.

6. Determine the desired input filter frequency for the channel and enter the 2-digit binary code in bit field 11-12 of the channel configuration word. A lower filter frequency increases the channel update time, but also increases the noise rejection and channel resolution. A higher filter frequency decreases the channel update time, but also decreases the noise rejection and effective resolution.

7. If an RTD or resistance input type was selected, enter the digit binary code corresponding to 2- or 4-wire, or 3-wire, RTD inputs in bit 13. If a thermocouple, mV, V, or mA type is used, enter a 0 in bit 13.

8. If auto-calibration is desired, place a zero in bit 14. If auto-calibration is not desired, place a one in bit 14.

9. Determine whether the channel input image word should contain data or status. Place a one in bit 15 if channel data is desired. Place a zero in bit 15 if status is desired.

10. Build the channel configuration word for every channel on each universal module repeating the procedures given in steps 1-9.

11. Enter this configuration into your ladder program and copy it to the universal module.

Each channel has a word in the module’s output image which determines the way that channel functions. Channels 0 through 3 may be configured for current, voltage or thermocouple input types. No RTD or resistance input types are allowed on those channels. Channels 4 through 7 may be configured for current, voltage, thermocouple, RTD or resistance inputs. The definition of the bits in the configuration words are described in the charts below.

Table 4.1 Channel Configuration Word (O:e.3:0)

Channel 3:0		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Channel	Channel disable																0
Enable	Channel enable																1
	4 to 20 mA											0	0	0	0	0	
	0 to 20 mA											0	0	0	0	1	
	± 0.05 V											0	0	0	1	0	
	± 0.10 V											0	0	0	1	1	
	± 0.50 V											0	0	1	0	0	
	± 2.0 V											0	0	1	0	1	
	0 to 5 V											0	0	1	1	0	
Input	1 to 5V											0	0	1	1	1	
Type	0 to 10V											0	1	0	0	0	
	±10V											0	1	0	0	1	
	Thermocouple Type J											0	1	0	1	0	
	Thermocouple Type K											0	1	0	1	1	
	Theromcouple Type T											0	1	1	0	0	
	Thermocouple Type E											0	1	1	0	1	
	Thermocouple Type R											0	1	1	1	0	
	Thermocouple Type S											0	1	1	1	1	
	Thermocouple Type B											1	0	0	0	0	
	Thermocouple Type N											1	0	0	0	1	
	Invalid											1	0	0	1	x	
	Invalid											1	0	1	x	x	
	Invalid											1	1	0	x	x	
	Invalid											1	1	1	0	x	
	Thermocouple Type C											1	1	1	1	0	
	CJC											1	1	1	1	1	
	Engineering Units x1									0	0						
Data	Engineering Units x10									0	1						
Format	Scaled for PID									1	0						
	Proportional counts									1	1						
	Zero on open circuit							0	0								
Open	Max. on open circuit							0	1								
Circuit	Min. on open circuit							1	0								
	Disabled							1	1								
Temperature	Degrees C						0										
Units	Degrees F						1										
Channel	10 Hz input filter				0	0											
filter	50 Hz input filter				0	1											
freq.	60 Hz input filter				1	0											
	250 Hz input filter				1	1											
Unused				0													
Auto-cal	Enabled		0														
	Disabled		1														
Input Image	Status word	0															
Type	Data word	1															

Table 4.2 Channel Configuration Word (O:e.7:4)

Channel 7:4		**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Channel Enable	Channel disable																0
	Channel enable																1
Input Type	4 to 20 mA											0	0	0	0	0	
	0 to 20 mA											0	0	0	0	1	
	± 0.05 V											0	0	0	1	0	
	± 0.10 V											0	0	0	1	1	
	± 0.50 V											0	0	1	0	0	
	± 2.0 V											0	0	1	0	1	
	0 to 5 V											0	0	1	1	0	
	1 to 5 V											0	0	1	1	1	
	0 to 10 V											0	1	0	0	0	
	±10V											0	1	0	0	1	
	Thermocouple Type J											0	1	0	1	0	
	Thermocouple Type K											0	1	0	1	1	
	Thermocouple Type T											0	1	1	0	0	
	Thermocouple Type E											0	1	1	0	1	
	Thermocouple Type R											0	1	1	1	0	
	Thermocouple Type S											0	1	1	1	1	
	Thermocouple Type B											1	0	0	0	0	
	Thermocouple Type N											1	0	0	0	1	
	RTD 100 Ω 385											1	0	0	1	0	
	RTD 200 Ω Pt 385											1	0	0	1	1	
	RTD 500 Ω Pt 385											1	0	1	0	0	
	RTD 1000 Ω Pt 385											1	0	1	0	1	
	RTD 100 Ω Pt 3916											1	0	1	1	0	
	RTD 200 Ω Pt 3916											1	0	1	1	1	
	RTD 500 Ω Pt 3916											1	1	0	0	0	
	RTD 1000 Ω Pt 3916											1	1	0	0	1	
	RTD 10 Ω Cu 426											1	1	0	1	0	
	RTD 120 Ω Ni 618											1	1	0	1	1	
	RTD 120 Ω Ni 672											1	1	1	0	0	
	Resistance 3000 Ω											1	1	1	0	1	
	Thermocouple Type C											1	1	1	1	0	
	CJC											1	1	1	1	1	
Data Format	Engineering Units x1									0	0						
	Engineering Units x10									0	1						
	Scaled for PID									1	0						
	Proportional counts									1	1						
Open Circuit	Zero on open circuit							0	0								
	Max. on open circuit							0	1								
	Min. on open circuit							1	0								
	Disabled							1	1								
Temperature Units	Degrees C						0										
	Degrees F						1										
Channel filter freq.	10 Hz input filter				0	0											
	50 Hz input filter				0	1											
	60 Hz input filter				1	0											
	250 Hz input filter				1	1											
RTD Type	2 or 4 wire			0													
	3 wire			1													
Auto-cal	Enabled		0														
	Disabled		1														
Input Image Type	Status word	0															
	Data word	1															

The configuration word default setting is all zeros. Whan a voltage or current input type is selected, the bit setting for temperature units is ignored.

Select Channel Enable (Bit 0)

Use the channel enable bit to enable a channel. The universal module only scans those channels that are enabled. To optimize module operation and minimize throughput times, unused channels should be disabled by setting the channel enable bit to zero.

When set (1) the channel enable bit is used by the module to read the configuration word information you have selected. While the enable bit is set, modification of the configuration word may lengthen the module update time for one cycle. If any change is made to the configuration word, the change will be reflected in the status word before new data is valid (described in the last section of this chapter).

While the channel enable bit is cleared (0), the associated channel data/status word values are cleared. After the channel enable bit is set, the associated channel data/status word remains cleared until the universal module sets the channel status bit (bit 0) in the channel status word.

Select Input Types (Bits 1-5)

The input type bit field lets you configure the channel for the type of input device you have connected to the module. Valid input devices are types J, K, T, E, R, S, B, N, and C thermocouple sensors, 100Ω, 200Ω, 500Ω, and 1000Ω Pt 385 RTDs; 100Ω, 200Ω, 500Ω, and 1000Ω Pt 3916 RTDs; 10Ω Cu 426 RTD, 120Ω Ni 618 RTD, and 120Ω Ni 672 RTD sensors; 3000Ω resistance devices and ±50mV, ± 100mV, ±500mV, ±2V, 0-5V, 1-5V, 0-10V, ±10V, 0-20mA, and 4-20mA analog input signals. The channel can also be configured to read the cold-junction temperature calculated for that specific channel. When the cold-junction compensation (CJC) temperature is selected, the channel ignores the physical input signal. RTD and resistance inputs can only be supported by channels 4-7.

Select Data Format (Bits 6 and 7)

The data format bit field lets you define the expressed format for the channel data word contained in the module input image. The data types are engineering units, scaled-for-PID, and proportional counts.

The **engineering units** allow you to select from two resolutions, x1 or x10. For engineering units x1, values are expressed in 0.1 degrees, 0.01mV or 0.001mA. For engineering units x10, values are expressed in 1.0 degrees, 1mV or 0.01mA. (Use the x10 setting to produce temperature readings in whole degrees Celsius or Fahrenheit.) You will notice in Table 11 that not all input types can support the x1 format.

The **scaled-for-PID** value is the same for millivolt, milliamp, thermocouple, RTD, resistance,) and CJC input types. The input signal range is proportional to your selected input type and scaled into a 0-16,383 range, which is standard to the SLC PID algorithm.

The **proportional counts** are scaled to fit the defined temperature, voltage, or current range. The input signal range is proportional to your selected input and scaled into a (-32,768 to 32,767) range.

Using Scaled-for-PID and Proportional Counts

The universal module provides eight options for displaying input channel data. These are 0.1°F, 0.1°C, 1°F, 1°C, 0.01 mV, 0.1 mV, Scaled-for-PID, and Proportional Counts. The first six options represent real Engineering Units provided/displayed by the 1746sc-NI8u, and do not require explanation. The Scaled-for-PID and Proportional Counts selections provide the highest NI8u display resolution, but also require you to manually convert the channel data to real Engineering Units.

The equations below show how to convert from Scaled-for-PID to Engineering Units, Engineering Units to Scaled-for-PID, Proportional Counts to Engineering Units, and Engineering Units to Proportional Counts. To perform the conversions, you must know the defined temperature or millivolt range for the channel's input type. Refer to the Channel Data Word Format table on the following page. The lowest possible value for an input type is S_{LOW}, and the highest possible value is S_{HIGH}.

It is important to note that the Scaled for PID and proportional counts format do not linearize inputs that are not linear. The module assumes that current and voltage inputs are linear prior to insertion into the universal module's input stage. Thermocouple inputs are cold junction compensated, and are linearized in their temperature conversion process through the NIST ITS-90 tables. RTDs are converted from their resistance value to degrees according to their associated IEC or JISC standards.

Scaling Examples

Scaled-for-PID to Engineering Units

<u>**Equation:**</u> Engr Units Equivalent = S_{LOW} + [(S_{HIGH}-S_{LOW}) x (Scaled-for-PID value displayed/16384)]

Assume type J input type, scaled-for-PID display type, channel data = 3421.
Want to calculate °C equivalent.
From Channel Data Word Format table, S_{LOW} = -210°C and S_{HIGH} = 760°C.

<u>**Solution:**</u> Engr Units Equivalent = -210°C + [(760°C-(-210°C)) x (3421/16384)] = -7.46°C.

Engineering Units to Scaled-for-PID

<u>**Equation:**</u> Scaled-for-PID Equivalent = 16384 x [(Engineering Units desired -S_{LOW})/(S_{HIGH}-S_{LOW})]

Assume type J input type, scaled-for-PID display type, desired channel temp. = 344°C.
Want to calculate Scaled-for-PID equivalent.
From Channel Data Word Format table, S_{LOW} = -210°C and S_{HIGH} = 760°C.

<u>**Solution:**</u> Scaled-for-PID Equivalent = 16384 x [(344°C - (-210°C))/(760°C - (-210°C))] = 9357

Proportional Counts to Engineering Units

Equation: Engr Units Equivalent = S_{LOW} + {(S_{HIGH}-S_{LOW}) x [(Proportional Counts value displayed + 32768)/65536]}

Assume type E input type, proportional counts display type, channel data = 21567.
Want to calculate °F equivalent.
From Channel Data Word Format table, S_{LOW} = -454°F an d S_{HIGH} =1832°F

Solution: Engr Units Equivalent = -454°F + {[1832°F -(-454°F)] x [(21567 + 32768)/65536]} = 1441.3°F

Engineering Units to Proportional Counts

Equation: Proportional Counts Equivalent = {65536 x[(Engineering Units desired - S_{LOW})/(S_{HIGH}-S_{LOW})]} -32768

Assume type E input type, proportional counts display type, desired channel temp. = 1000°F.
Want to calculate Proportional Counts equivalent.
From Channel Data Word Format table, S_{LOW} = -454°F and S_{HIGH} = 1832°F.

Solution: Proportional Counts Equivalent = {65536 x[{1000°F - (-454°F))/(1832°F - (-454°F))]} - 32768 = 8916.

Table 4.3 1746sc-NI8u Universal Module - Channel Data Word Format

Data Format

Input Type	Engineering Units x 10 ° Celsius	Engineering Units x 10 ° Fahrenheit	Engineering Units x 1 ° Celsius	Engineering Units x 1 ° Fahrenheit	Scaled-for-PID	Proportional Counts
4-20 mA *	+400 to +2,000		+4,000 to +20,000		0 to 16,383	-32,768 to 32,767
0-20 mA *	0 to +2,000		+0 to +20,000		0 to 16,383	-32,768 to 32,767
± 0.05 V *	-500 to +500		-5,000 to +5,000		0 to 16,383	-32,768 to 32,767
± 0.10 V *	-1,000 to +1,000		-10,000 to +10,000		0 to 16,383	-32,768 to 32,767
± 0.50 V *	-5,000 to +5,000		N/A		0 to 16383	-32,768 to 32,767
± 2.0 V *	-2,000 to +2,000		-20,000 to +20,000		0 to 16,383	-32,768 to 32,767
0-5 V *	0 to +5,000		N/A		0 to 16,383	-32,768 to 32,767
1-5 V *	+1,000 to +5,000		N/A		0 to 16,383	-32,768 to 32,767
0-10 V *	0 to +10,000		N/A		0 to 16,383	-32,768 to 32,767
±10 V *	-10,000 to +10,000		N/A		0 to 16,383	-32,768 to 32,767
J	-210 to 760	-346 to 1,400	-2,100 to 7,600	-3,460 to 14,000	0 to 16,383	-32,768 to 32,767
K	-270 to 1,370	-454 to 2,498	-2,700 to 13,700	-4,540 to 24,980	0 to 16,383	-32,768 to 32,767
T	-270 to 400	-454 to 752	-2,700 to 4,000	-4,540 to 7,520	0 to 16,383	-32,768 to 32,767
E	-270 to 1,000	-454 to 1,832	-2,700 to 10,000	-4,540 to 18,320	0 to 16,383	-32,768 to 32,767
R	0 to 1,768	32 to 3,214	0 to 17,680	320 to 32,140	0 to 16,383	-32,768 to 32,767
S	0 to 1,768	32 to 3,214	0 to 17,680	320 to 32,140	0 to 16,383	-32,768 to 32,767
B	300 to 1,820	572 to 3,308	3,000 to 18,200	5,720 to 32,767**	0 to 16,383	-32,768 to 32,767
N	0 to 1,300	32 to 2,372	0 to 13,000	320 to 23,720	0 to 16,383	-32,768 to 32,767
C	0 to 2315	32 to 4199	0 to 23,150	32 to 32767**	0 to 16,383	-32, 768 to 32-767
10Ω Cu 426	-100 to 260	-148 to 500	-1,000 to 2,600	-1,480 to 5,000	0 to 16,383	-32, 768 to 32-767
120 Ω Ni 618	-100 to 260	-148 to 500	-1,000 to 2,600	-1,480 to 5,000	0 to 16,383	-32, 768 to 32-767
120 Ω Ni 672	-80 to 260	-112 to 500	-800 to 2,600	-1,120 to 5,000	0 to 16,383	-32, 768 to 32-767
3000Ω*	0 to 3,000		0 to 30,000		0 to 16,383	-32, 768 to 32-767
100Ω Pt 385	-200 to 850	-328 to 1,562	-2,000 to 8,500	-3,280 to 15,620	0 to 16,383	-32,768 to 32,767
200Ω Pt 385	-200 to 750	-328 to 1,382	-2,000 to 7,500	-3,280 to 13,820	0 to 16,383	-32,768 to 32,767
500Ω Pt 385	-200 to 850	-328 to 1,562	-2,000 to 8,500	-3,280 to 15,620	0 to 16,383	-32,768 to 32,767
1,000Ω Pt 385	-200 to 850	-328 to 1,562	-2,000 to 8,500	-3,280 to 15,620	0 to 16,383	-32,768 to 32,767
100Ω Pt 3916	-200 to 630	-328 to 1,166	-2,000 to 6,300	-3,280 to 11,660	0 to 16,383	-32,768 to 32,767
200Ω Pt 3916	-200 to 630	-328 to 1,166	-2,000 to 6,300	-3,280 to 11,660	0 to 16,383	-32,768 to 32,767
500Ω Pt 3916	-200 to 630	-328 to 1,166	-2,000 to 6,300	-3,280 to 11,660	0 to 16,383	-32,768 to 32,767
1,000Ω Pt 3916	-200 to 630	-328 to 1,166	-2,000 to 6,300	-3,280 to 1,1660	0 to 16,383	-32,768 to 32,767
CJC	-25 to 105	-13 to 221	-250 to 1,050	-130 to 2,210	0 to 16,383	-32,768 to 32,767

* When current, voltage, or resistance input types are selected, the temperature setting is ignored and does not affect the data format.

** When Type B or Type C thermocouples cannot be represented in engineering units x 1 in °F above 3276.6°F, the module's software will treat it as an over range condition if that channel has input to full scale.

Table 4.4 1746sc-NI8u Thermocouple Module - Channel Data Word Resolution

Data Format

Input Type	Engineering Units x 10		Engineering Units x 1		Scaled-for-PID		Proportional Counts	
	° Celsius	° Fahrenheit	° Celsius	° Fahrenheit	° Celsius	° Fahrenheit	° Celsius	° Fahrenheit
0-20mA ❶	0.01mA/step	0.01mA/step	0.001mA/step	0.001mA/step	1.221µA/step	1.221µA/step	0.3052µA/step	0.3052µA/step
4-20mA ❶	0.01mA/step	0.01mA/step	0.001mA/step	0.001mA/step	0.9766µA/step	0.9766µA/step	0.2441µA/step	0.2441µA/step
±0.05V ❶	0.1mV/step	0.1mV/step	0.01mV/step	0.01mV/step	6.104µV/step	6.104µV/step	1.526µV/step	1.526µV/step
±0.100V ❶	0.1mV/step	0.1mV/step	0.01mV/step	0.01mV/step	12.21µV/step	12.21µV/step	3.052µV/step	3.052µV/step
±0.5V ❶	0.1mV/step	0.1mV/step	N/A	N/A	61.04µV/step	61.04µV/step	15.26µV/step	15.26µV/step
±2.0V ❶	0.001V/step	0.001V/step	0.01mV/step	0.01mV/step	244.1µV/step	244.1µV/step	61.04µV/step	61.04µV/step
0-5V ❶	0.001V/step	0.001V/step	N/A	N/A	305.2µV/step	305.2µV/step	76.29µV/step	76.29µV/step
1-5V ❶	0.001V/step	0.001V/step	N/A	N/A	244.1µV/step	244.1µV/step	61.04µV/step	61.04µV/step
0-10V ❶	0.001V/step	0.001V/step	N/A	N/A	610.4µV/step	610.4µV/step	152.6µV/step	152.6µV/step
±10V ❶	0.001V/step	0.001V/step	N/A	N/A	1.221mV/step	1.221mV/step	305.2µV/step	305.2µV/step
100Ω Pt 385	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.06409°C/step	0.01154°F/step	0.01602°C/step	0.02884°F/step
200Ω Pt 385	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.06409°C/step	0.01154°F/step	0.01602°C/step	0.02884°F/step
500Ω Pt 385	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.06409°C/step	0.01154°F/step	0.01602°C/step	0.02884°F/step
1,000Ω Pt 385	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.06409°C/step	0.01154°F/step	0.01602°C/step	0.02884°F/step
100Ω Pt 3916	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.05066°C/step	0.09119°F/step	0.01266°C/step	0.02280°F/step
200Ω Pt 3916	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.05066°C/step	0.09119°F/step	0.01266°C/step	0.02280°F/step
500Ω Pt 3916	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.05066°C/step	0.09119°F/step	0.01266°C/step	0.02280°F/step
1,000Ω Pt 3916	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.05066°C/step	0.09119°F/step	0.01266°C/step	0.02280°F/step
10Ω Cu 426	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0220°C/step	0.0396°F/step	0.0055°C/step	0.00990°F/step
120Ω Ni 618	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0220°C/step	0.0396°F/step	0.0055°C/step	0.00990°F/step
120Ω Ni 672	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0208°C/step	0.0374°F/step	0.0052°C/step	0.00993°F/step
3,000Ω	1Ω/step	1Ω/step	0.1Ω/step	0.1Ω/step	0.183Ω/step	0.183Ω/step	0.0458Ω/step	0.0458Ω/step
J	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0592°C/step	0.1066°F/step	0.0148°C/step	0.0266°F/step
K	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.1001°C/step	0.1802°F/step	0.0250°C/step	0.0450°F/step
T	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0409°C/step	0.0736°F/step	0.0102°C/step	0.0184°F/step
E	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0775°C/step	0.1395°F/step	0.0194°C/step	0.0349°F/step
R	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.1079°C/step	0.1942°F/step	0.0270°C/step	0.0486°F/step
S	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.1079°C/step	0.1942°F/step	0.0270°C/step	0.0486°F/step
B	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0928°C/step	0.1670°F/step	0.0232°C/step	0.0417°F/step
N	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0793°C/step	0.1428°F/step	0.0198°C/step	0.0357°F/step
C	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.1413°C/step	0.2543°F/step	0.0353°C/step	0.0636°F/step
CJC Sensor	1°C/step	1°F/step	0.1°C/step	0.1°F/step	0.0079°C/step	0.0143°F/step	0.0020°C/step	0.0036°F/step

❶ When millivolts or resistance are selected, the temperature setting is ignored. Analog input data is the same for either °C or °F selection.

Important: Data resolution is not equivalent to data accuracy. Data resolution merely indicates what a bit-weight is in any given input type and data format combination. Input accuracy of ±50µV may span multiple steps for PID and Proportional Counts data types. As an example a Type B thermocouple temperature range of 0 to 1820°C provides a voltage input range of 0 to 13.82mV to the NI8u. This is a very small input range and when it is scaled to PID or proportional counts ranges a small input change will result in many counts being changed.

Select Open Circuit State (Bits 8 and 9)

The open-circuit bit field lets you define the state of the channel data word when an open-circuit condition is detected for that channel. The open circuit does not apply to the 0-5V, 1-5V, 0-10V, ±2V, ±10V, or 0-20mA input types and should be disabled when those types are selected, or else a configuration error will result. It can be enabled for all other types, including the CJC input. This feature can be disabled by selecting the disable option.

An open circuit condition occurs when the input path is physically separated or open. For thermocouples or RTDs, either the sensor or the extension wire may be broken. The voltage or current input wire may be cut or disconnected from the terminal block. For RTDs only, a short circuit of less than 3 ohms will also flag this error.

If either of the two CJC devices are removed from the module wiring terminal, any input channel configured for either a thermocouple or CJC temperature input will be placed in an open circuit condition. An input channel configured for millivolt, volt, milliamp, or RTD input is not affected by CJC open-circuit conditions.

The results of the data word in an open-circuit condition depend upon the selection of bits 8 and 9.

If **zero** is selected, the channel data word is forced to 0 during an open-circuit condition.

Selecting **maximum** forces the channel data word value to its full scale value during an open-circuit condition. The full scale value is determined by the selected input type and data format.

Selecting **minimum** forces the channel data word value to its low scale value during an open-circuit condition. The low scale value is determined by the selected input type and data format.

When the open-circuit option applies, disabling the open-circuit selection may result in unintended operation on a failure because the returned data word value is unknown. The open circuit error bit and the channel LED will flag the condition until the error is resolved.

For example, if channel one is configured as a thermocouple type when the CJC breaks in an open-circuit condition, if open-circuit detection is disabled, the data word will remain unchanged. If the circuit selection is set at minimum, the data word will be set to the low scale value for the range and format.

Select Temperature Units (Bit 10)

The temperature units bit lets you select temperature engineering units for thermocouple, RTD, and CJC input types. Units are either degrees Celsius (°C) or degrees Fahrenheit (°F). This bit field is only active for thermocouple, RTD and CJC input types. It is ignored when millivolt or current inputs types are selected.

Select Channel Filter Frequency (Bits 11 and 12)

The channel filter frequency bit field lets you select one of four filters available for a channel. The filter frequency affects the channel update time and noise rejection characteristics. A smaller filter frequency increases the channel update time, but also increases the noise rejection and channel resolution. A larger filter frequency decreases the noise rejection, but also decreases the channel update time and channel resolution.

- 250 Hz setting provides minimal noise filtering.
- 60 Hz setting provides 60 Hz AC line noise filtering.
- 50 Hz setting provides 50 Hz AC line noise filtering.
- 10 Hz setting provides both 50 Hz and 60 Hz AC line noise filtering.

When a CJC input type is selected, this field is ignored. To maximize the speed versus resolution trade-off, CJC inputs are sampled at 60 Hz.

Select RTD Type (Bit 13)

The selection for RTD or resistance type is only valid for channels 4 through 7, and should be set to zero for channels 0 through 3.

If the Input Type selection defines an RTD or resistance type, then the wire type also needs to be specified. The universal module converts the RTD or resistance type input data differently according to whether the 2 or 4 wire method is used, or the 3 wire method is used.

Select Auto-Calibration Disable (Bit 14)

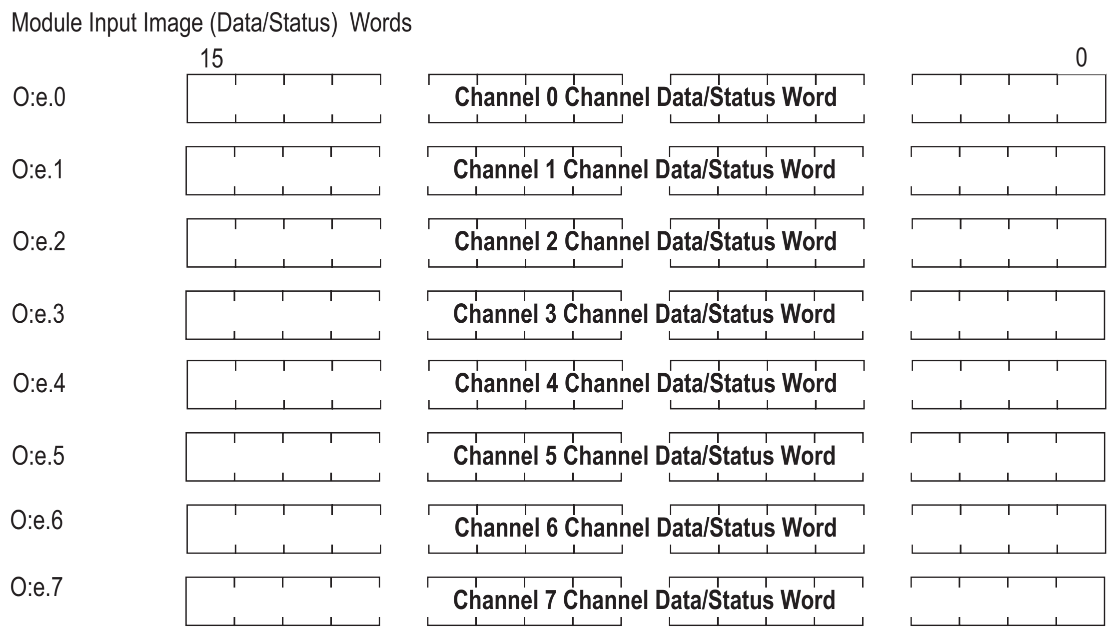
The auto-calibration disable bit allows you to disable periodic auto-calibration. Set this bit on any enabled channel to disable auto-calibration for all channels. Clear this bit on all enabled channels to enable auto-calibration on all channels.

Select Input Image Type (Bit 15)

The input image type bit allows you to select data or status information in the channel's input image word. When set (1) the module places channel data in the corresponding input image word. When the bit is cleared (0) the module places channel status in the corresponding input image word.

Channel Data/Status Word

The actual thermocouple, RTD, resistance, millivolt, volt, or milliamp input data values or channel status reside in I:e.0 through I:e.7 of the universal module input image file. The data values present will depend on the input type and data formats you have selected. When an input channel is disabled, its data word is reset (0).



Channel Status Checking

The input image of the module is 8 words. Since there are 8 channels with a data word and a status word for each channel, the input image information is multiplexed. The information in the input image is the channel data word if bit 15 of the channel's configuration word is 1. The information in the input image is the channel status word if bit 15 of the channel's configuration word is 0.

You can use the information provided in the status word to determine if the input configuration data for any channel is valid per your configuration in O:e.0 through O:e.7.

The channel status can be analyzed bit by bit. In addition to providing information about an enabled or disabled channel, each bit's status (0 or 1) tells you how the input data from the analog sensor connected to a specific channel will be translated for your application. The bit status also informs you of any error condition and can tell you what type of error occurred.

The status word definitions for channels 0 through 3 do not include the RTD or resistance support that is provided by channels 4 through 7. The charts on the following pages provide a bit by bit examination of the respective status words.

Table 4.5 Channel 0-7 Status Word (I:e.0 through I:e.7) - Bit Definitions

Channel 3:0		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Channel Status	Channel disabled																0
	Channel enable																1
Input Type	4 to 20 mA											0	0	0	0	0	
	0 to 20 mA											0	0	0	0	1	
	± 0.05 V											0	0	0	1	0	
	± 0.10 V											0	0	0	1	1	
	± 0.50 V											0	0	1	0	0	
	± 2.0 V											0	0	1	0	1	
	0 to 5 V											0	0	1	1	0	
	1 to 5V											0	0	1	1	1	
	0 to 10V											0	1	0	0	0	
	±10V											0	1	0	0	1	
	Thermocouple Type J											0	1	0	1	0	
	Thermocouple Type K											0	1	0	1	1	
	Theromcouple Type T											0	1	1	0	0	
	Thermocouple Type E											0	1	1	0	1	
	Thermocouple Type R											0	1	1	1	0	
	Thermocouple Type S											0	1	1	1	1	
	Thermocouple Type B											1	0	0	0	0	
	Thermocouple Type N											1	0	0	0	1	
	Invalid											1	0	0	1	x	
	Invalid											1	0	1	x	x	
	Invalid											1	1	0	x	x	
	Invalid											1	1	1	0	x	
	Thermocouple Type C											1	1	1	1	0	
	CJC temperature											1	1	1	1	1	
Data Format	Engineering Units x1									0	0						
	Engineering Units x10									0	1						
	Scaled for PID									1	0						
	Proportional counts									1	1						
Open Circuit	Zero on open circuit							0	0								
	Max. on open circuit							0	1								
	Min. on open circuit							1	0								
	Disabled							1	1								
Channel filter freq.	10 Hz input filter					0	0										
	50 Hz input filter					0	1										
	60 Hz input filter					1	0										
	250 Hz input filter					1	1										
Open circuit	No error				0												
	Open circuit detected				1												
Under range error	No error			0													
	Under range condition			1													
Over range error	No error		0														
	Over range condition		1														
Channel error	No error	0															
	Channel error	1															

Channel 7:4		**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Channel Status	Channel disabled																0
	Channel enable																1
Input Type	4 to 20 mA											0	0	0	0	0	
	0 to 20 mA											0	0	0	0	1	
	± 0.05 V											0	0	0	1	0	
	± 0.10 V											0	0	0	1	1	
	± 0.50 V											0	0	1	0	0	
	± 2.0 V											0	0	1	0	1	
	0 to 5 V											0	0	1	1	0	
	1 to 5 V											0	0	1	1	1	
	0 to 10 V											0	1	0	0	0	
	±10V											0	1	0	0	1	
	Thermocouple Type J											0	1	0	1	0	
	Thermocouple Type K											0	1	0	1	1	
	Thermocouple Type T											0	1	1	0	0	
	Thermocouple Type E											0	1	1	0	1	
	Thermocouple Type R											0	1	1	1	0	
	Thermocouple Type S											0	1	1	1	1	
	Thermocouple Type B											1	0	0	0	0	
	Thermocouple Type N											1	0	0	0	1	
	RTD 100 Ω 385											1	0	0	1	0	
	RTD 200 Ω Pt 385											1	0	0	1	1	
	RTD 500 Ω Pt 385											1	0	1	0	0	
	RTD 1000 Ω Pt 385											1	0	1	0	1	
	RTD 100 Ω Pt 3916											1	0	1	1	0	
	RTD 200 Ω Pt 3916											1	0	1	1	1	
	RTD 500 Ω Pt 3916											1	1	0	0	0	
	RTD 1000 Ω Pt 3916											1	1	0	0	1	
	RTD 10 Ω Cu 426											1	1	0	1	0	
	RTD 120 Ω Ni 618											1	1	0	1	1	
	RTD 120 Ω Ni 672											1	1	1	0	0	
	Resistance 3000 Ω											1	1	1	0	1	
	Thermocouple Type C											1	1	1	1	0	
	CJC temperature											1	1	1	1	1	
Data Format	Engineering Units x1									0	0						
	Engineering Units x10									0	1						
	Scaled for PID									1	0						
	Proportional counts									1	1						
Open Circuit	Zero on open circuit							0	0								
	Max. on open circuit							0	1								
	Min. on open circuit							1	0								
	Disabled							1	1								
Channel filter freq.	10 Hz input filter					0	0										
	50 Hz input filter					0	1										
	60 Hz input filter					1	0										
	250 Hz input filter					1	1										
Open circuit	No error				0												
	Open circuit detected				1												
Under range error	No error			0													
	Under range condition			1													
Over range error	No error		0														
	Over range condition		1														
Channel error	No error	0															
	Channel error	1															

Important: If the channel for which you are seeking status is disabled, all bit fields are cleared. The status word for any disabled channel is always 0000 0000 0000 0000 regardless of any previous setting that may have been made to the configuration word.

Explanations of the status conditions follow.

Channel Status (Bit 0)

The channel status bit indicates operational state of the channel. When the channel enable bit is set in the configuration word (bit 0), the universal module configures the selected channel and takes a data sample for the channel data word before setting this bit in the status word.

Input Type Status (Bits 1-5)

The input type bit field indicates what type of input signal you have configured for the channel. This field reflects the input type defined in the channel configuration word.

Data Format Type Status (Bits 6 and 7)

The data format bit field indicates the data format you have defined for the channel. This field reflects the data type selected in bits 6 and 7 of the channel configuration word.

Open Circuit Type Status (Bits 8 and 9)

The open-circuit bit field indicates how you have defined the open circuit bits configuration word, and therefore, the response of the universal module to an open-circuit condition. This feature does not apply to the 0-5 V, 1-5 V, 0-10 V, ±2 V, ±10 V, or 0-20mA input ranges, and a properly configured channel of those types will give the disabled status. It applies to all others, including CJC temperature input.

Channel Filter Frequency (Bits 10 and 11)

The channel filter frequency bit field reflects the filter frequency you selected in the configuration word.

Open Circuit Error (Bit 12)

This bit is set (1) whenever a configured channel detects an open-circuit condition at its input. Short circuited RTD inputs will also flag this error condition. A short circuit for RTDs exist when the module reads less than 3 ohms across the RTD input. An open-circuit at the CJC sensor will also flag this error if the channel input type is either thermocouple or CJC temperature. A range error on the CJC sensor will also flag this bit if the input type is a thermocouple type.

Under-Range Error (Bit 13)

This bit is set (1) whenever a configured channel detects an under-range condition for the channel data. An under-range condition exists when the input value is equal to or below the specified lower limit of the particular sensor connected to that channel.

Over-Range Error (Bit 14)

This bit is set (1) whenever a configured channel detects an over-range condition for the channel data. An over-range condition exists when the input value is equal to or above the specified upper limit of the particular sensor connected to that channel.

Channel Error (Bit 15)

This bit is set (1) whenever a configured channel detects an error in the configuration word, or an error has occurred while acquiring the ADC data value. If during the auto-calibration process, the module detects an out-of-range condition for the filter frequency selected for the channel, the channel error bit will be set. An out-of-range condition occurring during auto-calibration would be the result of an overly noisy environment, whereby the module cannot maintain accuracy specifications, thus flagging an error. The error bit is cleared when the error condition is resolved. The channel data word is still updated during a period of auto-calibration filter frequency tolerance errors, but accuracy may be degraded.

Programming Examples

Earlier chapters explained how the configuration word defines the way a channel operates. This chapter shows the programming required to enter the configuration word into the processor memory. It also provides you with segments of ladder logic specific to unique situations that might apply to your programming requirements. The example segments include:

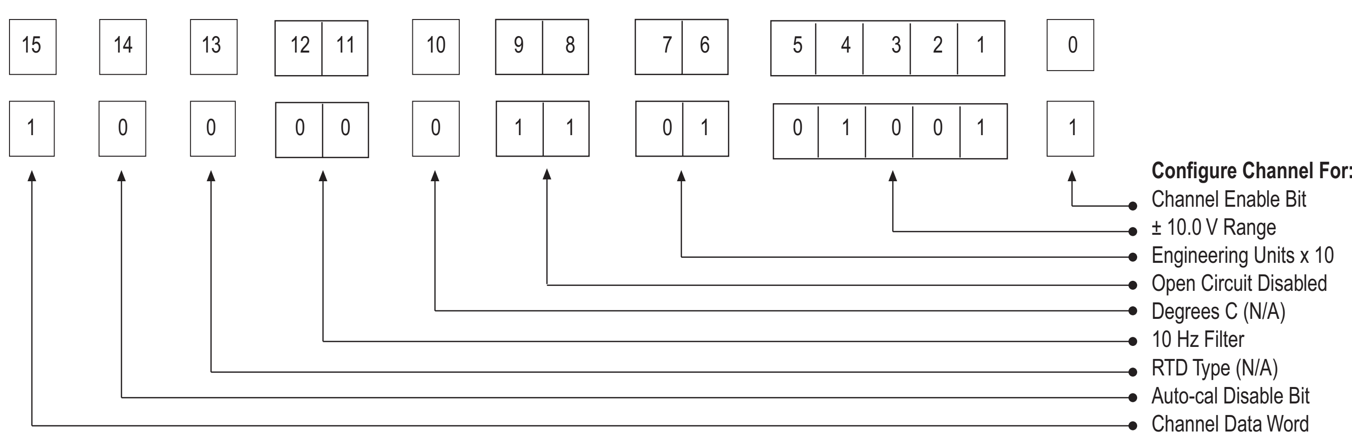
- initial programming of the configuration word
- dynamic programming of the configuration word
- verifying channel configuration changes
- interfacing the universal module to a PID instruction
- monitoring channel status bit

Initial Programming

To enter data into the channel configuration word (O:e.0 through O:e.7) when the channel is disabled (bit 0 = 0), follow these steps. Refer to page 30 (Table 9) for specific configuration details.

Example - Configure eight channels of a universal module residing in slot 3 of a 1746 chassis. Configure each channel with the same parameters.

Figure 5.1 Channel configuration



This example transfers configuration data and sets the channel enable bits of all eight channels with a single File Copy instruction.

Procedure

1. Using the memory map function, create integer file N10. Integer file N10 should contain eight elements (N10:0 through N10:7).

2. Using the APS software data monitor function, enter the configuration parameters for all eight universal channels into a source integer data file N10.

Figure 5.2 Data table for initial programming

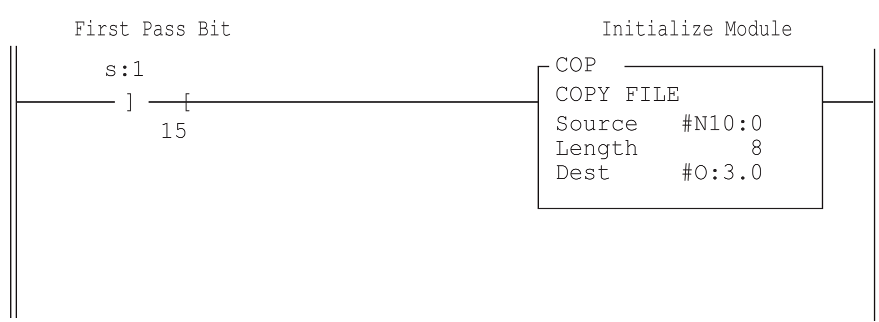
address	15		data	0	address	15	data	0
N10:0	0000	0010	0010	0011				
N10:3	0000	0010	0010	0011				
N10:4	0000	0010	0010	0011				
N10:5	0000	0010	0010	0011				
N10:6	0000	0010	0010	0011				
N10:7	0000	0010	0010	0011				

Press a key or enter value
N10:3/0 = 1
offline no forces binary data decimal addr File EXMPL

CHANGE RADIX	SPECIFY ADDRESS	NEXT FILE	PREV FILE
F1	F5	F7	F8

3. Program a rung in your ladder logic to copy the contents of integer file N10 to the eight consecutive output words of the universal module beginning with O:3.0.

Figure 5.3 Initial programming example



On power up, bit S:1/15 is set for the first program scan, and integer file N10 is sent to the NI8u channel configuration words.

Dynamic Programming

The following example explains how to change data in the channel configuration word when the channel is currently enabled.

Example - Execute a dynamic configuration change to channel 2 of the universal module located in slot 3 of a 1746 chassis. Change from monitoring a bipolar 10 V signal to monitoring the CJC sensors mounted on the terminal block. This gives a good indication of what the temperature is inside the control cabinet. Finally, set channel 2 back to the bipolar 10 V range.

Figure 5.4 Dynamic programming example

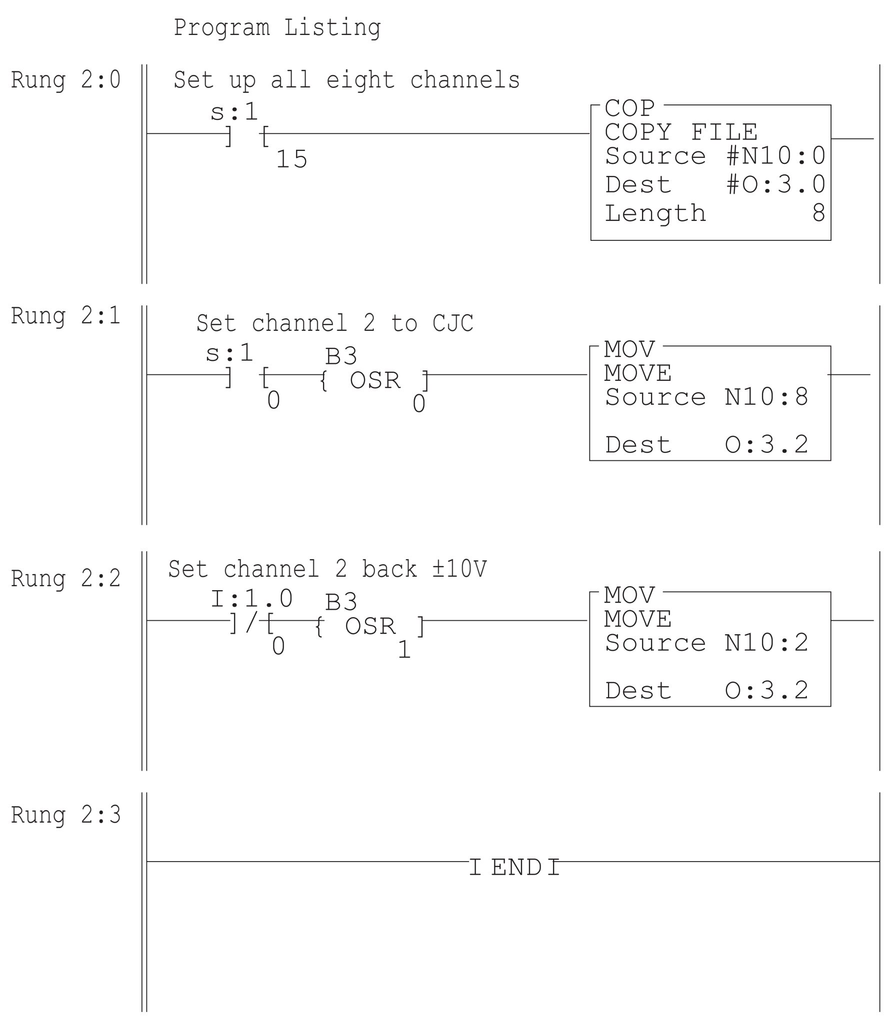


Figure 5.5 Data table for dynamic programming

address	15 data 0	address	15 data 0
N10:0	1000 0011 0101 0011	N10:8	1000 0000 0111 1111
N10:1	1000 0011 0101 0011		
N10:2	1000 0011 0101 0011		
N10:3	1000 0011 0101 0011		
N10:4	1000 0011 0101 0011		
N10:5	1000 0011 0101 0011		
N10:6	1000 0011 0101 0011		
N10:7	1000 0011 0101 0011		

Important: While the module performs the configuration alteration, it does not monitor input device data change at any channel.

Verifying Channel Configuration Changes

When executing a dynamic channel configuration change, there will always be a delay from the time the ladder program makes the change to the time the NI8u gives you a data word using that new configuration information. Therefore, it is very important to verify that a dynamic channel configuration change took effect in the module, particularly if the channel being dynamically configured is used for control. The following example explains how to verify that channel configuration changes have taken effect.

Example - Execute a dynamic configuration change to channel 2 of the universal module located in slot 3 of a 1746 chassis, and set an internal "data valid" bit when the new configuration has taken effect. In this example the input image of the channel is selected to contain the channel status word.

Figure 5.6 Programming for configuration changes example

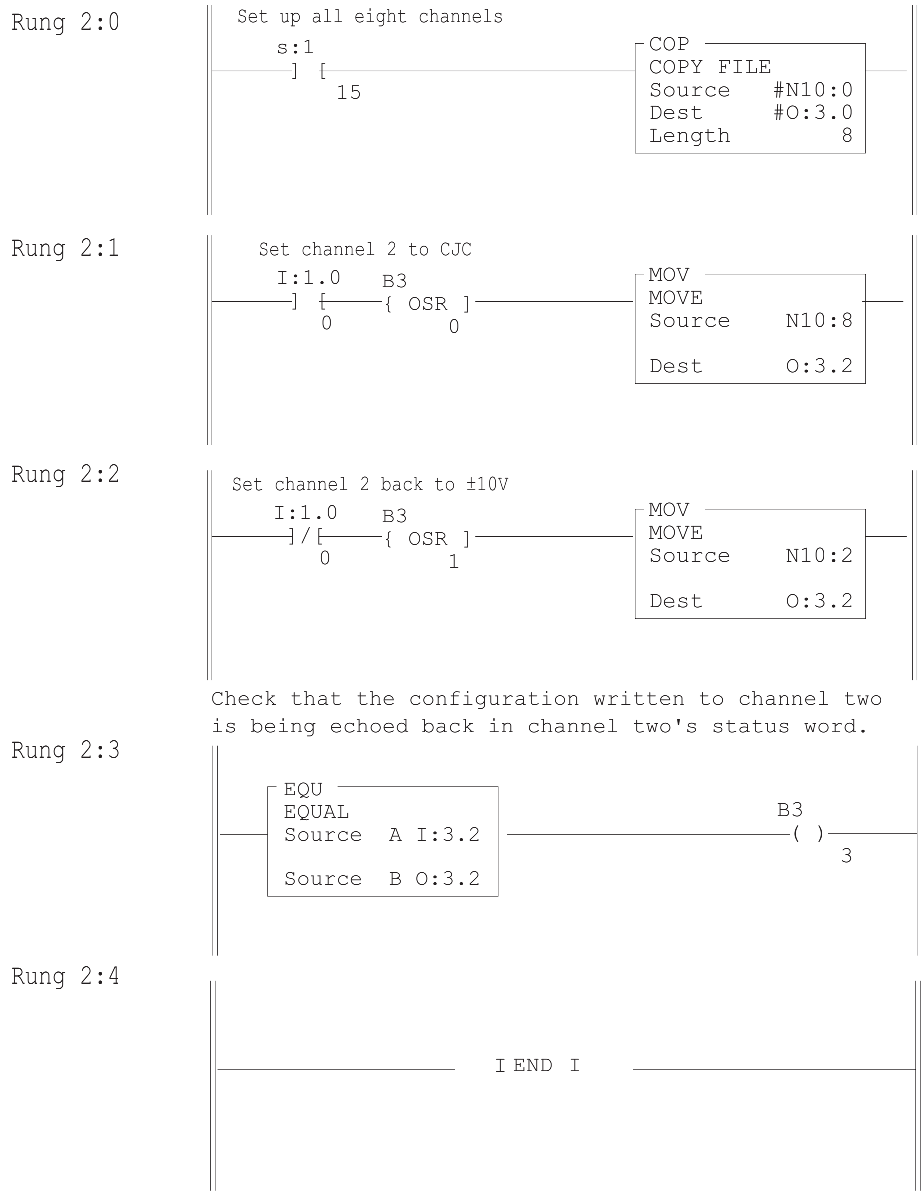


Figure 5.7 Data table for configuration changes

Data Table

address	15 data 0	address	15 data 0
N10:0	1000 0011 0101 0011	N10:8	0000 0000 0111 1111
N10:1	1000 0011 0101 0011		
N10:2	1000 0011 0101 0011		
N10:3	1000 0011 0101 0011		
N10:4	1000 0011 0101 0011		
N10:5	1000 0011 0101 0011		
N10:6	1000 0011 0101 0011		
N10:7	1000 0011 0101 0011		

Interfacing to the PID Instruction

The universal module was designed to interface directly to the SLC 5/02™ or later processor PID instruction without the need for an immediate scale operation.

Example - Use NI8u channel data as the process variable in the PID instruction.

1. Select *scaled-for-PID* as the data type in the channel configuration word.
2. Specify the input channel data word as the process variable for the PID instruction.

In this example, the value -32,617 is the numeric equivalent of configuration word N10:0 for channel 0. It is configured for a type K thermocouple, scaled-for-PID, zero the signal for an open circuit, 10 Hz, °C, channel enabled, to return the data word.

Figure 5.8 Programming for PID Control Example

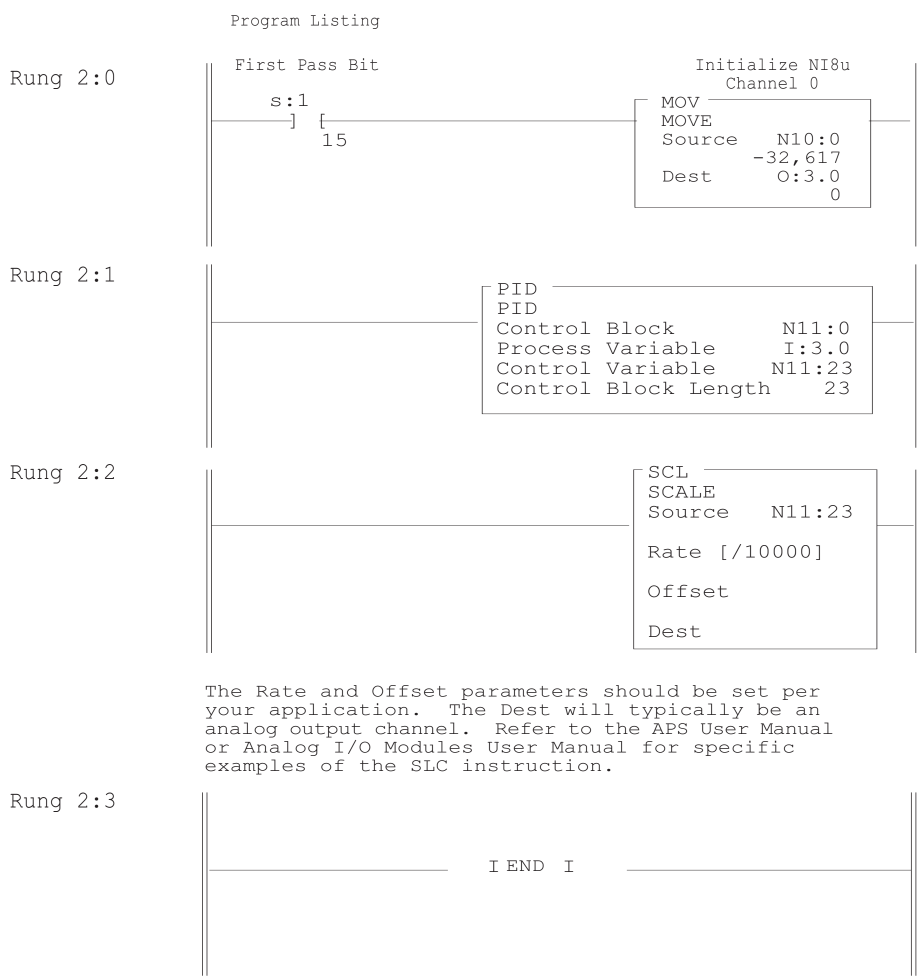


Figure 5.9 Data table for PID Control

Data Table

address	15 data 0	address	15 data 0
N10:0	1000 0000 1001 0111		

Monitoring Channel Status Bits

The example shows how you could monitor the open circuit error bits of each channel and set an alarm in the processor if one of the inputs opens. An open circuit error can occur if one of the input signal wires gets cut or disconnected from the terminal block, or if the CJC sensors are not installed or are damaged.

Important: If a CJC input is not installed or is damaged, all thermocouple alarms are set, and their respective channel LEDs blink.

Figure 5.10 Monitoring channel status bits example

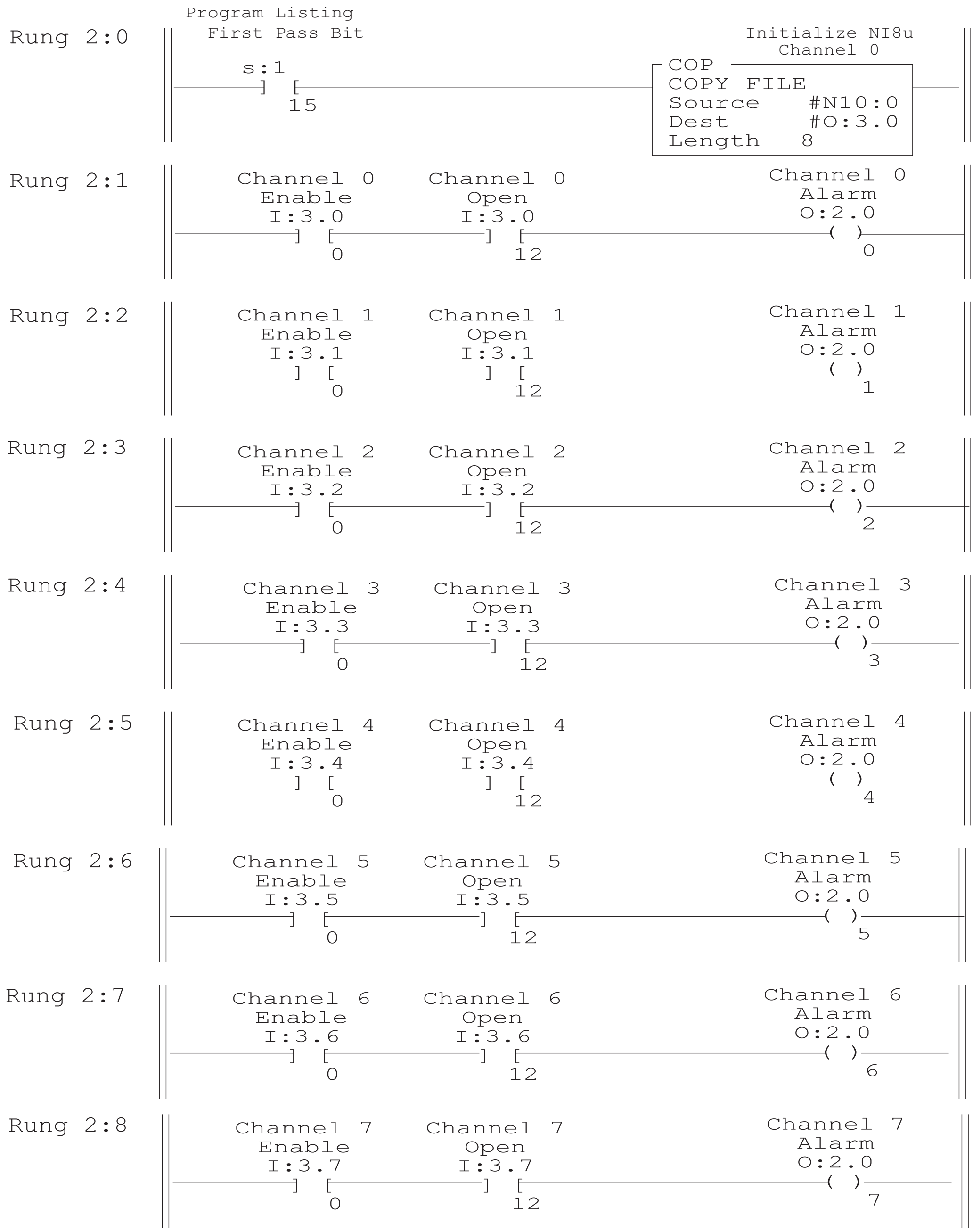


Figure 5.11 Data table for monitoring channel status bits

Data Table

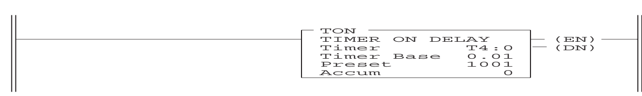
address	15 data 0	address	15 data 0
N10:0	0000 0000 1001 0111	N10:4	0000 0000 1001 0111
N10:1	0000 0000 1001 0111	N10:5	0000 0000 1001 0111
N10:2	0000 0000 1001 0111	N10:6	0000 0000 1001 0111
N10:3	0000 0000 1001 0111	N10:7	0000 0000 1001 0111

This is an example of how to automatically switch between reading the channel status words and channel data words. Specifically, this example shows a very simple method of utilizing a timer to periodically switch between reading the channel status and data words.

The program utilizes a timer accumulator value to determine when to set up the configuration words, and when to read in the channel status and channel data information. The channel status information is copied from the I:2.0 to I:2.7 registers into registers N7:10 to N7:17. The channel data information is copied from I:2.0 to I:2.7 into registers N7:0 to N7:7. This allows sensor data and channel status information to be accessed at any time from these registers. However, when the module channels are configured to read sensor data, the channel status words (as reflected in N7:10 to N7:17) are not being dynamically updated, and vice-versa.

A longer interval between reading in the channel status information could be achieved through the utilization of a combination of counters and timers. If you are utilizing an SLC 5/03 or SLC 5/04 or later processor, the internal processor clock registers S:40 to S:42 could be utilized to determine the timing.

Rung 2:0

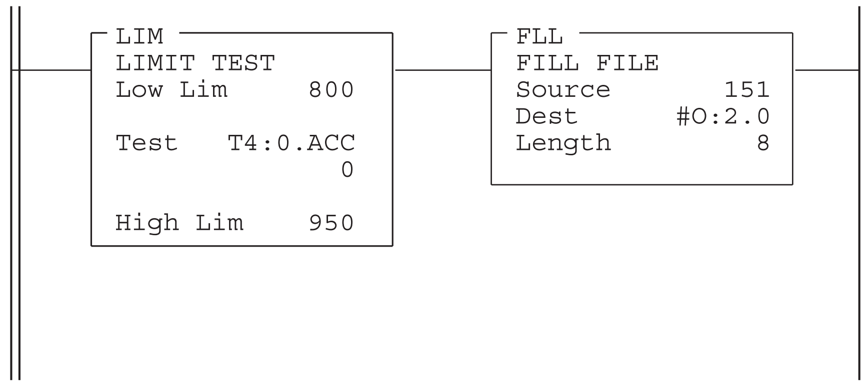


Timer T4:0 counts out a 10 second interval. Its accumulator indicates the progress it has made toward completion. The accumulator value shall be utilized to determine when to set the channel configuration word to send sensor data or to send status information.

A longer interval between transitions can be achieved using a combination of timers and counters.

Rung 2:1

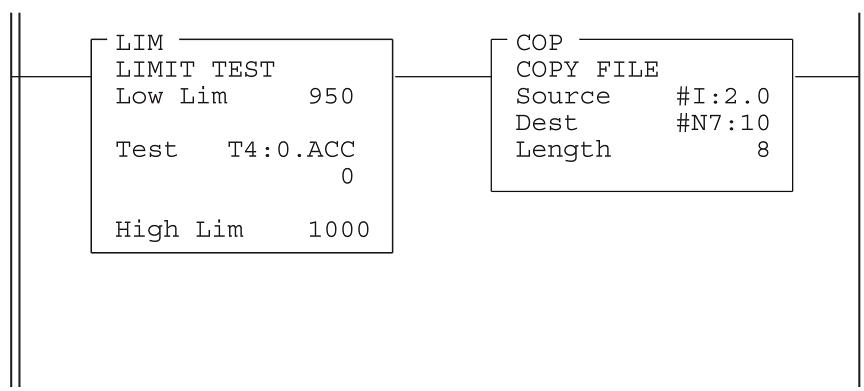
This rung tests to see if T4:0.ACC is at a value between 800 and 950 counts. If so, the channel configuration words are defined (through the Fill File command) to send status information.



Rung 2:2

This rung executes a Copy File command to move the channel status word (as enabled in the previous rung) into registers N7:10 through N7:17 for all channels.

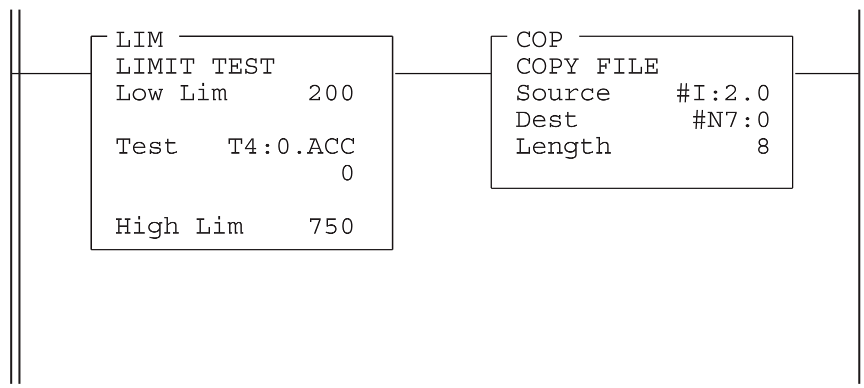
Though the module is quick about switching from sensor data to status information, it is a good idea to give the module a little time to switch modes. That is why this example uses a half second period in time between when the channel is set-up to send the status word and when the status word is read into the N7 table.



Rung 2:3

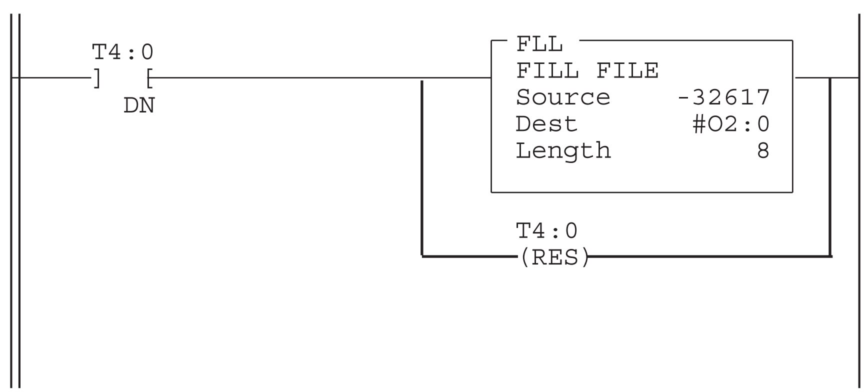
This rung will copy the channel sensor data into registers N7:0 through N7:7, about 2 seconds after the configuration word has been changed to send sensor data.

Timing is important here. Because the channels are multiplexed, it can take the module some amount of time to update the channel input word with sensor data it has been sending channel status information. That amount of time is determined by the module update time and the worst case autocalibration time that could occur based on the filter frequencies and input types selected.

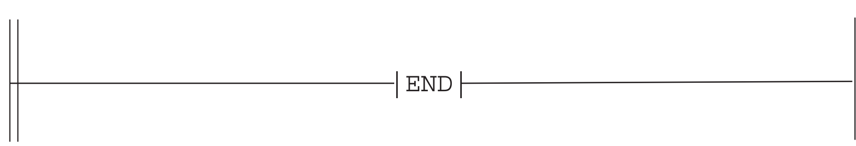


Rung 2:4

This rung will set the channel configuration words for sending sensor data, each time the timer completes a cycle. It also resets the timer.



Rung 2:5



Testing Your Module

This chapter describes troubleshooting with channel-status and module-status LEDs. It explains the types of conditions that might cause the module to flag an error, and suggests what corrective action you could take. Topics include:

- module and channel diagnostics
- LED indicators
- Interpreting I/O error codes
- troubleshooting flowchart

Module and Channel Diagnostics

The module operates at two levels:

- module level
- channel level

Module level operation includes functions such as power-up, configuration, and communication with the SLC processor. ON indicates the module is OK. OFF indicates a fault.

Channel level operation includes functions such as data conversion and open-circuit detection. ON indicates the channel is OK. Blinking indicates a fault.

The module performs internal diagnostics at both levels, and immediately indicates detected error conditions with either of its status LEDs. When a status LED is continuously ON, the status is OK.

Module Diagnostics at Power-up

At module power-up, the module performs a series of internal diagnostic tests. If the module detects a failure, its module status LED remains off.

Channel Diagnostics

When a channel is enabled, the module checks for a valid configuration. Then on each scan of its inputs, the module checks for out-of-range and open-circuit fault conditions of its inputs including the CJC input.

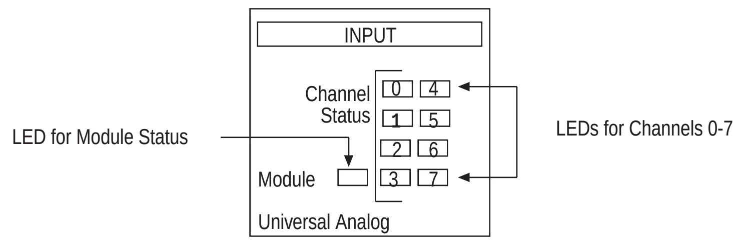
When the module detects a failure of any channel diagnostic test, it causes the channel status LED to blink and sets the corresponding channel fault bit (bits 12-15 of the channel status word). Channel fault bits and LEDs are self-clearing when fault conditions are corrected.

Important: If you clear the channel enable bit, channel status bits are reset.

LED Indicators

The module has nine LEDs:

- eight channel-status LEDs, numbered to correspond with each channel
- one module-status LED



LED Troubleshooting Tables

Table 6.1 Module-status LED

If Module Status LED is:	Then:	Take this Corrective Action:
On	The module is OK.	No action required.
Off	The module is turned off, or it detected a module fault.	Cycle power. If the condition persists, call your local distributor or Spectrum Controls for assistance.

Table 6.2 Module-status and Channel-status LED

If Module Status LED is:	And Channel Status LED is:	Then:	Take this Corrective Action:
On	On	The channel is enabled.	No action required.
	Blinking	The module detected: open-circuit condition under-range condition over-range condition channel error	Examine error bits in status word if bit 12=1, the input has an open circuit if bit 13=1, the input value is under range if bit 14=1, the input value is over range if bit 15=1, the channel has a diagnostic or channel error
	Off	The module is in power up, or the channel is disabled.	No action is required.

Channel-status LEDs (Green)

The channel-status LED operates with status bits in the channel status word to indicate the following faults detected by the module:

- invalid channel configuration
- an open-circuit input
- out-of-range errors
- selected filter frequency data acquisition or auto-calibration errors

When the module detects any of the following fault conditions, it causes the channel-status LED to blink and sets the corresponding fault bit in the channel status word. Channel fault bits (bits 12-15) and channel-status LEDs are self-clearing when fault conditions are corrected.

Open-circuit Detection (Bit 12)

If open-circuit is enabled for an applicable input channel, the module tests the channel for an open-circuit condition each time it scans its input. Open-circuit detection is always performed for the CJC inputs. Open circuit does not apply to ±2V, 0-5V, 1-5V, ±10V, 0-10V, or 0-20mA ranges. Possible causes of an open circuit include:

- broken thermocouple, RTD or CJC sensor
- thermocouple, RTD or CJC sensor wire cut or disconnected
- millivolt, volt or milliamp input wire cut or disconnected
- less than 3 ohms has been detected on an RTD input.

Out-of-Range Detection (Bit 13 for under range, bit 14 for over range)

The module tests all enabled channels for an out-of-range condition each time it scans its inputs. Possible causes of an out-of-range condition include:

- the temperature is too hot or too cold for the thermocouple or RTD being used
- a type B thermocouple may be registering a °F value in EU x1 beyond the range allowed by the SLC processor (beyond 32,767) for the data word
- a CJC sensor may be damaged or the temperature being detected by the CJC may be outside the CJC sensor range limits
- the millivolt, Volt, or milliamp input is outside of its selected input range

Channel Error (Bit 15)

The module sets this fault bit when it detects any of the following:

Configuration erorrs:

- configuration bits Data Format definition, invalid Input Types for channels 0 through 3: 10010 - 11101
- configuration bits Data Format definition of Engineering Units x 1 for Input Types of ±500mV, 0-5V, 1-5V, 0-10V, ±10V, 0-20mA
- configuration bits where Open Circuit is enabled with Input types of 0-5V, 1-5V, 0-10V, ±10V, or 0-20mA
- invalid data acquisition of an input channel
- the filter frequency selected for the valid channel currently fails autocalibration range checks

Module Status LED (Green)

The module-status LED indicates when the module detects a nonrecoverable fault at power up or during operation. For this type of fault, the module:

- no longer communicates with the SLC processor
- disables all channels
- clears all data and status words

A module failure is non-recoverable and requires the assistance of your local distributor or Spectrum Controls.

Interpreting I/O Error Codes

I/O error codes appear in word S:6 of the SLC processor status file. The first two digits of the error code identify the slot (in hexadecimal) with the error. The last two digits identify the I/O error code (in hexadecimal).

The error codes that apply to your module include (in hexadecimal):

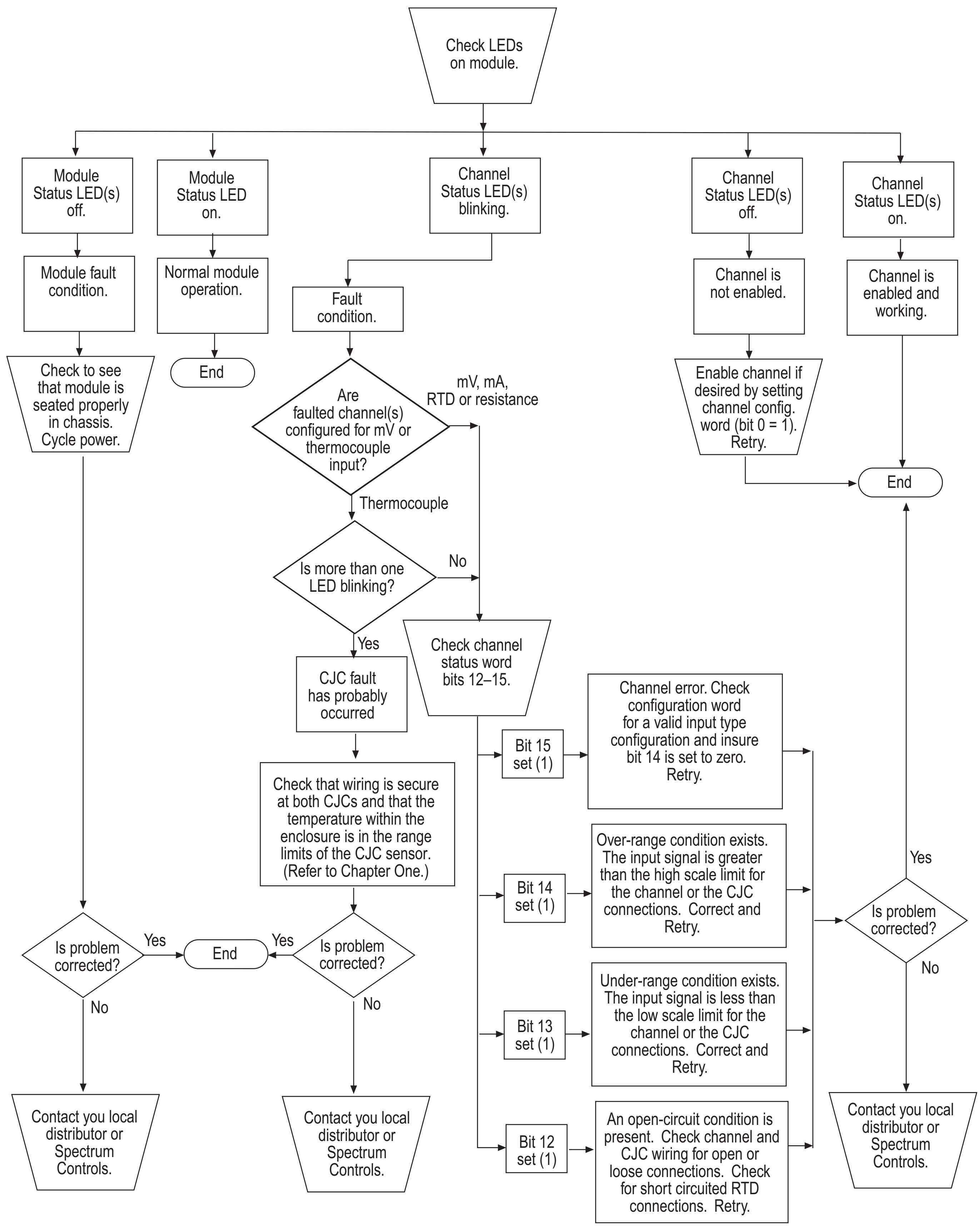
- 50–5E
- 71 (watchdog error)
- 90–94

For a description of the error codes, refer to the *Allen-Bradley Advanced Programming Software (APS) Reference Manual*, Allen-Bradley publication 1746-6.11.

Verifying With Test Instrumentation

The 1746sc-NI8u has multiplexed channel inputs which switch in order to read an input channel. The settling time is 3ms. Caution must be used when testing the module with a test instrument, because the instrument may require a settling time much greater than 3 ms. Errors will result in the test instrument sourcing if its settling time requirement is not met. Contact the instrumentation manufacturer for settling time requirements before using the instrument to test your module.

Figure 6.1 Troubleshooting Flowchart



Maintaining Your Module And Ensuring Safety

Read this chapter to familiarize yourself with:

- preventive maintenance
- safety considerations

The National Fire Protection Association (NFPA) recommends maintenance procedures for electrical equipment. Refer to article 70B of the NFPA for general safety-related work practices.

Preventive Maintenance

The printed circuit boards of your module must be protected from dirt, oil, moisture, and other airborne contaminants. To protect these boards, install the SLC 500 system in an enclosure suitable for its operating environment. Keep the interior of the enclosure clean, and whenever possible, keep the enclosure door closed.

Also, regularly inspect the terminal connections for tightness. Loose connections may cause a malfunctioning of the SLC system or damage to the components.

WARNING

POSSIBLE LOOSE CONNECTIONS

Before inspecting connections, always ensure that incoming power is OFF.

Failure to observe this precaution can cause personal injury and equipment damage.

Safety Considerations

Safety is always the most important consideration. Actively think about the safety of yourself and others, as well as the condition of your equipment. The following are some things to consider:

Indicator Lights – When the module status LED on your module is illuminated, your module is receiving power.

Activating Devices When Troubleshooting – Never reach into a machine to activate a device; the machine may move unexpectedly. Use a wooden stick.

Standing Clear Of Machinery – When troubleshooting a problem with any SLC 500 system, have all personnel remain clear of machinery. The problem may be intermittent, and the machine may move unexpectedly. Have someone ready to operate an emergency stop switch.

CAUTION

POSSIBLE EQUIPMENT OPERATION

Never reach into a machine to actuate a switch. Also, remove all electrical power at the main power disconnect switches before checking electrical connections or inputs/outputs causing machine motion.

Failure to observe these precautions can cause personal injury or equipment damage.

Safety Circuits – Circuits installed on machinery for safety reasons (like over-travel limit switches, stop push-buttons, and interlocks) should always be hard-wired to the master control relay. These circuits should also be wired in series so that when any one circuit opens, the master control relay is de-energized, thereby removing power. Never modify these circuits to defeat their function. Serious injury or equipment damage may result.

WARNING

EXPLOSION HAZARD

SUBSTITUTION OF COMPONENTS MAY IMPAIR SUITABILITY FOR CLASS I DIVISION 2.

WARNING

EXPLOSION HAZARD

DO NOT DISCONNECT EQUIPMENT UNLESS POWER HAS BEEN SWITCHED OFF OR THE AREA IS KNOWN TO BE NON-HAZARDOUS.

NOTE: THIS EQUIPMENT IS SUITABLE FOR USE IN CLASS I, DIVISION 2, GROUPS A, B, C, AND D OR NON-HAZARDOUS LOCATIONS ONLY.

WARNING

EXPLOSION HAZARD

WHEN IN HAZARDOUS LOCATIONS, TURN OFF POWER BEFORE REPLACING OR WIRING MODULES.

WARNING

THIS DEVICE IS INTENDED TO ONLY BE USED WITH THE ALLEN-BRADLEY SLC500 SYSTEMS.

Refer to your system's *Installation & Operation Manual* for more information.

Module Specifications

This appendix lists the specifications for the 1746sc-NI8u Universal analog Input Module.

Electrical Specifications

Backplane Current Consumption	120 mA at 5 VDC 100 mA at 24 VDC
Backplane Power Consumption	3.00W maximum (0.6W @ 5 VDC, 2.4W @ 24 VDC)
Number of Channels	8 (backplane and channel-to-channel isolated)
I/O Chassis Location	Any I/O module slot except 0
A/D Conversion Method	Sigma-Delta Modulation
Input Filtering	Low pass digital filter with programmable notch (filter) frequencies
Normal Mode Rejection (between [+] input and [-] input)	100 dB at 50 Hz 100 dB at 60 Hz
Common Mode Rejection (between inputs and chassis ground)	100 dB at 50/60 Hz
Input Filter Cut-Off Frequencies	2.6 Hz at 10 Hz filter frequency 13.1 Hz at 50 Hz filter frequency 15.72 Hz at 60 Hz filter frequency 65.5 Hz at 250 Hz filter frequency
Calibration	Module autocalibrates at power-up and approximately every two minutes afterwards*
Input Overvoltage Protection	±14.5 VDC continuous 250W pulsed for 1 msec.
Input Overcurrent Protection	28 mA continuous 40 mA, 1mS pulsed, 10% duty cycle maximum
Isolation	500 VDC continuous between inputs and chassis ground and between inputs and backplane. 12.5 VDC continuous between channels of TC / V / i 0 VDC between channels of RTD

* = See page 28 for detailed explanation of auto-calibration.

Physical Specifications

LED Indicators	9 green status indicators, one for each of 8 channels and one for module status
Module ID Code	3500
Recommended Cable: for thermocouple inputs... for mV, V or mA inputs for RTD inputs	 Shielded twisted pair thermocouple extension wire❶ Belden 8761 or equivalent shielded Belden #9501, #9533, #83503❷
Maximum Wire Size	One 16 AWG wire or two 22 AWG wires per terminal

❶ Refer to the thermocouple manufacturer for the correct extension wire.
❷ Refer to the RTD manufacturer and Chapter 1 of this user's manual.

Environmental Specifications

Operating Temperature	0°C to 60°C (32°F to 140°F)
Storage Temperature	-40°C to 85°C (-40°F to 185°F)
Relative Humidity	5% to 95% (without condensation)
Certification	UL & CUL approved
Hazardous Environment Classification	Class1 Division 2 Hazardous Environment Groups A, B, C, D
EMC	CE compliant

Input Specifications

Type of Input (Selectable)	Thermocouple Type J	-210°C to 760°C	(-346°F to 1400°F)
	Thermocouple Type K	-270°C to 1370°C	(-454°F to 2498°F)
	Thermocouple Type T	-270°C to 400°C	(-454°F to 752°F)
	Thermocouple Type E	-270°C to 1000°C	(-454°F to 1832°F)
	Thermocouple Type R	0°C to 1768°C	(32°F to 3214°F)
	Thermocouple Type S	0°C to 1768°C	(32°F to 3214°F)
	Thermocouple Type B	300°C to 1820°C	(572°F to 3308°F)
	Thermocouple Type N	0°C to 1300°C	(32°F to 2372°F)
	Thermocouple Type C	0°C to 2315°C	(32°F to 4199°F)
	Millivolt (-50 mVdc to +50 mVdc)		
	Millivolt (-100 mVdc to +100 mVdc)		
	Millivolt (±500mV, ±2V, 0-5V, 1-5V, 0-10V, ±10V)		
	Current (4 to 20mA)		
	Current (0 to 20mA)		
	RTD Pt 385 (100Ω, 500Ω, 1000Ω)	-200°C to 850°C	-328°F to 1562°F
	RTD Pt 385 (200Ω)	-200°C to 750°C	-328°F to 1382°F
	RTD Pt 3916 (100Ω, 200Ω, 500Ω, 1000Ω)	-200°C to 630°C	-328°F to 1166°F
	RTD 10Ω Cu 426	-100°C to 260°C	-148°F to 500°F
	RTD 120Ω Ni 618	-100°C to 260°C	-148°F to 500°F
	RTD 120Ω Ni 672	-80°C to 260°C	-112°F to 500°F
	Resistance (0 to 3000Ω)		

RTD Conversion	JIS C 1602-1997 for Pt 385 JIS C 1604-1989 for Pt 3916 SAMA RC21-4-1966 for the 10Ω Cu 426 RTD DIN 43760 Sept. 1987 for the 120Ω Ni 618 RTD MINCO Application Aid #18 May 1990 for the 120Ω Ni 672 RTD

Thermocouple Linearization	NIST ITS-90 standard
Channel Multiplexing Settling Time	3 mS
RTD Current Source	200µA, one for each RTD channel
Cold Junction Compensation	Accuracy ±1.72°C, -25°C to +105° On board CJC Sensor Required, Analog Devices AD592CN
Input Impedence	Greater than 10MΩ > Ohm Voltage / Thermocouple / RTD < 250 Ω current
Temperature Scale (Selectable)	°C of °F and 0.1°C or 0.1°F
DC Millivolt Scale (Selectable)	0.1 mV, 0.01 mV, or 0.001 mV Depending on input type
Milliamp Scale (Selectable)	.01 mA or .001mA
Open Circuit Detection (Selectable)	Upscale, Downscale, Zero, or Disabled Does not apply to 5 or 10V range, or 0-20mA input type
Time to Detect Open Circuit	One module update time
Input Step Response	0 to 95% in 300 msec (10 Hz)
Display Resolution	See Channel Data Word Resolution table in Chapter 4
Overall Module Accuracy @ 25°C (77°F)	See Module Accuracy Tables below
Overall Module Accuracy (0°C to 60°C, 32°F to 140°F)	See Module Accuracy Tables below
Overall Module Drift	See Module Accuracy Tables below
Module Update Time	Dependent upon enabled channels (see Update Time, Chap 3)
Channel Turn-Off Time	Up to one module update time

Overall Accuracy

The accuracy of the module is determined by many aspects of the hardware and software functionality of the module. The following attempts to explain what the user can expect in terms of accuracy based on the thermocouple, RTD, resistance, and millivolt, volt, and milliamp inputs for the NI8u module.

The accuracies specified as follows include errors due to the cold junction compensation for thermocouples, current source errors for RTDs, and hardware and software errors associated with the system, which depends upon input path. RTD accuracies do not include errors due to lead resistance. The hardware and software errors include calibration of the system, and non-linearity of the ADC. For the sake of the calculations the resolution of the ADC was assumed to be at least 16 bits (use of the 10Hz, 50Hz, and 60Hz filter frequencies). Note: The 250Hz frequency should not be applied to thermocouple or RTD inputs if accuracy is a concern.

Thermocouple

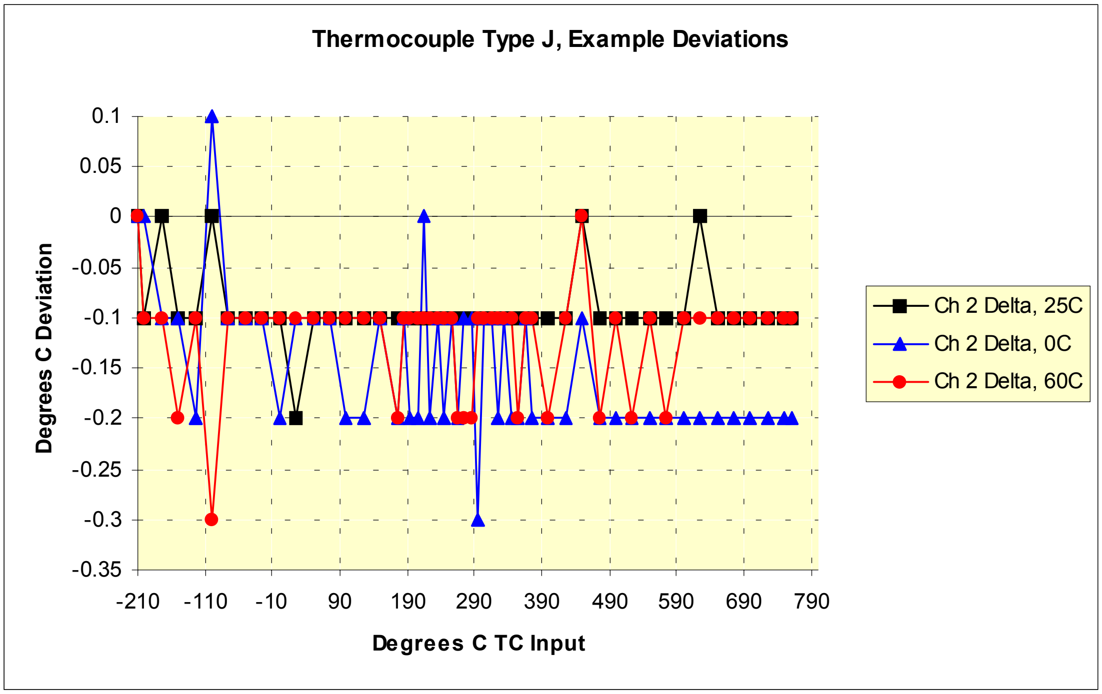
The following table provides the maximum error for each thermocouple type when the 10Hz, 50Hz, or 60Hz filters are used and the module is operating at 25°C and was calibrated at 25°C. Inaccuracies in the cold junction compensation sensors are not included.

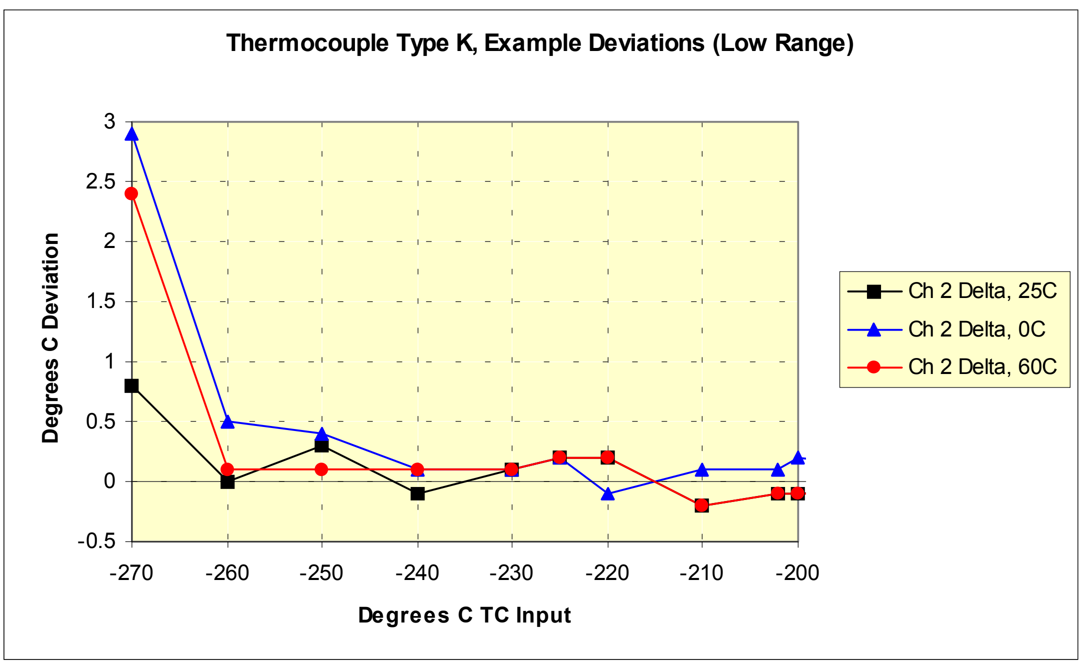
Thermocouple Type		Max. Error 25°C
J		±0.6°C
K	-225°C to 1370°C	±1.0°C
K	-270°C to -225°C	±7.5°C
T	-230°C to +400°C	±1.0°C
T	-270°C to -230°C	±5.4°C
E	-210°C to +1000°C	±0.5°C
E	-270°C to -210°C	±4.2°C
R		±1.7°C
S		±1.7°C
B		±3.0°C
N		±0.4°C
C		±1.8°C

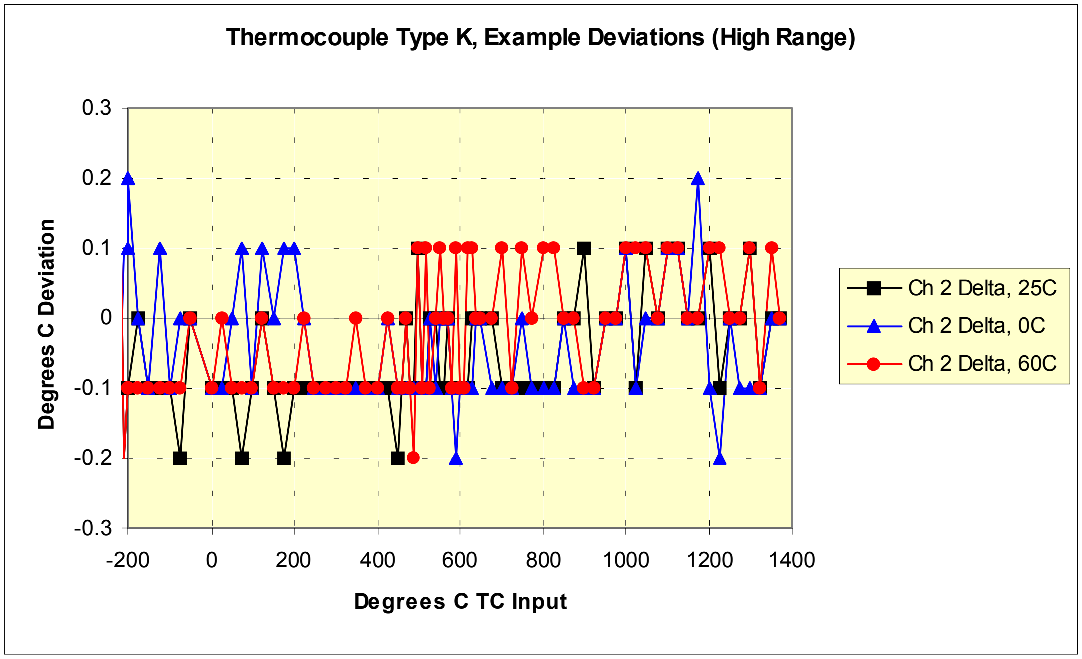
The following table provides the maximum error for each thermocouple type when the 10Hz, 50Hz, or 60Hz filters are used and the module is operating at 0°C to 60°C and was calibrated at that temperature. Inaccuracies in the cold junction compensation sensors are not included.

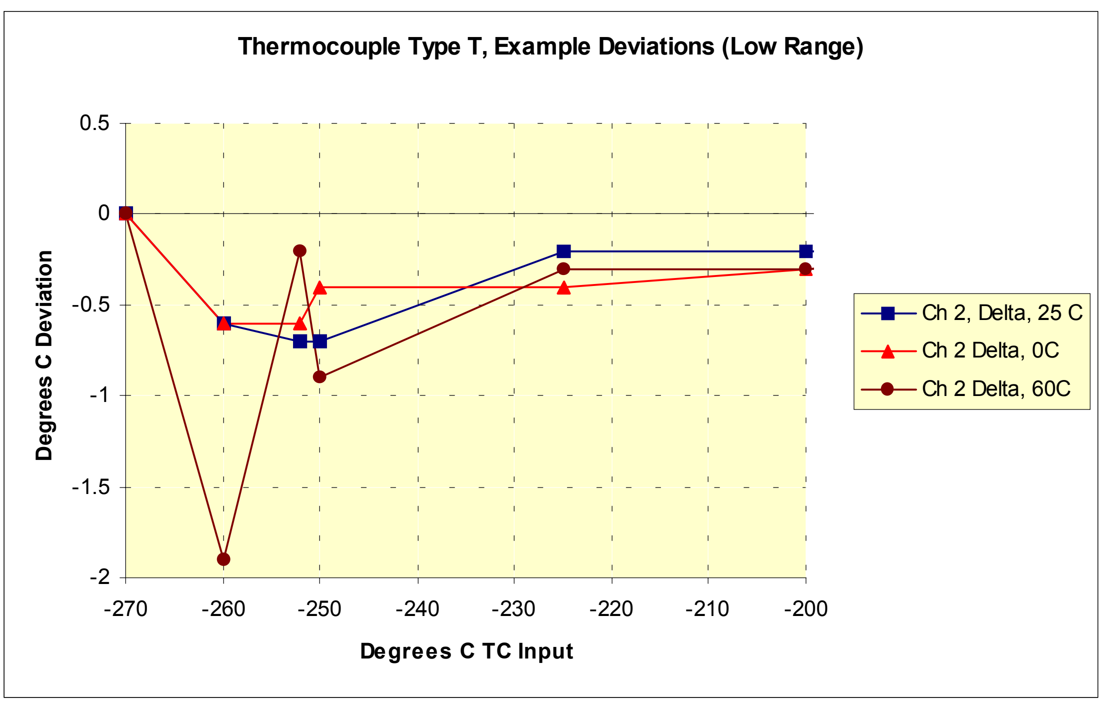
Thermocouple Type		Max. Error 0°C to 60°C
J		±0.9°C
K	-225°C to 1370°C	±1.5°C
K	-270°C to -225°C	±10.0°C
T	-230°C to +400°C	±1.5°C
T	-270°C to -230°C	±7.0°C
E	-210°C to +1000°C	±0.8°C
E	-270°C to -210°C	±6.3°C
R		±2.6°C
S		±2.6°C
B		±4.5°C
N		±0.6°C
C		±3.5°C

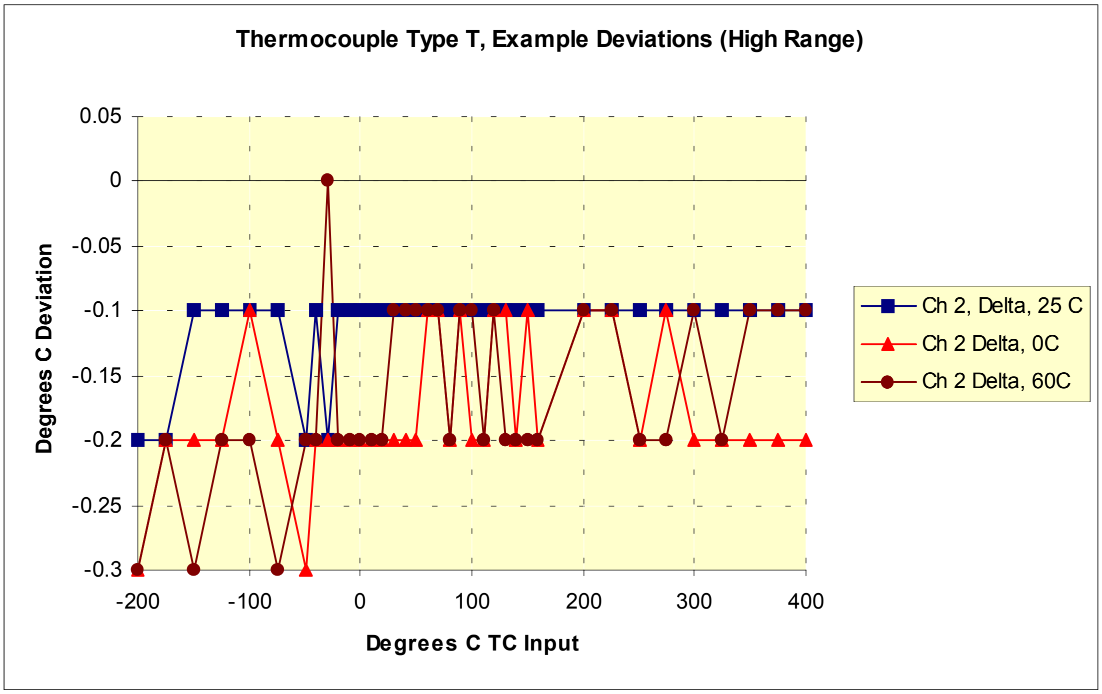
The diagrams that follow for each thermocouple type, give data for a sample module over the input range of the thermocouple, over temperature. Thermocouples are usually parabolic in their µV to degrees C curves. Normally, at the ends of any given thermocouple range, the ratio of change in temperature increases as a result of a change in voltage. In other words, at the ends, a smaller change in voltage results in a larger change in degrees.

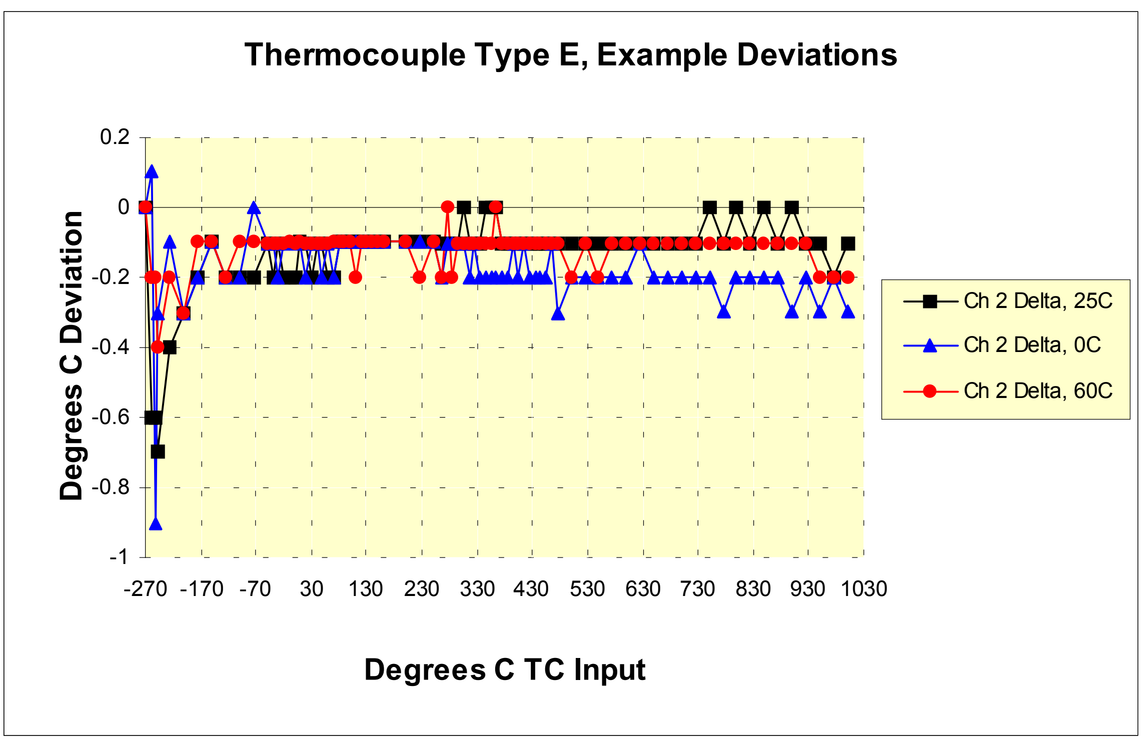


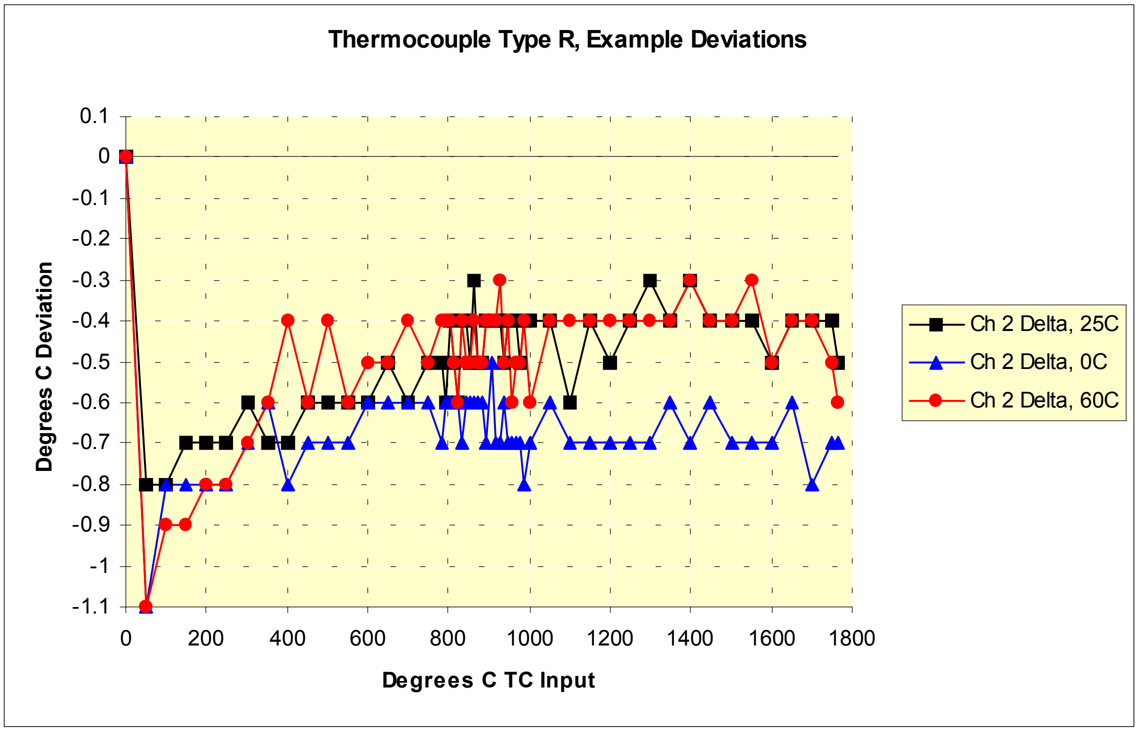


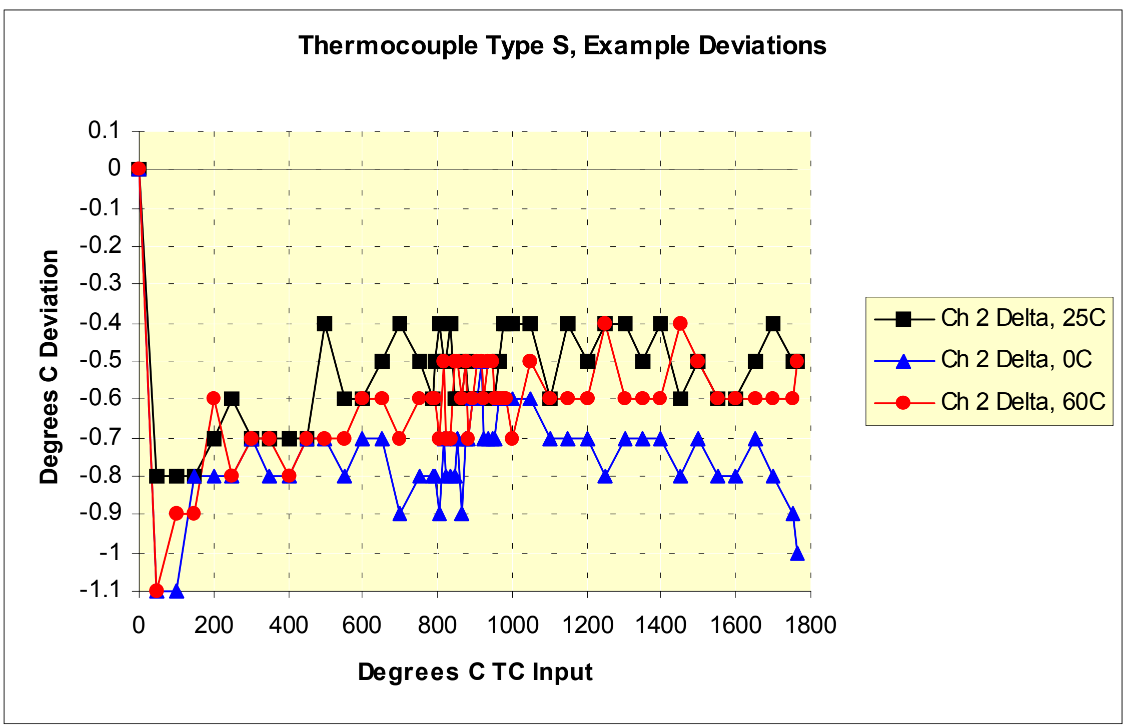

Thermocouple Type K, Example Deviations (High Range)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Degrees C Deviation
-200
0
200
400
600
800
1000
1200
1400
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C

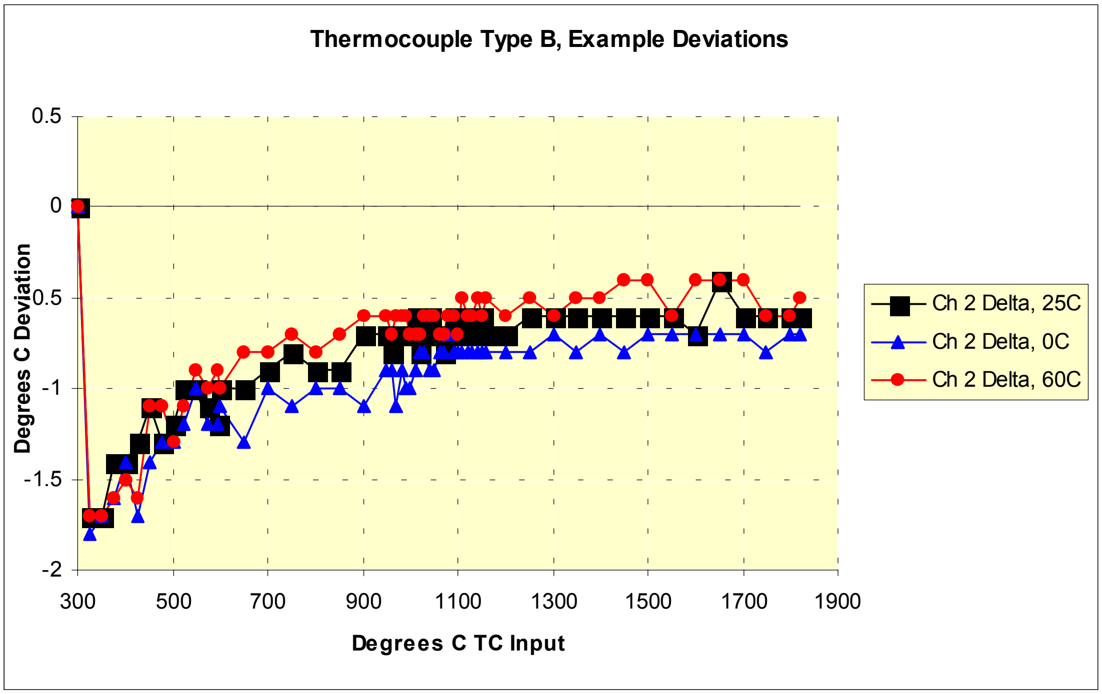

Thermocouple Type T, Example Deviations (Low Range)
0.5
0
-0.5
-1
-1.5
-2
Degrees C Deviation
-270
-260
-250
-240
-230
-220
-210
-200
Degrees C TC Input
Ch 2, Delta, 25 C
Ch 2 Delta, 0C
Ch 2 Delta, 60C


Thermocouple Type T, Example Deviations (High Range)
Degrees C Deviation
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-200
-100
0
100
200
300
400
Degrees C TC Input
Ch 2, Delta, 25 C
Ch 2 Delta, 0C
Ch 2 Delta, 60C

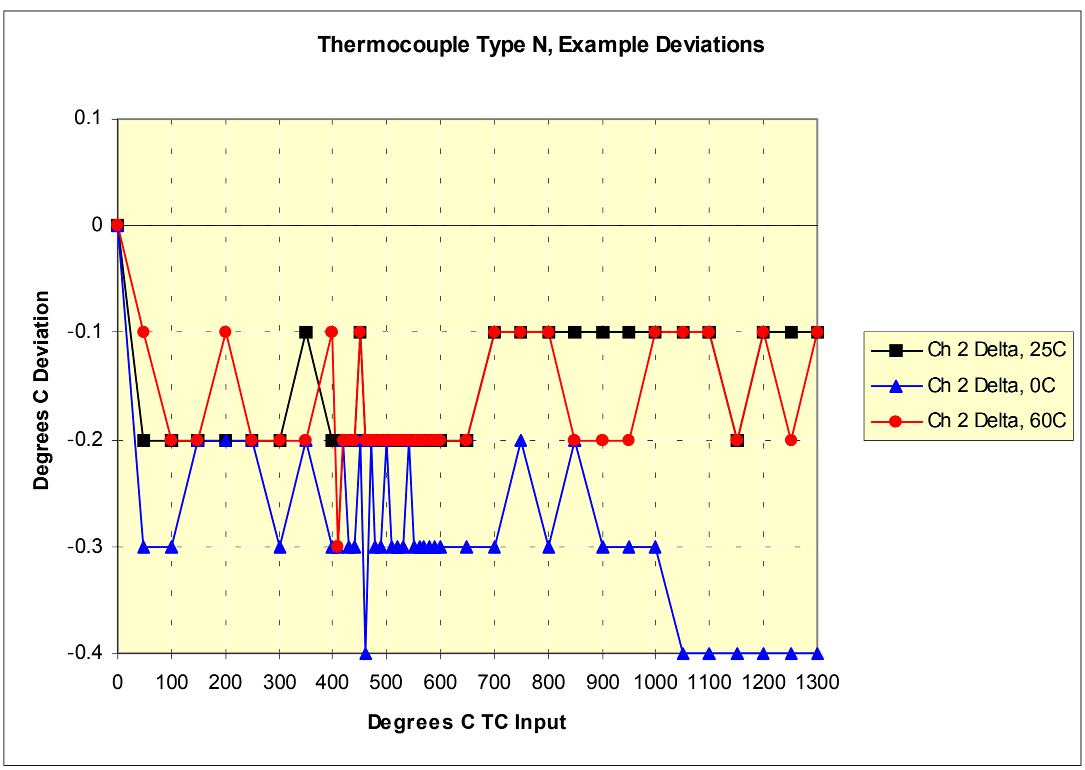

Thermocouple Type E, Example Deviations
Degrees C Deviation
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-270
-170
-70
30
130
230
330
430
530
630
730
830
930
1030
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C


Thermocouple Type R, Example Deviations
Degrees C Deviation
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
0
200
400
600
800
1000
1200
1400
1600
1800
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C

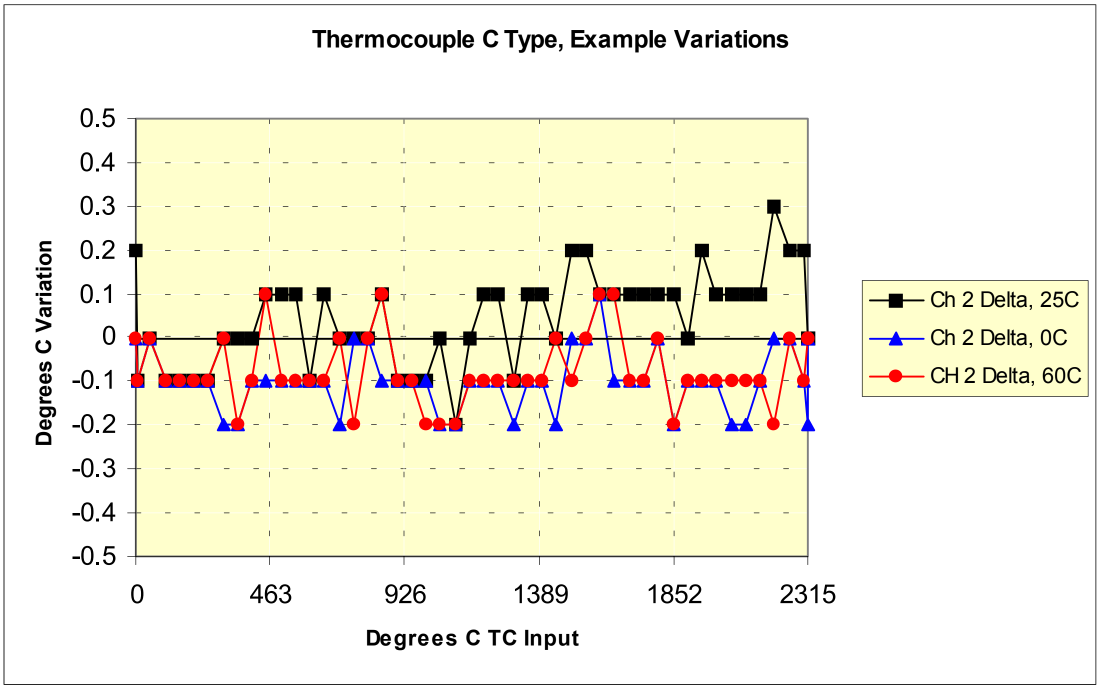

Thermocouple Type S, Example Deviations
Degrees C Deviation
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
0
200
400
600
800
1000
1200
1400
1600
1800
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C



Thermocouple Type B, Example Deviations
0.5
0
-0.5
-1
-1.5
-2
Degrees C Deviation
300
500
700
900
1100
1300
1500
1700
1900
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C



Thermocouple Type N, Example Deviations
0.1
0
-0.1
-0.2
-0.3
-0.4
Degrees C Deviation
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Degrees C TC Input
Ch 2 Delta, 25C
Ch 2 Delta, 0C
Ch 2 Delta, 60C



RTD and Resistance

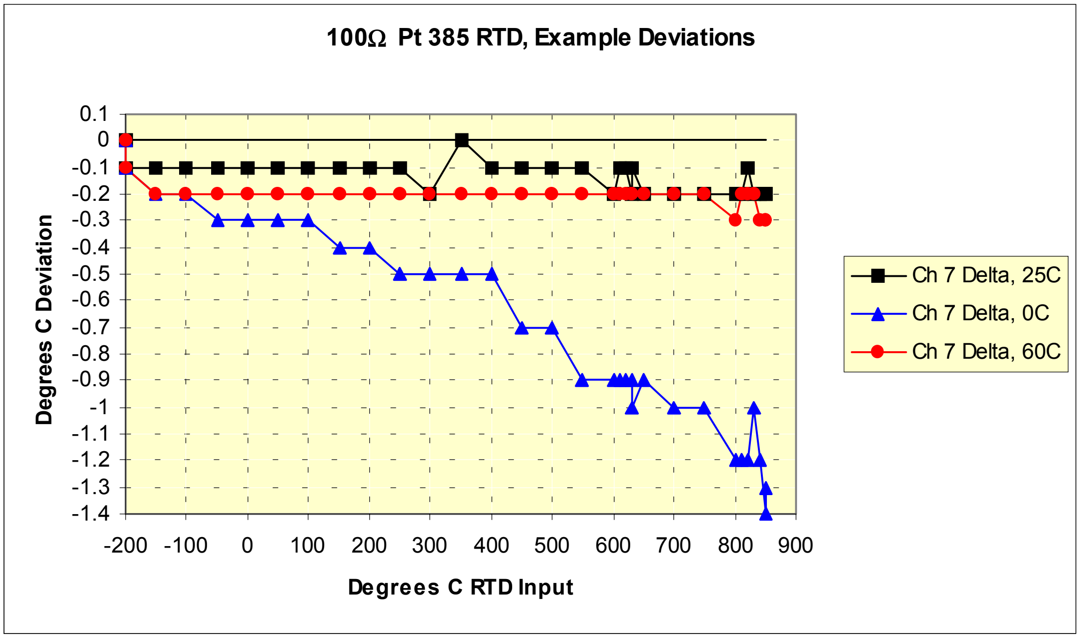
The following table provides the maximum error for each RTD and resistance type when the 10 Hz, 50 Hz, and 60 Hz filters are used and the module is operating at 25°C and was calibrated at 25°C. Errors due to lead wire resistance mismatches are not included.

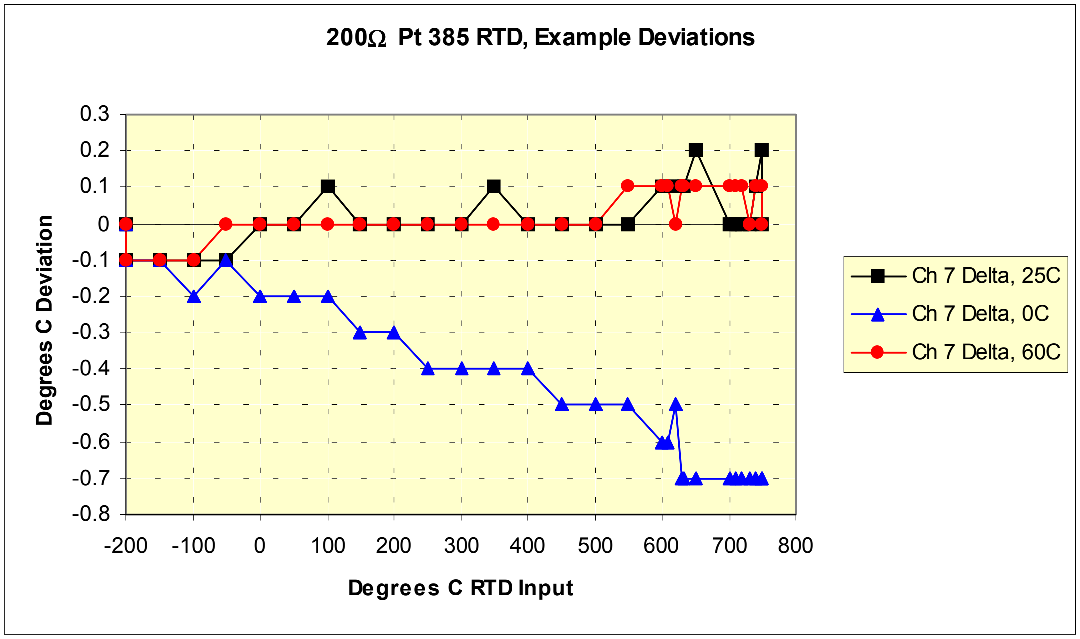
Input Type	Max. Error 25°C
100Ω Pt 385	±1.0°C
200Ω Pt 385	±0.7°C
500Ω Pt 385	±0.6°C
1000Ω Pt 385	±0.5°C
100Ω Pt 3916	±0.9°C
200Ω Pt 3916	±0.6°C
500Ω Pt 3916	±0.5°C
1000Ω Pt 3916	±0.4°C
10Ω Cu 426	±3.0°C
120Ω Ni 618	±0.4°C
120Ω Ni 672	±0.4°C
3000Ω Resistance	±2.0Ω

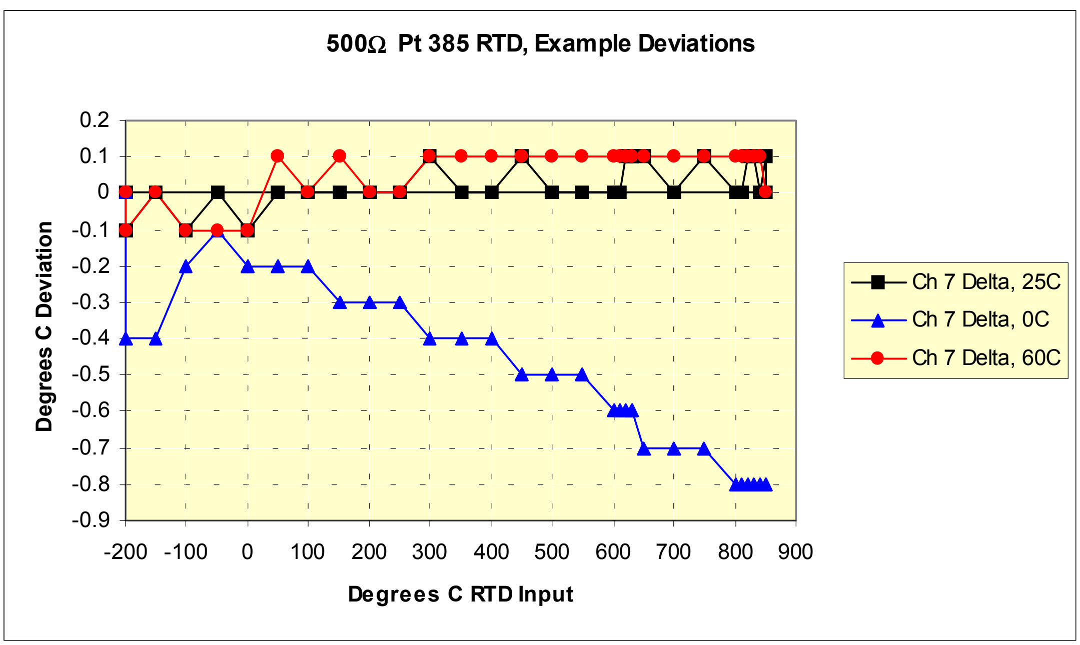
The following table provides the maximum error for each RTD and resistance type when the 10 Hz, 50 Hz, and 60 Hz filters are used and the module is operating at 0°C to 60°C and was at that temperature. Errors due to lead wire resistance mismatches are not included.

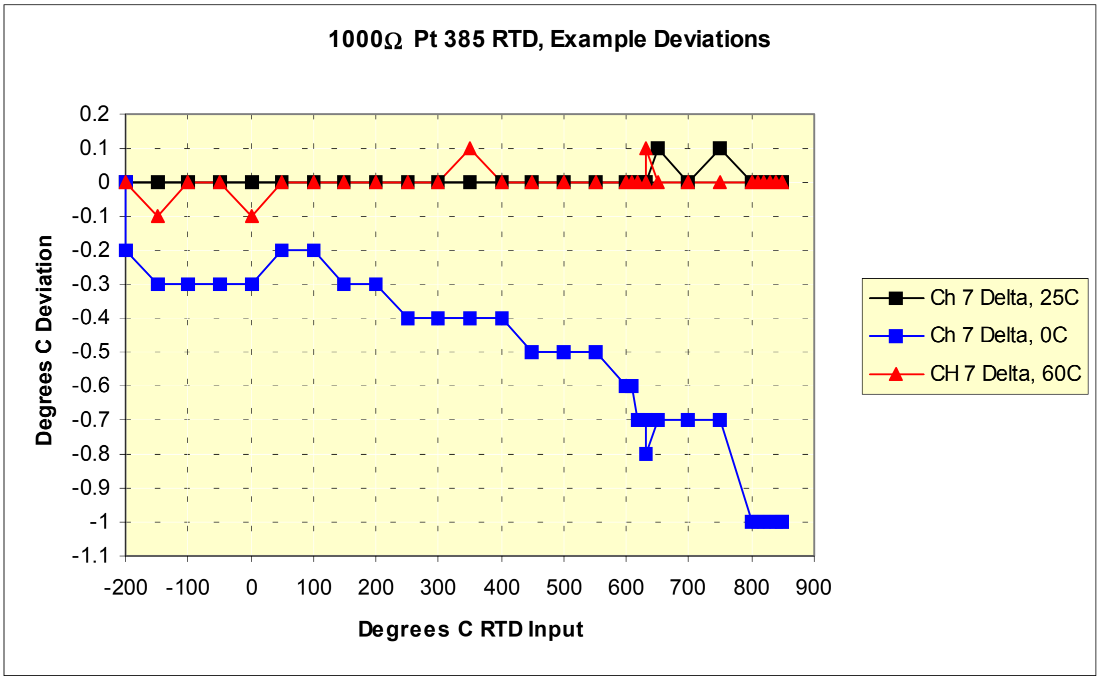
Input Type	Max. Error 0°C to 60°C
100Ω Pt 385	±3.3°C
200Ω Pt 385	±2.8°C
500Ω Pt 385	±3.0°C
1000Ω Pt 385	±2.9°C
100Ω Pt 3916	±2.7°C
200Ω Pt 3916	±2.4°C
500Ω Pt 3916	±2.3°C
1000Ω Pt 3916	±2.2°C
10Ω Cu 426	±4.5°C
120Ω Ni 618	±0.8°C
120Ω Ni 672	±0.8°C
3000Ω Resistance	±7.0Ω

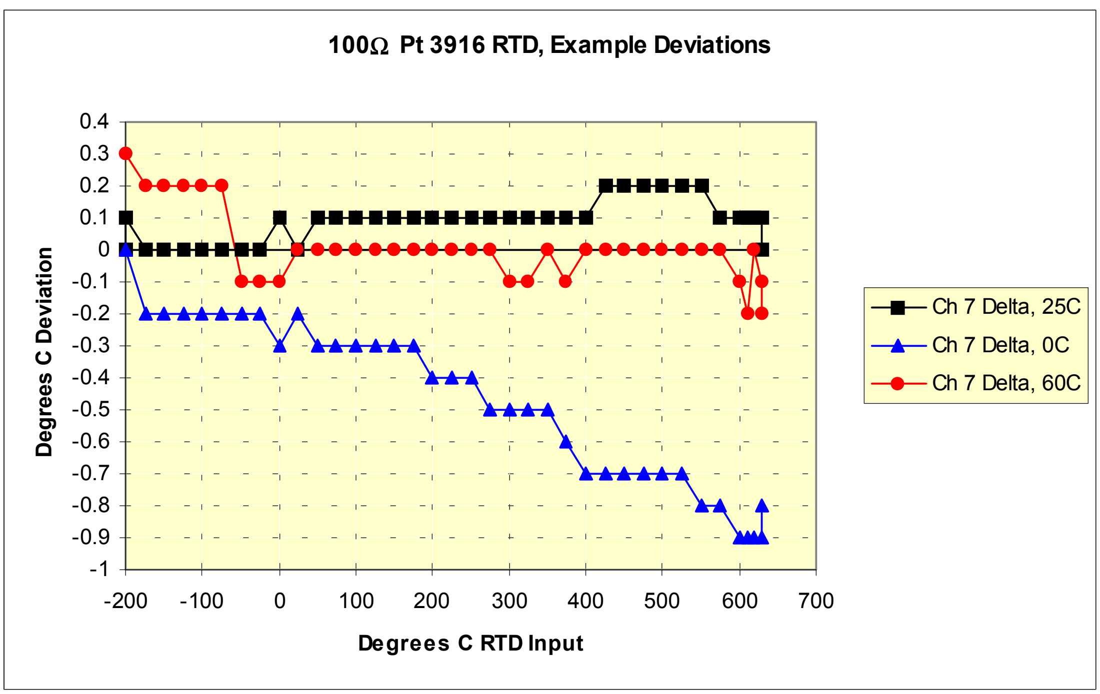
The diagrams that follow provide data from a sample module for a given RTD type over a range of inputs, over temperature.

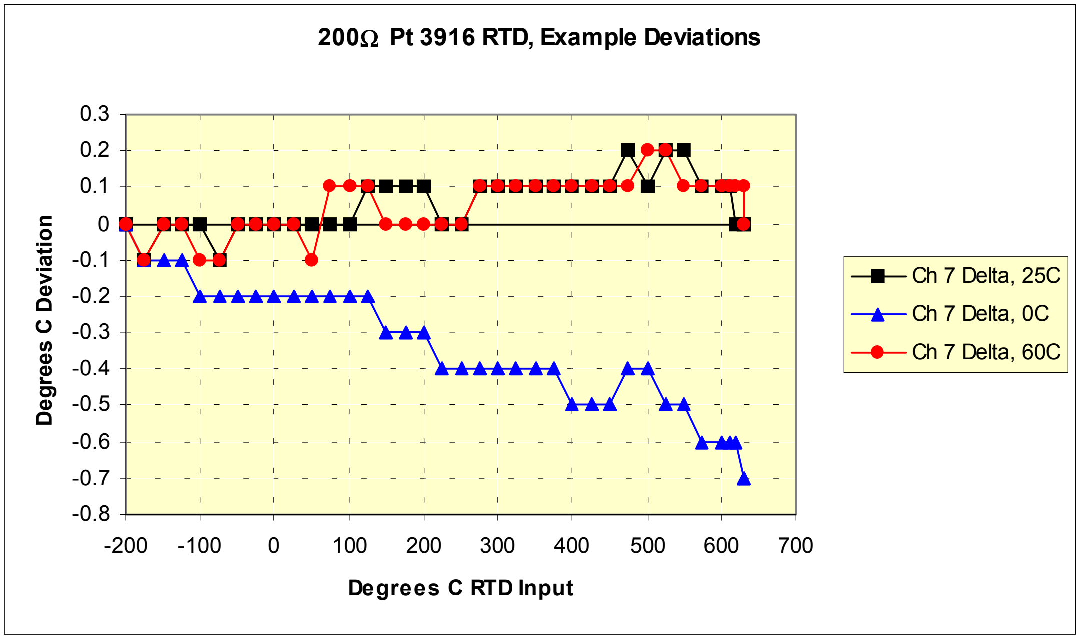


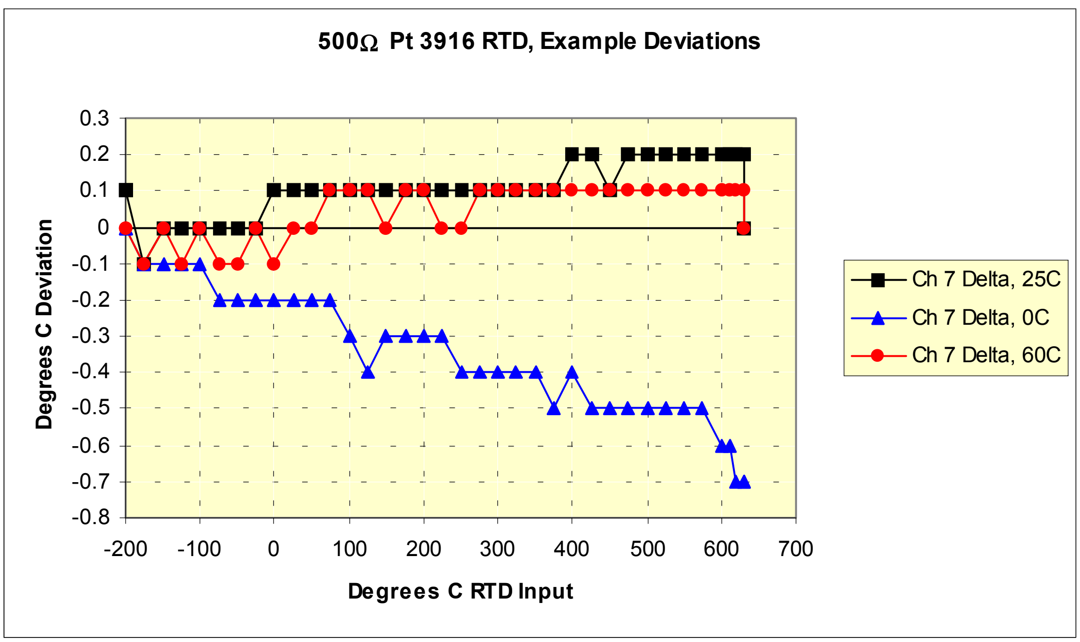

200Ω Pt 385 RTD, Example Deviations
Degrees C Deviation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-200
-100
0
100
200
300
400
500
600
700
800
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
Ch 7 Delta, 60C

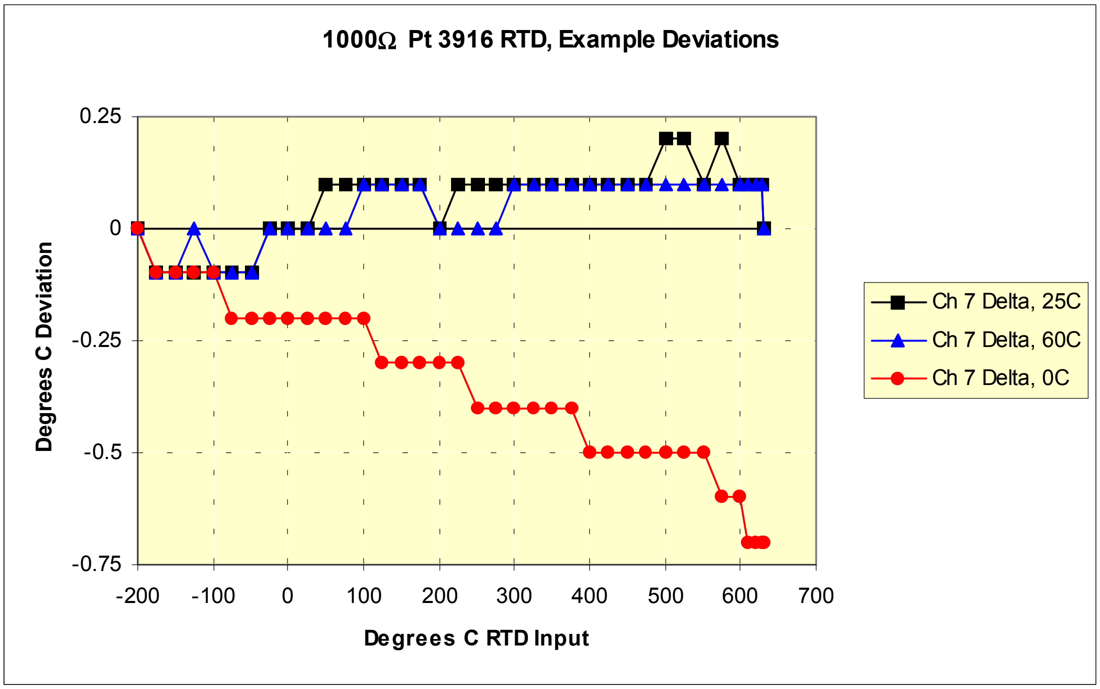

500Ω Pt 385 RTD, Example Deviations
Degrees C Deviation
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-200
-100
0
100
200
300
400
500
600
700
800
900
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
Ch 7 Delta, 60C


1000Ω Pt 385 RTD, Example Deviations
Degrees C Deviation
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-200 -100 0 100 200 300 400 500 600 700 800 900
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
CH 7 Delta, 60C

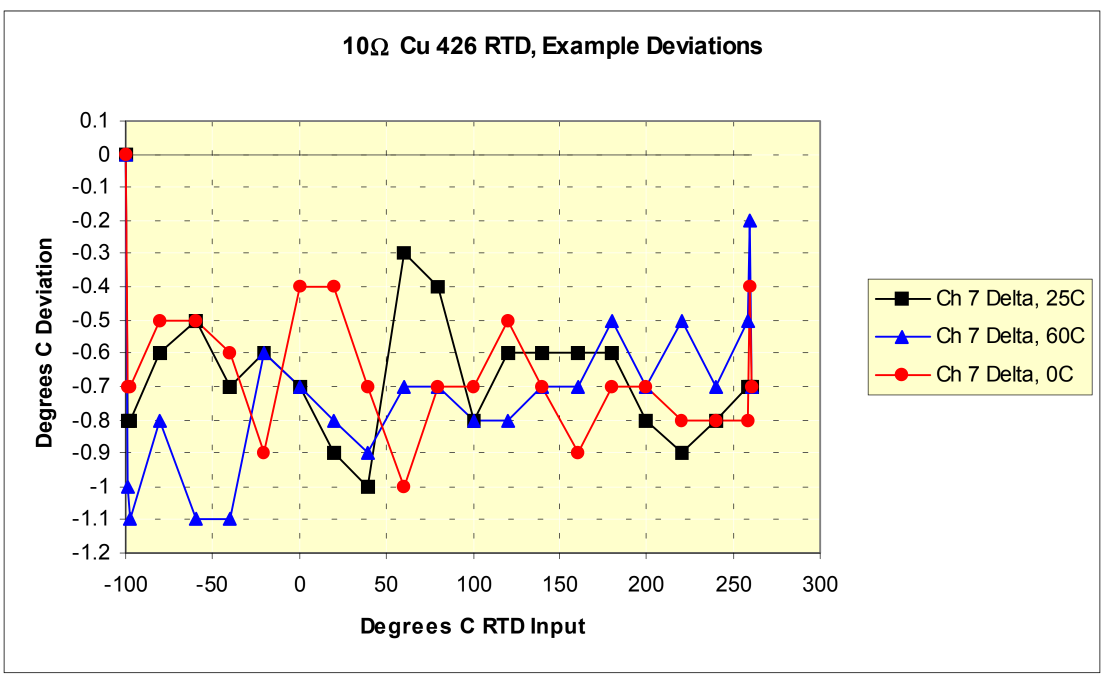

100Ω Pt 3916 RTD, Example Deviations
Degrees C Deviation
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-200 -100 0 100 200 300 400 500 600 700
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
Ch 7 Delta, 60C


200Ω Pt 3916 RTD, Example Deviations
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
Degrees C Deviation
-200
-100
0
100
200
300
400
500
600
700
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
Ch 7 Delta, 60C

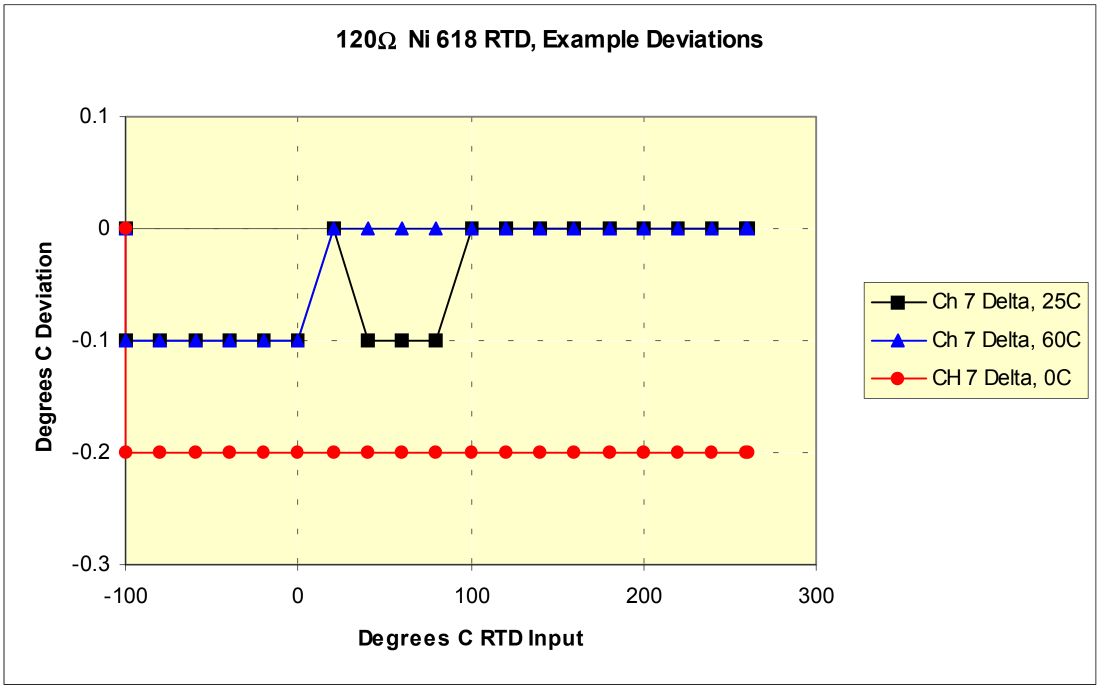

500Ω Pt 3916 RTD, Example Deviations
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
Degrees C Deviation
-200
-100
0
100
200
300
400
500
600
700
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 0C
Ch 7 Delta, 60C

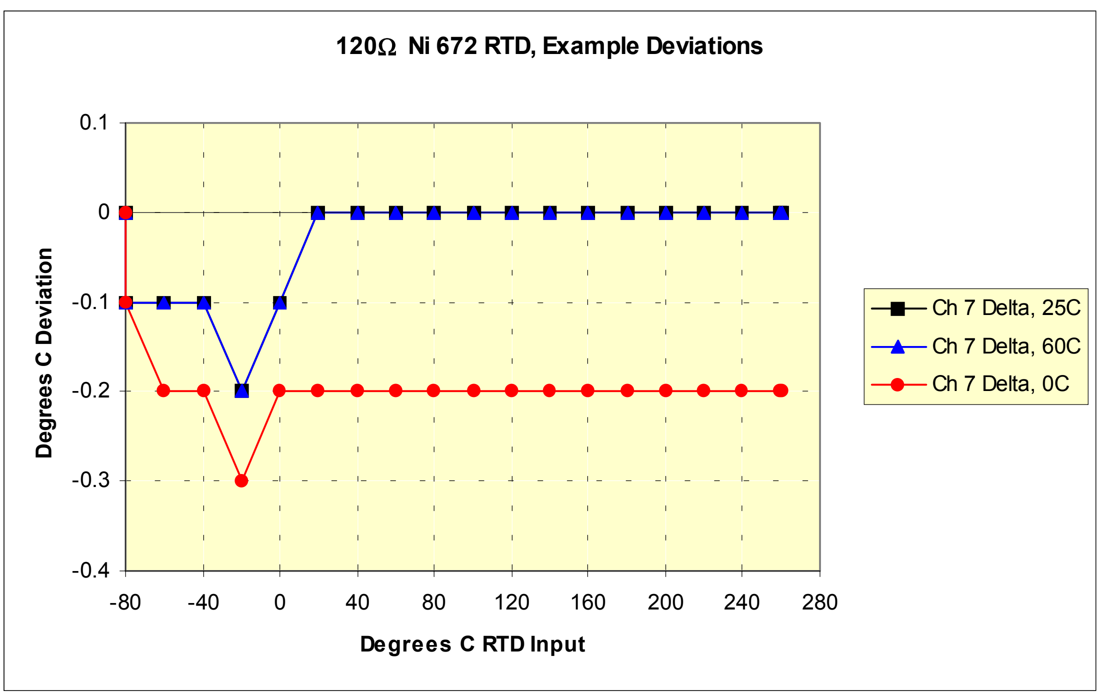


1000Ω Pt 3916 RTD, Example Deviations
Degrees C Deviation
0.25
0
-0.25
-0.5
-0.75
-200
-100
0
100
200
300
400
500
600
700
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 60C
Ch 7 Delta, 0C



10Ω Cu 426 RTD, Example Deviations
Degrees C Deviation
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1.2
-100
-50
0
50
100
150
200
250
300
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 60C
Ch 7 Delta, 0C


120Ω Ni 618 RTD, Example Deviations
0.1
0
-0.1
-0.2
-0.3
-100
0
100
200
300
Degrees C Deviation
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 60C
CH 7 Delta, 0C


120Ω Ni 672 RTD, Example Deviations
0.1
0
-0.1
-0.2
-0.3
-0.4
-80
-40
0
40
80
120
160
200
240
280
Degrees C Deviation
Degrees C RTD Input
Ch 7 Delta, 25C
Ch 7 Delta, 60C
Ch 7 Delta, 0C

Millivolt, volt, and current

The universal module supports many input paths in order to support the many different thermocouple, RTD, resistance, millivolt, volt, and millamp input options. Thus the hardware/software errors of the system depends greatly upon the input path.

The following table provides the maximum error for each voltage or current input type when the module is operating at 25°C and was calibrated at 25°C.

Input Type	Max. Error 25°C
± 50mV	±20 uV
± 100mV	±30 uV
± 0.5V	±0.3 mV
± 2.0V	±1.0 mV
0 to 5V	±2.5 mV
1 to 5V	±2.5 mV
0 to 10V	±5.0 mV
± 10V	±5.0 mV
4 to 20mA	±40 uA
0 to 20mA	±40 uA

The following table provides the maximum error for each voltage or current input type when the module is operating at 0°C to 60°C and was calibrated at that temperature.

Input Type	Max. Error 0°C to 60°C
± 50mV	±30 uV
± 100mV	±50 uV
± 0.5V	±0.5 mV
± 2.0V	±1.5 mV
0 to 5V	±4.0 mV
1 to 5V	±4.0 mV
0 to 10V	±8.0 mV
± 10V	±8.0 mV
4 to 20mA	±80 uA
0 to 20mA	±80 uA

Appendix B

Thermocouple Descriptions

The following information was extracted from the NIST Monograph 175 issued in January 1990, which supersedes the IPTS-68 Monograph 125 issued in March 1974. NIST Monograph 175 is provided by the United States Department of Commerce, National Institute of Standards and Technology.

International Temperature Scale of 1990

The ITS-90 [1,3] is realized, maintained and disseminated by NIST to provide a standard scale of temperature for use in science and industry in the United States. This scale was adopted by the International Committee of Weights and Measures (CIPM) at its meeting in September 1989, and it became the official international temperature scale on January 1, 1990. The ITS-90 supersedes the IPTS-68(75) [2] and the 1976 Provisional 0.5 °K to 30 °K Temperature Scale (EPT-76) [4].

The adoption of the ITS-90 has removed several deficiencies and limitations associated with IPTS-68. Temperatures on the ITS-90 are in closer agreement with thermodynamic values than were those of the IPTS-68 and EPT-76. Additionally, improvements have been made in the non-uniqueness and reproducibility of the temperature scale, especially in the temperature range from t68 = 630.74°C to 1064.43°C, where the type S thermocouple was the standard interpolating device on the IPTS-68.

For additional technical information regarding ITS-90, refer to the NIST Monograph 175.

J Type Thermocouples

Iron Versus Copper-Nickel Alloy (SAMA) Thermocouples

This is one of the most common types of industrial thermocouples, because of its relatively high Seebeck coefficient and low cost. It has been reported that more than 200 tons of type J materials are supplied annually to industry in this country. However, this type is least suitable for accurate thermometry because there are significant nonlinear deviations in the thermoelectric output of thermocouples obtained from different manufacturers. These irregular deviations lead to difficulties in obtaining accurate calibrations based on a limited number of calibration points. The positive thermoelement is commercially pure (99.5% Fe) iron, usually containing significant impurity levels of carbon, chromium, copper, manganese, nickel, phosphorus, silicon, and sulfur. Thermocouple wire represents such a small fraction of the total production of commercial iron wire that the producers do not control the chemical composition to maintain constant thermoelectric properties. Instead, instrument companies and thermocouple fabricators select material most suitable for the thermocouple usage. The total and specific types of impurities that occur in commercial iron change with time, location of primary ores, and methods of smelting. Many unusual lots have been selected in the past, for example spools of industrial iron wire and even scrapped rails from an elevated train line. At present, iron wire that most closely fits these tables has about 0.25 percent manganese and 0.12 percent copper, plus other minor impurities.

The negative thermoelement for type J thermocouples is a copper-nickel alloy known ambiguously as constantan. The word constantan has commonly referred to copper-nickel alloys containing anywhere from 45 to 60 percent copper, plus minor impurities of carbon, cobalt, iron, and manganese. Constantan for type J thermocouples usually contains about 55 percent copper, 45 percent nickel, and a small but thermoelectrically significant amount of cobalt, iron, and manganese, about 0.1 percent or more. **It should be emphasized that type JN thermoelements are NOT generally interchangeable with type TN (or EN) thermoelements, although they are all referred to as "constantan".** In order to provide some differentiation in nomenclature, type JN is often referred to as SAMA constantan.

Type J thermocouples are recommended by the ASTM [5] for use in the temperature range from 0°C to 760°C in vacuum, oxidizing, reducing, or inert atmospheres. If used for extended times in air above 500°C, heavy gage wires are recommended because the oxidation rate is rapid at elevated temperatures. Oxidation normally causes a gradual decrease in the thermoelectric voltage of the thermocouple with time. Because iron rusts in moist atmospheres and may become brittle, type J thermocouples are not recommended for use below 0°C. In addition, they should not be used unprotected in sulfurous atmospheres above 500°C.

The positive thermoelement, iron, is relatively insensitive to composition changes under thermal neutron irradiation, but does exhibit a slight increase in manganese content. The negative thermoelement, a copper-nickel alloy, is subject to substantial composition changes under thermal neutron irradiation since copper is converted to nickel and zinc.

Iron undergoes a magnetic transformation near 769°C and an alpha-gamma crystal transformation near 910°C [6]. Both of these transformations, especially the latter, seriously affect the thermoelectric properties of iron, and therefore of type J thermocouples. This behavior and the rapid oxidation rate of iron are the main reasons why iron versus constantan thermocouples are not recommended as a standardized type above 760°C. If type J thermocouples are taken to high temperatures, especially above 900°C, they will lose the accuracy of their calibration when they are recycled to lower temperatures. If type J thermocouples are used in air at temperatures above 760°C, only the largest wire, AWG 8 (3.3mm) should be used and they should be held at the measured temperature for 10 to 20 minutes before readings are taken. The thermoelectric voltage of the type J thermocouples may change by as much as 40uV (or 0.6°C equivalent) per minute when first brought up to temperatures near 900°C.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type J commercial thermocouples be +/-2.2°C or +/-0.75% (whichever is greater) between 0°C and 750°C. Type J thermocouples can also be supplied to meet special tolerances, which are equal to approximately one-half the standard tolerances given above. Tolerances are not specified for type J thermocouples below 0°C or above 750°C.

The suggested upper temperature limit of 760°C given in the above ASTM standard [7] for protected type J thermocouples applies to AWG 8 (3.25mm) wire. For smaller diameter wires the suggested upper temperature limit decreases to 590°C for AWG 14 (1.63mm), 480°C for AWG 20 (0.81mm), 370°C for AWG 24 or 28 (0.51mm or 0.33mm), and 320°C for AWG 30 (0.25mm). These temperature limits apply to thermocouples used in conventional closed-end protecting tubes and they are intended only as a rough guide to the user. They do not apply to sheathed thermocouples having compacted mineral oxide insulation.

K Type Thermocouples

Nickel-Chromium Alloy Versus Nickel-Aluminum Alloy Thermocouples

This type is more resistant to oxidation at elevated temperatures than types E, J, or T thermocouples and, consequently, it finds wide application at temperatures above 500°C. The positive thermoelement, KP, which is the same as EP, is an alloy that typically contains about 89 to 90% nickel, 9 to about 9.5% chromium, both silicon and iron in amounts up to about 0.5%, plus smaller amounts of other constituents such as carbon, manganese, cobalt, and niobium. The negative thermoelement, KN, is typically composed of about 95 to 96% nickel, 1 to 1.5% silicon, 1 to 2.3% aluminum, 1.6 to 3.2% manganese, up to about 0.5% cobalt and smaller amounts of other constituents such as iron, copper, and lead. Also, type KN thermoelements with modified compositions are available for use in special applications. These include alloys in which the manganese and aluminum contents are reduced or eliminated, while the silicon and cobalt contents are increased.

The low temperature research [8] by members of the NBS Cryogenics Division showed that the type K thermocouple may be used down to liquid helium temperatures (about 4°K) but that its Seebeck coefficient becomes quite small below 20°K. Its Seebeck coefficient at 20°K is only about 4uV/°K, being roughly one-half that of the type E thermocouple which is the most suitable of the letter-designated thermocouples types for measurements down to 20°K. Type KP and type KN thermoelements do have a relatively low thermal conductivity and good resistance to corrosion in moist atmospheres at low temperatures. The thermoelectric homogeneity of type KN thermoelements, however, was found [8] to be not quite as good as that of type EN thermoelements.

Type K thermocouples are recommended by the ASTM [5] for use at temperatures within the range -250°C to 1260°C in oxidizing or inert atmospheres. Both the KP and the KN thermoelements are subject to deterioration by oxidation when used in air above about 750°C, but even so, type K thermocouples may be used at temperatures up to about 1350°C for short periods with only small changes in calibration. When oxidation occurs it normally leads to a gradual increase in the thermoelectric voltage with time. The magnitude of the change in the thermoelectric voltage and the physical life of the thermocouple will depend upon such factors as the temperature, the time at temperature, the diameter of the thermoelements and the conditions of use.

The ASTM Manual [5] indicates that type K thermocouples should not be used at high temperatures in sulfurous, reducing, or alternately oxidizing and reducing atmospheres unless suitably protected with protecting tubes. They also should not be used in vacuum (at high temperatures) for extended times because the chromium in the positive thermoelement, a nickel-chromium alloy, vaporizes out of solution and alters the calibration. In addition, their use in atmospheres that promote "green-rot" corrosion [9] of the positive thermoelement should be avoided. Such corrosion results from the preferential oxidation of chromium in atmospheres with low, but not negligible, oxygen content and can lead to a large decrease in the thermoelectric voltage of the thermocouple with time. The effect is most serious at temperatures between 800°C and 1050°C.

Both thermoelements of type K thermocouples are reasonably stable, thermoelectrically, under neutron irradiation since the resulting changes in their chemical compositions due to transmutation are small. The KN thermoelements are somewhat less stable than the KP thermoelements in that they experience a small increase in the iron content accompanied by a slight decrease in the manganese and cobalt contents.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type K commercial thermocouples be +/2.2°C or +/-0.75% (whichever is greater) between 0°C and 1250°C, and +/-2.2°C or +/-2% (whichever is greater) between -200°C and 0°C. In the 0°C to 1250°C range, type K thermocouples can be supplied to meet special tolerances that are equal to approximately one-half the standard tolerances given above. Type K thermocouple materials are normally supplied to meet the tolerances specified for temperatures above 0°C. However, the same materials may not satisfy the tolerances specified for the -200°C to 0°C range. If materials are required to meet the tolerances below 0°C, this should be specified when they are purchased.

The suggested upper temperature limit of 1260°C given in the ASTM standard [7] for protected type K thermocouples applies to AWG 8

(3.25mm) wire. It decreases to 1090°C for AWG 14 (1.63mm), 980°C for AWG 20 (0.81mm), 870 for AWG 24 or 28 (0.51mm or 0.33mm), and 760°C for AWG 30 (0.25mm). These temperature limits apply to thermocouples used in conventional closed-end protecting tubes and they are intended only as a rough guide to the user. They do not apply to thermocouples having compacted mineral oxide insulation.

T Type Thermocouples

Copper Versus Copper-Nickel Alloy Thermocouples

This type is one of the oldest and most popular thermocouples for determining temperatures within the range from about 370°C down to the triple point of neon (-248.5939°C). its positive thermoelement, TP, is typically copper of high electrical conductivity and low oxygen content that conforms to ASTM Specification B3 for soft or annealed bare copper wire. Such material is about 99.95% pure copper with an oxygen content varying from 0.02 to 0.07% (depending upon sulfur content) and with other impurities totaling about 0.01%. Above about -200°C the thermoelectric properties of type TP thermoelements, which satisfy the above conditions, are exceptionally uniform and exhibit little variation between lots. Below about -200°C the thermoelectric properties are affected more strongly by the presence of dilute transition metal solutes, particularly iron.

The negative thermoelement, TN or EN, is a copper-nickel alloy known ambiguously as constantan. The word constantan refers to a family of copper-nickel alloys containing anywhere from 45 to 60% copper. These alloys also typically contain small percentages of cobalt, manganese and iron, as well as trace impurities of other elements such as carbon, magnesium, silicon, etc. The constantan for type T thermocouples usually contains about 55% copper, 45% nickel, and small but thermoelectrically significant amounts, about 0.1% or larger, of cobalt, iron, or manganese. **It should be emphasized that type TN (or EN) thermoelements are NOT generally interchangeable with type JN thermoelements although they are all referred to as "constantan".** In order to provide some differentiation in nomenclature, type TN (or EN) is often referred to as Adams' (or RP1080) constantan and type JN is usually referred to as SAMA constantan.

The thermoelectric relations for type TN and type EN thermoelements are the same, that is the voltage versus temperature equations and tables for platinum versus type TN thermoelements apply to both types of thermoelements over the temperature range recommended for each thermocouple type. However, it should not be assumed that type TN and type EN thermoelements may be used interchangeably or that they have the same commercial initial calibration tolerances.

The low temperature research [8] by members of the NBS Cryogenics Division showed that the type T thermocouple may be used down to liquid helium temperatures (about 4°K) but that its Seebeck coefficient becomes quite small below 20°K. Its Seebeck coefficient at 20°K is only about 5.6uV/°K, being roughly two-thirds that of the type E thermocouple. The thermoelectric homogeneity of most type TP and type TN (or EN) thermoelements is reasonably good. There is considerable variability, however, in the thermoelectric properties of type TP thermoelements below about 70°K caused by variations in the amounts and types of impurities present in these nearly pure materials. The high thermal conductivity of the type TP thermoelements can also be troublesome in precise applications. For these reasons, type T thermocouples are generally unsuitable for use below about 20°K. Type E thermocouples are recommended as the most suitable of the letter-designated thermocouple types for general low-temperature use, since they offer the best overall combination of desirable properties.

Type T thermocouples are recommended by the ASTM [5] for use in the temperature range from -200°C to 370°C in vacuum or in oxidizing, reducing or inert atmospheres. The suggested upper temperature limit for continuous service of protected type T thermocouples is set at 370°C for AWG 14 (1.63mm) thermoelements since type TP thermoelements oxidize rapidly above this temperature. However, the thermoelectric properties of type TP thermoelements are apparently not grossly affected by oxidation since negligible changes in the thermoelectric voltage were observed at NBS [10] for AWG 12, 18, and 22 type TP thermoelements during 30 hours of heating in air at 500°C. At this temperature the type TN thermoelements have good resistance to oxidation and exhibit only small voltage changes heated in air for long periods of time, as shown by the studies of Dahl [11]. Higher operating temperatures, up to at least 800°C, are possible in inert atmospheres where the deterioration of the type TP thermoelement is no longer a problem. The use of type T thermocouples in hydrogen atmospheres at temperatures above about 370°C is not recommended since type TP thermoelements may become brittle.

Type T thermocouples are not well suited for use in nuclear environments since both thermoelements are subject to significant changes in composition under thermal neutron irradiation. The copper in the thermoelements is converted to nickel and zinc.

Because of the high thermal conductivity of type TP thermoelements, special care should be exercised when using the thermocouples to ensure that the measuring and reference junctions assume the desired temperatures.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type T commercial thermocouples be +/-1°C or +/-0.75% (whichever is greater) between 0°C and 350°C, and +/-1°C or +/-1.5% (whichever is greater) between -200°C and 0°C. Type T thermocouples can also be supplied to meet special tolerances which are equal to approximately one-half the standard tolerances given above. Type T thermocouple materials are normally supplied to meet the tolerances specified for temperatures above 0°C. However, the same materials may not satisfy the tolerances specified for the -200°C to 0°C range. If materials are required to meet the tolerances below 0°C, this should be specified when they are purchased.

The suggested upper temperature limit of 370°C given in the ASTM standard [7] for protected type T thermocouples applies to AWG 14 (1.63mm) wire. It decreases to 260°C for AWG 20 (0.81mm), 200°C for AWG 24 or 28 (0.51mm or 0.33mm), and 150°C for AWG 30 (0.25mm). These temperature limits apply to thermocouples used in conventional closed-end protecting tubes and they are intended only as a rough guide to the user. They do not apply to thermocouples having compacted mineral oxide insulation.

E Type Thermocouples

Nickel-Chromium Alloy Versus Copper-Nickel Alloy Thermocouples

This type, and the other base-metal types, do not have specific chemical compositions given in standards; rather, any materials whose emf-temperature relationship agrees with that of the specified reference table within certain tolerances can be considered to be a type E thermocouple. The positive thermoelement, EP, is the same material as KP. The negative thermoelement, EN, is the same material as TN.

The low-temperature research [8] by members of the NBS Cryogenics Division showed that type E thermocouples are very useful down to liquid hydrogen temperatures (n.b.p. about 20.3°K) where their Seebeck coefficient is about 8uV/°C. They may even be used down to liquid helium temperatures (4.2°K) although their Seebeck coefficient becomes quite low, only about 2uV/°C at 4°K. Both thermoelements of type E thermocouples have a relatively low thermal conductivity, good resistance to corrosion in moist atmospheres, and reasonably good homogeneity. For these three reasons and their relatively high Seebeck coefficients, type E thermocouples have been recommended [8] as the most useful of the letter-designated thermocouple types for low-temperature measurements.

For measurements below 20°K, the non-letter-designated thermocouple, KP versus gold-0.07 at .% iron, is recommended. The properties of this thermocouple have been described by Sparks and Powell [12].

Type E thermocouples also have the largest Seebeck coefficient above 0°C for any of the letter-designated thermocouples. For that reason they are being used more often whenever environmental conditions permit.

Type E thermocouples are recommended by the ASTM [5] for use in the temperature range from -200°C to 900°C in oxidizing or inert atmospheres. If used for extended times in air above 500°C, heavy gage wires are recommended because the oxidation rate is rapid at elevated temperatures. About 50 years ago, Dahl [11] studies the thermoelectric stability of EP and EN type alloys when heated in air at elevated temperatures and his work should be consulted for details. More recent stability data on these alloys in air were reported by Burley et al. [13]. Type E thermocouples should not be used at high temperatures in sulfurous, reducing, or alternately reducing and oxidizing atmospheres unless suitably protected with protecting tubes. They also should not be used in vacuum (at high temperatures) for extended times because the chromium in the positive thermoelement, a nickel-chromium alloy, vaporizes out of solution and alters the calibration. In addition, their use in atmospheres that promote "green-rot" corrosion of the positive thermoelement should be avoided. Such corrosion results from the preferential oxidation of chromium in atmospheres with low, but not negligible, oxygen content and can lead to a large decrease in the thermoelectric voltage of the thermocouple with time. The effect is most serious at temperatures between 800°C and 1050°C.

The negative thermoelement, a copper-nickel alloy, is subject to composition changes under thermal neutron irradiation since the copper is converted to nickel and zinc.

Neither thermoelement of type E thermocouples is very sensitive to minor changes in composition or impurity level because both are already heavily alloyed. Similarly, they are also not extremely sensitive to minor differences in heat treatment (provided that the treatment does not violate any of the restrictions mentioned above). For most general applications, they may be used with the heat treatment given by the wire manufacturers. However, when the highest accuracy is sought, additional preparatory heat treatments may be desirable in order to enhance their performance. Details on this and other phases of the use and behavior of type KP thermoelements (EP is the same as KP) are given in publications by Pots and McElroy [14], by Burley and Ackland [15], by Burley [16], by Wang and Starr [17,18], by Bentley [19], and by Kollie et al. [20].

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type E commercial thermocouples be +/-1.7°C or +/-0.5% (whichever is greater) between 0°C and 900°C, and +/-1.7°C or +/-1% (whichever is greater) between -200°C and 0°C. Type E thermocouples can also be supplied to meet special tolerances which are equal to +/-1°C or +/-0.4% (whichever is greater) between 0°C and 900°C, and +/-1°C or +/-0.5% (whichever is greater) between -200°C and 0°C. Type E thermocouple materials are normally supplied to meet the tolerances specified for temperatures above 0°C. The same materials, however, may not satisfy the tolerances specified for the -200°C to 0°C range. If materials are required to meet the tolerances below 0°C, this should be specified when they are purchased.

The suggested upper temperature limit, 870°C, given in the ASTM standard [7] for protected type E thermocouples applies to AWG 8 (3.25mm) wire. It decreases to 650°C for AWG 14 (1.63mm), 540°C for

AWG 20 (0.81mm), 430°C for AWG 24 or 28 (0.51mm or 0.33mm), and 370°C for AWG 30 (0.25mm). These temperature limits apply to thermocouples used in conventional closed-end protecting tubes and they are intended only as a rough guide to the user. They do not apply to thermocouples having compacted mineral oxide insulation.

R Type Thermocouples

Platinum-13% Rhodium Alloy Versus Platinum Thermocouples

This type is often referred to by the nominal chemical composition of its positive (RP) thermoelement: platinum-13% rhodium. The negative (RN) thermoelement is commercially-available platinum that has a nominal purity of 99.99% [21]. An industrial consensus standard (ASTM E1159-87) specifies that rhodium having a nominal purity of 99.98% shall be alloyed with platinum of 99.99% purity to produce the positive thermoelement, which typically contains 13.00 +/-0.05% rhodium by weight. This consensus standard [21] describes the purity of commercial type R materials that are used in many industrial thermometry applications and that meet the calibration tolerances described later in this section. It **does not** cover, however, the higher-purity, reference-grade materials that traditionally were used to construct thermocouples used as transfer standards and reference thermometers in various laboratory applications and to develop reference functions and tables [22,23]. The higher purity alloy material typically contains less than 500 atomic ppm of impurities and the platinum less than 100 atomic ppm of impurities [22]. Differences between such high purity commercial material and the platinum thermoelectric reference standard, Pt-67, are described in [22] and [23].

A reference function for the type R thermocouple, based on the ITS-90 and the SI volt, was determined recently from new data obtained in a collaborative effort by NIST and NPL. The results of this international collaboration were reported by Burns et al [23]. The function was used to compute the reference table given in this monograph.

Type R thermocouples have about a 12% larger Seebeck coefficient than do Type S thermocouples over much of the range. Type R thermocouples were not standard interpolating instruments on the IPTS-68 for the 630.74°C to gold freezing-point range. Other than these two points, and remarks regarding history and composition, all of the precautions and restrictions on usage given in the section on type S thermocouples also apply to type R thermocouples. Glawe and Szaniszlo [24], and Walker et al [25,26] have determined the effects that prolonged exposure at elevated temperatures (>1200°C) in vacuum, air, and argon atmospheres have on the thermoelectric voltages of type R thermocouples.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type R commercial thermocouples be +/-1.5°C or +/-0.25% (whichever is greater) between

0°C and 1450°C. Type R thermocouples can be supplied to meet special tolerances of +/-0.6°C or +/-0.1% (whichever is greater).

The suggested upper temperature limit, 1480°C, given in the ASTM standard [7] for protected type R thermocouples applies to AWG 24 (0.51mm) wire. This temperature limit applies to thermocouples used in conventional closed-end protecting tubes and it is intended only as a rough guide to the user. It does not apply to thermocouples having compacted mineral oxide insulation.

S Type Thermocouples

Platinum-10% Rhodium Alloy Versus Platinum Thermocouples

This type is often referred to by the nominal chemical composition of its positive (SP) thermoelement: platinum-10% rhodium. The negative (SN) thermoelement is commercially available platinum that has a nominal purity of 99.99% [21]. An industrial consensus standard (ASTM E1159-87) specifies that rhodium having a nominal purity of 99.98% shall be alloyed with platinum of 99.99% purity to produce the positive thermoelement, which typically contains 10.00 +/- 0.05% rhodium by weight. The consensus standard [21] describes the purity of commercial type S materials that are used in many industrial thermometry applications and that meet the calibration tolerances described later in this section. It **does not** cover, however, the higher-purity, reference-grade materials that traditionally were used to construct thermocouples used as standard instruments of the IPTS-68, as transfer standards and reference thermometers in various laboratory applications, and to develop reference functions and tables [27,28]. The higher purity alloy material typically contains less than 500 atomic ppm of impurities and the platinum less than 100 atomic ppm of impurities [27]. Difference between such high purity commercial material and the platinum thermoelectric reference standard, Pt-67, are described in [27] and [28].

A reference function for the type S thermocouple, based on the ITS-90 and the SI volt, was determined recently from new data obtained in an international collaborative effort involving eight national laboratories. The results of this international collaboration were reported by Burns et al. [28]. The new function was used to compute the reference table given in this monograph.

Research [27] demonstrated that type S thermocouples can be used from -50°C to the platinum melting-point temperature. They may be used intermittently at temperatures up to the platinum melting point and continuously up to about 1300°C with only small changes in their calibrations. The ultimate useful life of the thermocouples when used at such elevated temperatures is governed primarily by physical problems of impurity diffusion and grain growth, which lead to mechanical failure. The thermocouple is most reliable when used in a clean oxidizing atmosphere (air) but may be used also in inert gaseous atmospheres or in a vacuum for short periods of time. However, type B thermocouples are generally more suitable for such applications above 1200°C. Type S thermocouples should not be used in reducing atmospheres, nor in those containing metallic vapor (such as lead or zinc), nonmetallic vapors (such as arsenic, phosphorus, or sulfur) or easily reduced oxides, unless they are suitably protected with nonmetallic protecting tubes. Also, they should never be inserted directly into a metallic protection tube for use at high temperatures. The stability of type S thermocouples at high temperatures (>1200°C) depends primarily upon the quality of the materials used for protection and insulation, and has been studied by Walker et al. [25,26] and by Bentley [29]. High purity alumina, with low iron content, appears to be the most suitable material for insulating, protecting, and mechanically supporting the thermocouple wires.

Both thermoelements of type S thermocouples are sensitive to impurity contamination. In fact, type R thermocouples were developed essentially because of iron contamination effects in some British platinum-10% rhodium wires. The effects of various impurities on the thermoelectric voltages of platinum based thermocouple materials have been described by Rhys and Taimsalu [35], by Cochrane [36] and by Aliotta [37]. Impurity contamination usually causes negative changes [25,26,29] in the thermoelectric voltage of the thermocouple with time, the extent of which will depend upon the type and amount of chemical contaminant. Such changes were shown to be due mainly to the platinum thermoelement [25,26,29]. Volatilization of the rhodium from the positive thermoelement for the vapor transport of rhodium from the positive thermoelement to the pure platinum negative thermoelement also will cause negative drifts in the thermoelectric voltage. Bentley [29] demonstrated that the vapor transport of rhodium can be virtually eliminated at 1700°C by using a single length of twin-bore tubing to insulate the thermoelements and that contamination of the thermocouple by impurities transferred from the alumina insulator can be reduced by heat treating the insulator prior to its use.

McLaren and Murdock [30-33] and Bentley and Jones [34] thoroughly studied the performance of type S thermocouples in the range 0°C to 1100°C. They described how thermally reversible effects, such as quenched-in point defects, mechanical stresses, and preferential oxidation of rhodium in the type SP thermoelement, cause chemical and physical inhomogeneities in the thermocouple and thereby limit its accuracy in this range. They emphasized the important of annealing techniques.

The positive thermoelement is unstable in a thermal neutron flux because the rhodium converts to palladium. The negative thermoelement is relatively stable to neutron transmutation. Fast neutron bombardment, however, will cause physical damage, which will change the thermoelectric voltage unless it is annealed out.

At the gold freezing-point temperature, 1064.18°C, the thermoelectric voltage of type S thermocouples increases by about 340uV (about 3%) per weight percent increase in rhodium content; the Seebeck coefficient increases by about 4% per weight percent increase at the same temperature.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type S commercial thermocouples be +/-1.5°C or +/-0.25% (whichever is greater) between 0°C and 1450°C. Type S thermocouples can be supplied to meet special tolerances of +/-0.6°C or +/-0.1% (whichever is greater).

The suggested upper temperature limit, 1480°C, given in the ASTM standard [7] for protected type S thermocouples applies to AWG 24 (0.51mm) wire. This temperature limit applies to thermocouples used in conventional closed-end protecting tubes and it is intended only as a rough guide to the user. It does not apply to thermocouples having compacted mineral oxide insulation.

B Type Thermocouples

Platinum-30% Rhodium Alloy Versus Platinum-6% Rhodium Alloy Thermocouples

This type is sometimes referred to by the nominal chemical composition of its thermoelements: platinum - 30% rhodium versus platinum - 6% rhodium or "30-6". The positive (BP) thermoelement typically contains 29.60 +/- 0.2% rhodium and the negative (BN) thermoelement usually contains 6.12 +/- 0.02% rhodium. The effect of differences in rhodium content are described later in this section. An industrial consensus standard [21] (ASTM E1159-87) specifies that rhodium having a purity of 99.98% shall be alloyed with platinum of 99.99% purity to produce the thermoelements. This consensus standard [21] describes the purity of commercial type B materials that are used in many industrial thermometry applications that meet the calibration tolerances described later in this section. Both thermoelements will typically have significant impurities of elements such as palladium, iridium, iron, and silicon [38].

Studies by Ehringer [39], Walker et al. [25,26], and Glawe and Szaniszlo [24] have demonstrated that thermocouples, in which both legs are platinum-rhodium alloys, are suitable for reliable temperature measurements at high temperatures. Such thermocouples have been shown to offer the following distinct advantages over types R and S thermocouples at high temperatures: (1) improved stability, (2) increased mechanical strength, and (3) higher operating temperatures.

The research by Burns and Gallagher [38] indicated that the 30-6 thermocouple can be used intermittently (for several hours) up to 1790°C and continuously (for several hundred hours) at temperatures up to about 1700°C with only small changes in calibration. The maximum temperature limit for the thermocouple is governed, primarily, by the melting point of the Pt-6% rhodium thermoelement which is estimated to be about 1820°C by Acken [40]. The thermocouple is most reliable when used in a clean oxidizing atmosphere (air) but also has been used successfully in neutral atmospheres or vacuum by Walker et al [25,26], Hendricks and McElroy [41], and Glawe and Szaniszlo [24]. The stability of the thermocouple at high temperatures has been shown by Walker et al. [25,26] to depend, primarily, on the quality of the materials used for protecting and insulating the thermocouple. High purity alumina with low iron-content appears to be the most suitable material for the purpose.

Type B thermocouples should not be used in reducing atmospheres, nor those containing deleterious vapors or other contaminants that are reactive with the platinum group metals [42], unless suitably protected with nonmetallic protecting tubes. They should never be used in metallic protecting tubes at high temperatures.

The Seebeck coefficient of type B thermocouples decreases with decreasing temperature below about 1600°C and becomes almost negligible at room temperature. Consequently, in most applications the reference junction temperature of the thermocouple does not need to be controlled or even known, as long as it between 0°C and 50°C. For example, the voltage developed by the thermocouple, with the reference junction at 0°C, undergoes a reversal in sign at about 42°C, and between 0°C and 50°C varies from a minimum of -2.6uV near 21°C to a maximum of 2.3uV at 50°C. Therefore, in use, if the reference junction of the thermocouple is within the range 0°C to 50°C, then a 0°C reference junction temperature can be assumed and the error introduced will not exceed 3uV. At temperatures above 1100°C, an additional measurement error of 3uV (about 0.3°C) would be insignificant in most instances.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type B commercial thermocouples be +/-0.5% between 870°C and 1700°C. Type B thermocouples can also be supplied to meet special tolerances of +/-0.25%. Tolerances are not specified for type B thermocouples below 870°C.

The suggested upper temperature limit of 1700°C given in the ASTM standard [7] for protected type B thermocouples applies to AWG 24 (0.51mm) wire. This temperature limit applies to thermocouples used in conventional closed-end protecting tubes and it is intended only as a rough guide to the user. It does not apply to thermocouples having compacted mineral oxide insulation.

N Type Thermocouples

Nickel-Chromium-Silicon Alloy Versus Nickel-Silicon-Magnesium Alloy Thermocouples

This type is the newest of the letter-designated thermocouples. It offers higher thermoelectric stability in air above 1000°C and better air-oxidation resistance than types E, J, and K thermocouples. The positive thermoelement, NP, is an alloy that typically contains about 84% nickel, 14 to 14.4% chromium, 1.3 to 1.6% silicon, plus small amounts (usually not exceeding about 0.1%) of other elements such as magnesium, iron, carbon, and cobalt. The negative thermoelement, NN, is an alloy that typically contains about 95% nickel, 4.2 to 4.6% silicon, 0.5 to 1.5% magnesium, plus minor impurities of iron, cobalt, manganese and carbon totaling about 0.1 to 0.3%. The type NP and NN alloys were known originally [16] as nicrosil and nisil, respectively.

The research reported in NBS Monograph 161 showed that the type N thermocouple may be used down to liquid helium temperatures (about 4°K) but that its Seebeck coefficient becomes very small below 20°K. Its Seebeck coefficient at 20°K is about 2.5uV/°K, roughly one-third that of type E thermocouples which are the most suitable of the letter-designated thermocouples types for measurements down to 20°K. Nevertheless, types NP and NN thermoelements do have a relatively low thermal conductivity and good resistance to corrosion in moist atmospheres at low temperatures.

Type N thermocouples are best suited for use in oxidizing or inert atmospheres. Their suggested upper temperature limit, when used in conventional closed-end protecting tubes, is set at 1260°C by the ASTM [7] for 3.25mm diameter thermoelements. Their maximum upper temperature limit is defined by the melting temperature of the thermoelements, which are nominally 1410°C for type NP and 1340°C for type NN [5]. The thermoelectric stability and physical life of type N thermocouples when used in air at elevated temperatures will depend upon factors such as the temperature, the time at temperature, the diameter of the thermoelements, and the conditions of use. Their thermoelectric stability and oxidation resistance in air have been investigated and compared with those of type K thermocouples by Burley [16], by Burley and others [13,44-47], by Wang and Starr [17,43,48,49], by McLaren and Murdock [33], by Bentley [19], and by Hess [50].

Type N thermocouples, in general, are subject to the same environmental restrictions as types E and K. They are not recommended for use at high temperatures in sulfurous, reducing, or alternately oxidizing and reducing atmospheres unless suitably protected with protecting tubes. They also should not be used in vacuum (at high temperatures) for extended times because the chromium and silicon in the positive thermoelement, a nickel-chromium-silicon alloy, vaporize out of solution and alter the calibration. In addition, their use in atmospheres with low, but not negligible, oxygen content is not recommended, since it can lead to changes in calibration due to the preferential oxidation of chromium in the positive thermoelement. Nevertheless, Wang and Starr [49] studied the performances of type N thermocouples in reducing atmospheres, as well as in stagnant air, at temperatures in the 870°C to 1180°C range and found them to be markedly more stable thermoelectrically than type K thermocouples under similar conditions.

The performance of type N thermocouples fabricated in metal-sheathed, compacted ceramic insulated form also has been the subject of considerable study. Anderson and others [51], Bentley and Morgan [52], and Wang and Bediones [53] have evaluated the high-temperature, thermoelectric stability of thermocouples insulated with magnesium oxide and sheathed in Inconel and in stainless steel. Their studies showed that the thermoelectric instabilities of such assemblies increase rapidly with temperature above 1000°C. It was found also that the smaller the diameter of the sheath the greater the instability. Additionally, thermocouples sheathed in Inconel showed substantially less instability above 1000°C than those sheathed in stainless steel. Bentley and Morgan [52] stressed the importance of using Inconel sheathing with a very low manganese content to achieve the most stable performance. The use of special Ni-Cr based alloys for sheathing to improve the chemical and physical compatibility with the thermoelements also has been investigated by Burley [54-56] and by Bentley [57-60].

Neither thermoelement of a type N thermocouple is extremely sensitive to minor differences in heat treatment (provided that the treatment does not violate any of the restrictions mentioned above). For most general applications, they may be used with the heat treatment routinely given by the wire manufacturer. Bentley [61,62], however, has reported reversible changes in the Seebeck coefficient of type NP and NN thermoelements when heated at temperatures between 200°C and 1000°C. These impose limitations on the accuracy obtainable with type N thermocouples. The magnitude of such changes was found to depend on the source of the thermoelements. Consequently, when the highest accuracy and stability are sought, selective testing of materials, as well as special preparatory heat treatments beyond those given by the manufacturer, will usually be necessary. Bentley's articles [61,62] should be consulted for guidelines and details.

ASTM Standard E230-87 in the 1992 Annual Book of ASTM Standards [7] specifies that the initial calibration tolerances for type N commercial thermocouples be +/-2.2°C or +/-0.75% (whichever is greater) between 0°C and 1250°C. Type N thermocouples can also be supplied to meet special tolerances that are equal to approximately one-half the standard tolerances given above. Tolerances are not specified for type N thermocouples below 0°C.

The suggested upper temperature limit of 1260°C given in the ASTM standard [7] for protected type N thermocouples applies to AWG 8 (3.25mm) wire. It decreases to 1090°C for AWG 14 (1.63mm), 980°C for AWG 20 (0.81mm), 870°C for AWG 24 or 28 (0.51mm or 0.33mm), and 760°C for AWG 30 (0.25mm). These temperature limits apply to thermocouples used in conventional closed-end protecting tubes and they are intended only as a rough guide to the user. They do not apply to hermocouples having compacted mineral oxide insulation.

References

[1] Preston-Thomas, H. The International Temperature Scale of 1990 (ITS-90). *Metrologia* **27**, 3-10; 1990. *ibid.* p. 107.

[2] The International Practical Temperature Scale of 1968, Amended Edition of 1975. *Metrologia* **12**, 7-17, 1976.

[3] Mangum, B. W.; Furukawa, G. T. Guidelines for realizing the International Temperature Scale of 1990 (ITS-90). *Natl. Inst. Stand. Technol. Tech. Note 1265*; 1990 August. 190 p.

[4] The 1976 Provisional 0.5 to 30 K Temperature Scale. *Metrologia* **15**, 65-68; 1979.

[5] ASTM, American Society for Testing and Materials. Manual on the use of thermocouples in temperature measurement. *Special Tech. Publ. 470B*; edited by Benedict, R. P.; Philadelphia: ASTM; 1981. 258p.

[6] Hansen, M.; Anderko, K. Constitution of binary alloys. New York: McGraw-Hill Book Co.; 1958.

[7] ASTM, American Society for Testing and Materials, Standard E230-87, *1992 Annual Book of ASTM Standards*. Vol. **14.03**; Philadelphia: ASTM; 1992. 102-230.

[8] Sparks, L. L.; Powell, R. L.; Hall, W. J. Reference tables for low-temperature thermocouples. *Natl. Bur. Stand. (U.S.) Monogr. 124;* 1972 June. 61p.

[9] Starr, C.D.; Wang, T. P. Effect of oxidation on stability of thermocouples, *Proceedings of the American Society for Testing and Materials* Vol. **63**, 1185-1194; 1963.

[10] Roeser, W. F.; Dahl, A. I. Reference tables for iron-constantan and copper-constantan thermocouples. *J. Res. Natl. Bur. Stand. (U.S.)* **20**, 337-355; RP1080; 1938 March.

[11] Dahl, A. I. Stability of base-metal thermocouples in air from 800 to 2200F. *J. Res. Natl. Bur. Stand. (U.S.)* **24,** 205-224; RP1278; 1940 February.

[12] Sparks, L. L.; Powell, R. L. Low temperatures thermocouples: KP, "normal" silver, and copper versus Au-0.02 at % Fe and Au-0.07 at % Fe. *J. Res. Natl. Bur. Stand. (U.S.)* **76A(3),** 263-283; 1972 May-June.

[13] Burley, N. A.; Hess, R. M.; Howie, C. F.; Coleman, J. A. The nicrosil versus nisil thermocouple: A critical comparison with the ANSI standard letter-designated base-metal thermocouples. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 5, Schooley, J. F., ed.; New York: American Institute of Physics; 1982. 1159-1166.

[14] Potts, J. F. Jr.; McElroy, D. L. The effects of cold working, heat treatment, and oxidation on the thermal emf of nickel-base thermoelements. Herzfeld, C. M.; Brickwedde, F. G.; Dahl, A. I.; Hardy, J. D., ed. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 3, Part 2; New York: Reinhold Publishing Corp.; 1962. 243-264.

[15] Burley, N. A.; Ackland, R. G. The stability of the thermo-emf/ temperature characteristics of nickel-base thermocouples. *Jour. of Australian Inst. of Metals* **12(1)**, 23-31; 1967.

[16] Burley, N. A. Nicrosil and nisil: Highly stable nickel-base alloys for thermocouples. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 4, Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972. 1677-1695.

[17] Wang, T. P.; Starr, C. D. Electromotive force stability of nicrosil-nisil. *Journal of Testing and Evaluation* **8(4)**, 192-198; 1980.

[18] Starr, C. D.; Wang, T. P. Effect of oxidation on stability of thermocouples, *Proceedings of the American Society for Testing and Materials* Vol. **63** 1185-1194; 1963.

[19] Bentley, R. E. Short-term instabilities in thermocouples containing nickel-based alloys. *High Temperatures- High Pressures* **15,** 599-611; 1983.

[20] Kollie, T. G.; Horton, J. L.; Carr, K. R.; Herskovitz, M. B.; Mossman, C. A. Temperature measurement errors with type K (Chromel vs. Alumel) thermocouples due to short-ranged ordering in Chromel. *Rev. Sci. Instrum.* **46**, 1447-1461; 1975.

[21] ASTM, American Society for Testing and Materials, Standard E1159-87, *1992 Annual Book of ASTM Standards*. Vol. **14.03**; Philadelphia: ASTM; 1992. 388-389.

[22] Bedford, R. E.; Ma, C. K.; Barber, C. R.; Chandler, T. R.; Quinn, T. J.; Burns, G. W.; Scroger, M. New reference tables for platinum 10% rhodium/platinum and platinum 13% rhodium/platinum thermocouples. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 4, Part 3, p. 1585; Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972.

[23] Burns, G. W.; Strouse, G. F.; Mangum, B. W.; Croarkin, M. C.; Guthrie, W. F.; Chattle, M. New reference functions for platinum-13% rhodium versus platinum (type R) and platinum-30% rhodium versus platinum-6% rhodium (type B) thermocouples based on the ITS-90. in *Temperature: Its Measurement and Control in Science and Industry;* Vol. 6; Schooley, J. F., ed.; New York: American Institute of Physics; 1992. 559-564.

[24] Glawe, G. E.; Szaniszlo, A. J. Long-term drift of some noble- and refractory-metal thermocouples at 1600K in air, argon, and vacuum. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 4; Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972. 1645-1662.

[25] Walker, B. E.; Ewing, C. T.; Miller, R. R. Thermoelectric instability of some noble metal thermocouples at high temperatures. *Rev. Sci. Instrum.* **33**, 1029-1040; 1962.

[26] Walker, B. E.; Ewing, C. T.; Miller, R. R. Study of the instability of noble metal thermocouples in vacuum. *Rev. Sci. Instrum.* **36**, 601-606; 1965.

[27] Bedford, R. E.; Ma, C. K.; Barber, C. R.; Chandler, T. R.; Quinn, T. J.; Burns, G. W.; Scroger, M. New reference tables for platinum 10% rhodium/platinum and platinum 13% rhodium/platinum thermocouples. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 4; Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972. 1585-1603.

[28] Burns, G. W.; Strouse, G. F.; Mangum, B. W.; Croarkin, M. C.; Guthrie, W. F.; Marcarino, P.; Battuello, M.; Lee, H. K.; Kim, J. C.; Gam, K. S.; Rhee, C.; Chattle, M.; Arai, M.; Sakurai, H.; Pokhodun, A. I.; Moiseeva, N. P.; Perevalova, S. A.; de Groot, M. J.; Zhang, J.; Fan, K.; Wu, S. New reference functions for platinum-10% rhodium versus platinum (type S) thermocouples based on the ITS-90, Part I and Part II. in Temperature: Its Measurement and Control *in Science and Industry;* Vol. 6; Schooley, J. F., ed.; New York: American Institute of Physics; 1992. 537-546.

[29] Bentley, R. E. Changes in Seebeck coefficient of Pt and Pt 10% Rh after use to 1700C in high-purity polycrystalline alumina. *Int. J. Thermophys.* **6(1)**, 83-99; 1985.

[30] McLaren, E. H.; Murdock, E. G. New considerations on the preparation, properties and limitations of the standard thermocouple for thermometry. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 4; Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972. 1543-1560.

[31] McLaren, E. H.; Murdock, E. G. The properties of Pt/PtRh thermocouples for thermometry in the range 0-1100C: I. Basic measurements with standard thermocouples. *National Research Council of Canada Publication APH 2212/NRCC 17407*; 1979.

[32] McLaren, E. H.; Murdock, E. G. The properties of Pt/PtRh thermocouples for thermometry in the range 0-1100C: II. Effect of heat treatment on standard thermocouples. *National Research Council of Canada Publication APH 2213/NRCC 17408*; 1979.

[33] McLaren, E. H.; Murdock, E. G. Properties of some noble and base metal thermocouples at fixed points in the range 0-1100C. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 5; Schooley, J. F., ed.; New York: American Institute of Physics; 1982. 953-975.

[34] Bentley, R. E.; Jones, T. P. Inhomogeneities in type S thermocouples when used to 1064C. *High Temperatures- High Pressures* **12**, 33-45; 1980.

[35] Rhys, D. W.; Taimsalu, P. Effect of alloying additions on the thermoelectric properties of platinum. *Engelhard Tech. Bull.* **10**, 41-47; 1969.

[36] Cochrane, J. Relationship of chemical composition to the electrical properties of platinum. *Engelhard Tech. Bull.* **11**, 58-71; 1969. Also in *Temperature: Its Measurement and Control in Science and Industry;* Vol. 4; Plumb, H. H., ed.; Pittsburgh: Instrument Society of America; 1972. 1619-1632.

[37] Aliotta, J. Effects of impurities on the thermoelectric properties of platinum. *Inst. and Control Systems,* 106-107; March 1972.

[38] Burns, G. W.; Gallagher, J. S. Reference tables for the Pt-30 percent Rh versus Pt-6 percent Rh thermocouple. *J. Res. Natl. Bur. Stand. (U.S.)* **70C,** 89-125; 1966.

[39] Ehringer, H. Uber die lebensdauer von PtRh-thermoelementen. *Metall* **8**, 596-598; 1954.

[40] Acken, J. S. Some properties of platinum-rhodium alloys. *J. Res. Natl. Bur. Stand. (U.S.)* **12,** 249; RP650; 1934.

[41] Hendricks, J. W.; McElroy, D. L. High temperature- high vacuum thermocouple drift tests. *Environmental Quarterly,* 34-38; March 1967.

[42] Zysk, E. D. Platinum metal thermocouples. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 3; Herzfeld, C. M., ed.; New York: Reinhold Publishing Corp.; 1962. Part 2, pp. 135-156.

[43] Starr, C. D.; Wang, T. P. A new stable nickel-base thermocouple. *Journal of Testing and Evaluation* **4(1)**, 42-56; 1976.

[44] Burley, N. A.; Powell, R. L.; Burns, G. W.; Scroger, M. G. The nicrosil versus nisil thermocouple: properties and thermoelectric reference data. *Natl. Bur. Stand. (U.S.) Monogr. 161;* 1978 April. 167p.

[45] Burley, N. A.; Jones, T. P. Practical performance of nicrosil-nisil thermocouples. *Temperature Measurement, 1975;* Billing, B. F.; Quinn, T. J., ed.; London and Bristol: Institute of Physics; 1975. 172-180.

[46] Burley, N. A.; Hess, R. M.; Howie, C. F. Nicrosil and nisil: new nickel-based thermocouple alloys of ultra-high thermoelectric stability. *High Temperatures- High Pressures* **12**, 403-410; 1980.

[47] Burley, N. A.; Cocking, J. L.; Burns, G. W.; Scroger, M. G. The nicrosil versus nisil thermocouple: the influence of magnesium on the thermoelectric stability and oxidation resistance of the alloys. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 5, Schooley, J. F., ed.; New York: American Institute of Physics; 1982. 1129-1145.

[48] Wang, T. P.; Starr, C. D. Nicrosil-nisil thermocouples in production furnaces in the 538C (1000F) to 1177C (2150F) range. *ISA Transactions* **18(4)**, 83-99; 1979.

[49] Wang, T. P.; Starr, C. D. Oxidation resistance and stability of nicrosil-nisil in air and in reducing atmospheres. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 5, Schooley, J. F., ed.; New York: American Institute of Physics; 1982. 1147-1157.

[50] Hess, T. G. Nicrosil-nisil: high-performance thermocouple alloys. *ISA Transactions* **16(3)**, 81-84; 1977.

[51] Anderson, R. L.; Lyons, J. D.; Kollie, T. G.; Christie, W. H.; Eby, R. Decalibration of sheathed thermocouples. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 5., Schooley, J. F., ed.; New York: American Institute of Physics; 1982. 977-1007.

[52] Bentley, R. E.; Morgan, T. L. Ni-based thermocouples in the mineral-insulated metal-sheathed format: thermoelectric instabilities to 1100C. J. *Phys. E: Sci. Instrum.* **19**, 262-268; 1986.

[53] Wang, T. P.; Bediones, D. 10,000 hr. stability test of types K, N, and a Ni-Mo/Ni-Co thermocouple in air and short-term tests in reducing atmospheres. *Temperature: Its Measurement and Control in Science and Industry;* Vol. 6; Schooley, J. F., ed.; New York: American Institute of Physics; 1992. 595-600.

[54] Burley, N. A. N-CLAD-N: A novel advanced type N integrally-sheathed thermocouple of ultra-high thermoelectric stability. *High Temperatures- High Pressures* **8**, 609-616; 1986.

[55] Burley, N. A. A novel advanced type N integrally-sheathed thermocouple of ultra-high thermoelectric stability. *Thermal and Temperature Measurement in Science and Industry*; 3rd Int. IMEKO Conf.; Sheffield; Sept. 1987. 115-125.

[56] Burley, N. A. 'N-CLAD-N' A novel integrally sheathed thermocouple: optimum design rationale for ultra-high thermoelectric stability. T*emperature: Its Measurement and Control in Science and Industry*; Vol. 6; Schooley, J. F., ed.; New York: American Institute of Physics; 1992. 579-584.

[57] Bentley, R. E. The new nicrosil-sheathed type N MIMS thermocouple: an assessment of the first production batch. *Mater. Australas.* **18(6)**, 16-18; 1986.

[58] Bentley, R. E.; Russell, Nicrosil sheathed mineral-insulated type N thermocouple probes for short-term variable-immersion applications to 1100C. *Sensors and Actuators* **16**, 89-100; 1989.

[59] Bentley, R. E. Irreversible thermoelectric changes in type K and type N thermocouple alloys within nicrosil-sheathed MIMS cable. *J. Phys. D.* **22**, 1908-1915; 1989.

[60] Bentley, R. E. Thermoelectric behavior of Ni-based ID-MIMS thermocouples using the nicrosil-plus sheathing alloy. *Temperature: Its Measurement and Control in Science and Industry*; Vol. 6; Schooley, J. F., ed.; New York: American Institute of Physics; 1992. 585-590.

[61] Bentley, R. E. Thermoelectric hysteresis in nicrosil and nisil. *J. Phys. E: Sci. Instrum.* **20**, 1368-1373; 1987.

[62] Bentley, R. E. Thermoelectric hysteresis in nickel-based thermocouple alloys. *J. Phys. D.* **22**, 1902-1907; 1989.

Using Grounded Junction, Ungrounded Junction, and Exposed Junction Thermocouples

This appendix describes the types of thermocouples available, and explains the trade-offs in using them with the NI8u module.

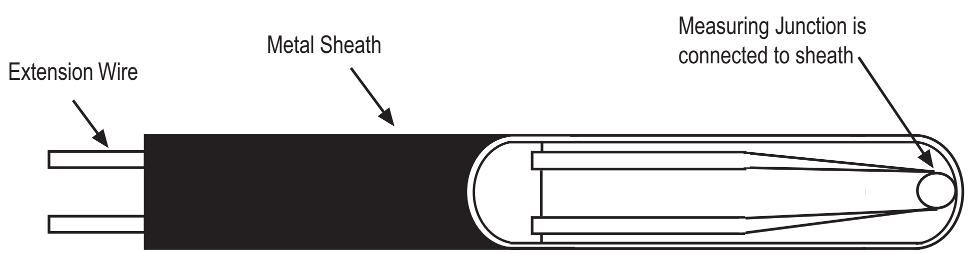
Thermocouple Types

There are three (3) types of thermocouple junctions:

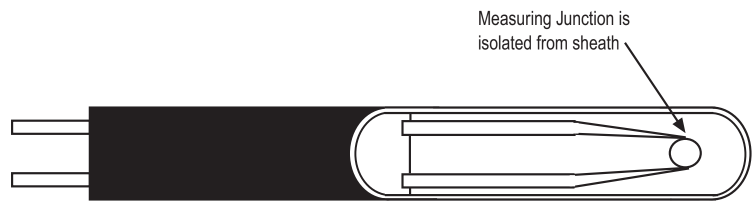
- Grounded Junction - The measuring junction is physically connected to the protective sheath forming a completely sealed integral junction. If the sheath is metal (or electrically conductive) then there is electrical continuity between the junction and sheath. The junction is protected from corrosive or erosive conditions. The response time approaches that of the exposed junction type.
- Ungrounded Junction - The measuring junction is electrically isolated from the protective metal sheath. This may also be referred to as an insulated junction. This type is often used where noise would affect the reading and for frequent or rapid temperature cycling. The response time is longer than the grounded junction.
- Exposed Junction - The measuring junction does not have a protective metal sheath so it is exposed. This junction style provides the fastest response time but leaves the thermocouple wires unprotected against corrosive or mechanical damage.

The illustration that follows shows each of the three (3) thermocouple types.

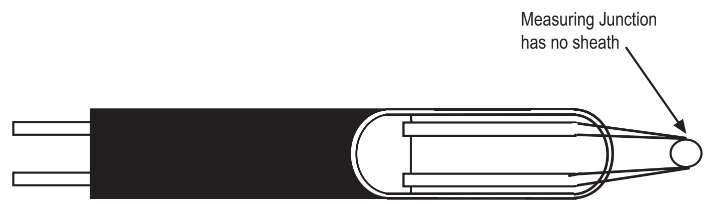
Grounded Junction



Ungrounded (Insulated) Junction



Exposed Junction



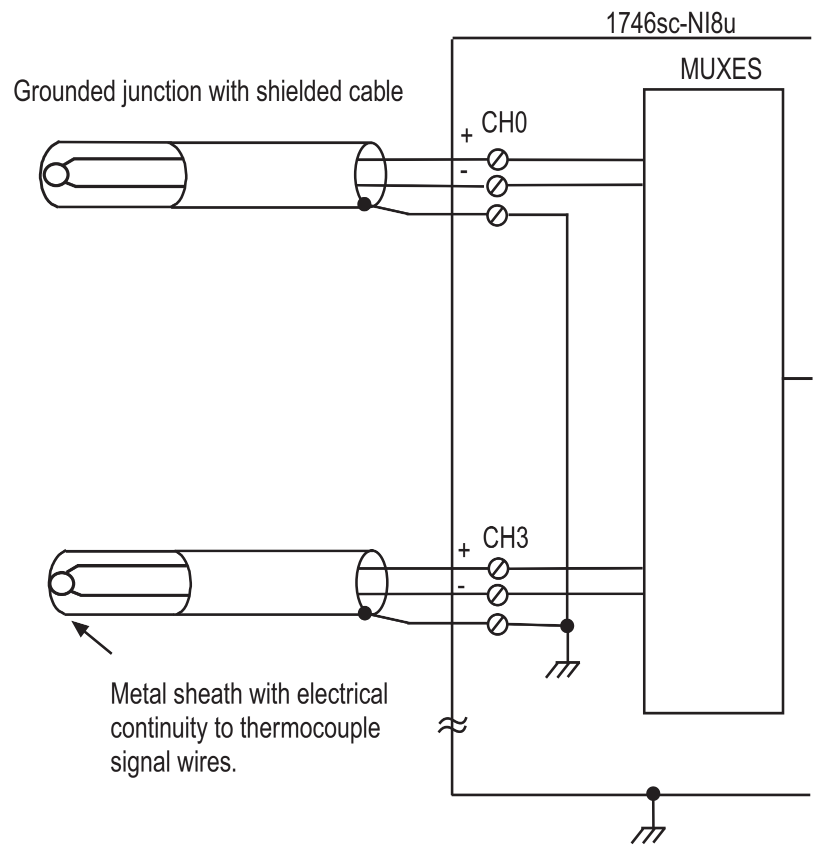
Isolation

The NI8u module provides 12.5 VDC electrical isolation channel to channel, 500 VDC electrical isolation channel to chassis ground, and 500 VDC electrical isolation channel to backplane. Care must be taken when choosing a thermocouple type, and connecting it from the environment being measured to the NI8u module. If adequate precautions are not taken for a given thermocouple type, the electrical isolation of the NI8u module may be compromised.

Grounded Junction Thermocouples

As shown in the illustration that follows, the shield input terminals are connected together, which are then connected to chassis ground. Using grounded junction thermocouples with electrically conductive sheaths, removes the thermocouple signal to chassis ground isolation of the module. This is inherent to the thermocouple construction. In addition, if multiple grounded junction thermocouples are used, the module's channel to channel isolation is removed since there is no isolation between signal and sheath, and the sheaths are tied together. It should be noted that the isolation is removed even if the sheaths are connected to chassis ground at a location other than the module, since the module is connected to chassis ground.

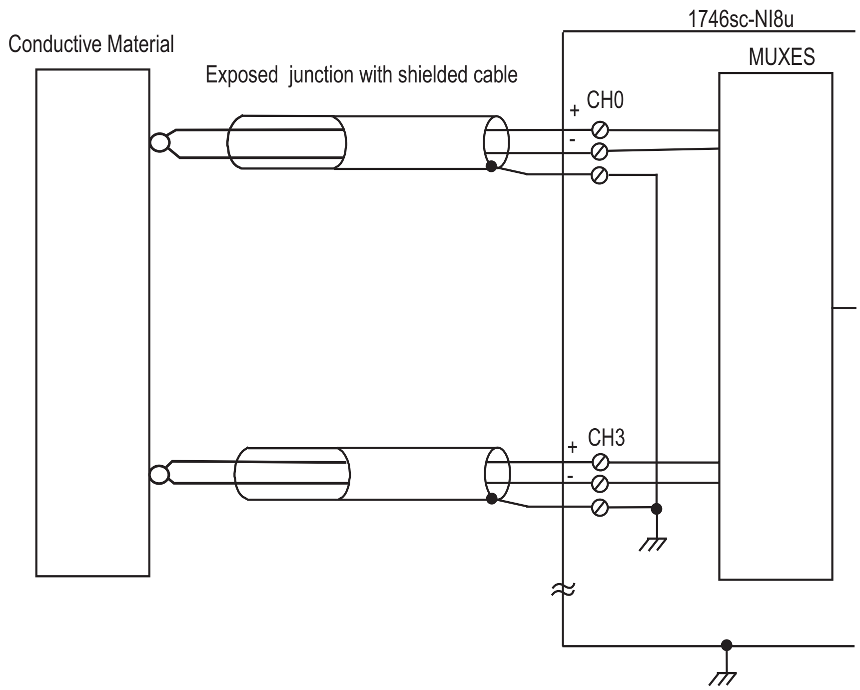
For grounded junction thermocouples it is recommended that they have protective sheathes made of electrically insulated material (e.g. ceramic), or the metal protective sheaths be floated. The metal sheaths would need to be floated with respect to any path to chassis ground or to another thermocouple metal sheath. This means the metal sheath must be insulated from electrically conductive process material, and have all connections to chassis ground broken. It should be noted that a floated sheath may result in a less noise immune thermocouple signal.



Exposed Junction Thermocouples

As shown in the illustration that follows, using exposed junction thermocouples may result in removal of channel to channel isolation. This may occur if multiple exposed thermocouples are in direct contact with electrically conductive process material. To prevent violation of channel to channel isolation:

- For multiple exposed thermocouples, do not allow the measuring junction of the thermocouple to make direct contact with electrically conductive process material.
- Use a single exposed junction thermocouple with multiple ungrounded junction thermocouples.
- Use all ungrounded junction thermocouple instead of the exposed junction type.



Getting Technical Assistance

If you need technical assistance, please review the information in Chapter 6, “Testing Your Module,” before calling your local distributor of Spectrum Controls.

Note that your module contains electronic components which are susceptible to damage from electrostatic discharge (ESD). An electrostatic charge can accumulate on the surface of ordinary plastic wrapping or cushioning material. **In the unlikely event that the module should need to be returned to Spectrum Controls, please ensure that the unit is enclosed in approved ESD packaging (such as static-shielding / metallized bag or black conductive container)**. Spectrum Controls reserves the right to void the warranty on any unit that is improperly packaged for shipment.

For further information or assistance, please contact your local distributor or call Spectrum Controls Customer Satisfaction department at (425) 746-9481 from 8:00 A.M. to 5:00 P.M. Pacific Time.

Declaration of Conformity

Available upon request.

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