Allen-Bradley

MicroLogix™ 1200 Thermocouple/mV Input Module

(Catalog Number 1762-IT4)

User Manual

Rockwell Automation

Important User Information

Because of the variety of uses for the products described in this publication, those responsible for the application and use of these products must satisfy themselves that all necessary steps have been taken to assure that each application and use meets all performance and safety requirements, including any applicable laws, regulations, codes and standards. In no event will Allen-Bradley be responsible or liable for indirect or consequential damage resulting from the use or application of these products.

Any illustrations, charts, sample programs, and layout examples shown in this publication are intended solely for purposes of example. Since there are many variables and requirements associated with any particular installation, Allen-Bradley does not assume responsibility or liability (to include intellectual property liability) for actual use based upon the examples shown in this publication.

Allen-Bradley publication SGI-1.1, *Safety Guidelines for the Application, Installation and Maintenance of Solid-State Control* (available from your local Allen-Bradley office), describes some important differences between solid-state equipment and electromechanical devices that should be taken into consideration when applying products such as those described in this publication.

Throughout this publication, notes may be used to make you aware of safety considerations. The following annotations and their accompanying statements help you to identify a potential hazard, avoid a potential hazard, and recognize the consequences of a potential hazard:

WARNING	Identifies information about practices or circumstances that can cause an explosion in a hazardous environment, which may lead to personal injury or death, property damage, or economic loss.
ATTENTION	Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss.
IMPORTANT	Identifies information that is critical for successful application and understanding of the product.

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Glossary

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Read this preface to familiarize yourself with the rest of the manual. This preface covers the following topics:

- who should use this manual
- how to use this manual
- related publications
- conventions used in this manual
- Rockwell Automation support

Who Should Use This Manual

Use this manual if you are responsible for designing, installing, programming, or troubleshooting control systems that use Allen-Bradley MicroLogix™ 1200.

How to Use This Manual

As much as possible, we organized this manual to explain, in a task-by-task manner, how to install, configure, program, operate and troubleshoot a control system using the 1762-IT4.

Manual Contents

If you want...	See
An overview of the thermocouple/mV input module	Chapter 1
Installation and wiring guidelines	Chapter 2
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Specifications for the input module	Appendix A
Information on understanding two's complement binary numbers	Appendix B
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An example of configuration using RSLogix 500	Appendix E

Related Documentation

The table below provides a listing of publications that contain important information about MicroLogix 1200 systems.

For	Read this document	Document number
A user manual containing information on how to install, use and program your MicroLogix 1200 controller	MicroLogix™ 1200 User Manual	1762-UM001
An overview of the MicroLogix 1200 System, including 1762 Expansion I/O.	MicroLogix™ 1200 Technical Data	1762-TD001
Information on the MicroLogix 1200 instruction set.	MicroLogix 1200 and MicroLogix 1500 Programmable Controllers Instruction Set Reference Manual	1762-RM001
In-depth information on grounding and wiring Allen-Bradley programmable controllers.	Allen-Bradley Programmable Controller Grounding and Wiring Guidelines	1770-4.1

If you would like a manual, you can:

- download a free electronic version from the internet at **www.theautomationbookstore.com**
- purchase a printed manual by:
  – contacting your local distributor or Rockwell Automation representative
  – visiting **www.theautomationbookstore.com** and placing your order
  – calling 1.800.963.9548 (USA/Canada) or 001.330.725.1574 (Outside USA/Canada)

Conventions Used in This Manual

The following conventions are used throughout this manual:

- Bulleted lists (like this one) provide information not procedural steps.
- Numbered lists provide sequential steps or hierarchical information.
- *Italic* type is used for emphasis.

Rockwell Automation Support

Rockwell Automation offers support services worldwide, with over 75 Sales/Support Offices, 512 authorized distributors and 260 authorized Systems Integrators located throughout the United States alone, plus Rockwell Automation representatives in every major country in the world.

Local Product Support

Contact your local Rockwell Automation representative for:

- sales and order support
- product technical training
- warranty support
- support service agreement

Technical Product Assistance

If you need to contact Rockwell Automation for technical assistance, please review the information in Chapter 4, *Diagnostics and Troubleshooting* first. Then call your local Rockwell Automation representative.

Your Questions or Comments on the Manual

If you find a problem with this manual, please notify us. If you have any suggestions for how this manual could be made more useful to you, please contact us at the address below:

Rockwell Automation
Automation Control and Information Group
Technical Communication, Dept. A602V
P.O. Box 2086
Milwaukee, WI 53201-2086

Overview

This chapter describes the 1762-IT4 Thermocouple/mV Input Module and explains how the module reads thermocouple or millivolt analog input data. Included is information about:

- the module's hardware and diagnostic features
- system and module operation
- calibration

General Description

The thermocouple/mV input module supports thermocouple and millivolt signal measurement. It digitally converts and stores thermocouple and/or millivolt analog data from any combination of up to four thermocouple or millivolt analog sensors. Each input channel is individually configurable via software for a specific input device, data format and filter frequency, and provides open-circuit, over-range and under-range detection and indication.

Thermocouple/mV Inputs and Ranges

The table below defines thermocouple types and their associated full-scale temperature ranges. The second table lists the millivolt analog input signal ranges that each channel will support. To determine the practical temperature range your thermocouple supports, see the specifications in Appendix A.

Thermocouple Type	°C Temperature Range	°F Temperature Range
J	-210 to +1200°C	-346 to +2192°F
K	-270 to +1370°C	-454 to +2498°F
T	-270 to +400°C	-454 to +752°F
E	-270 to +1000°C	-454 to +1832°F
R	0 to +1768°C	+32 to +3214°F
S	0 to +1768°C	+32 to +3214°F
B	+300 to +1820°C	+572 to +3308°F
N	-210 to +1300°C	-346 to +2372°F
C	0 to +2315°C	+32 to + 4199°F

Millivolt Input Type	Range
± 50 mV	-50 to +50 mV
± 100 mV	-100 to +100 mV

Data Formats

The data can be configured on board each module as:

- engineering units x 1
- engineering units x 10
- scaled-for-PID
- percent of full-scale
- raw/proportional data

Filter Frequencies

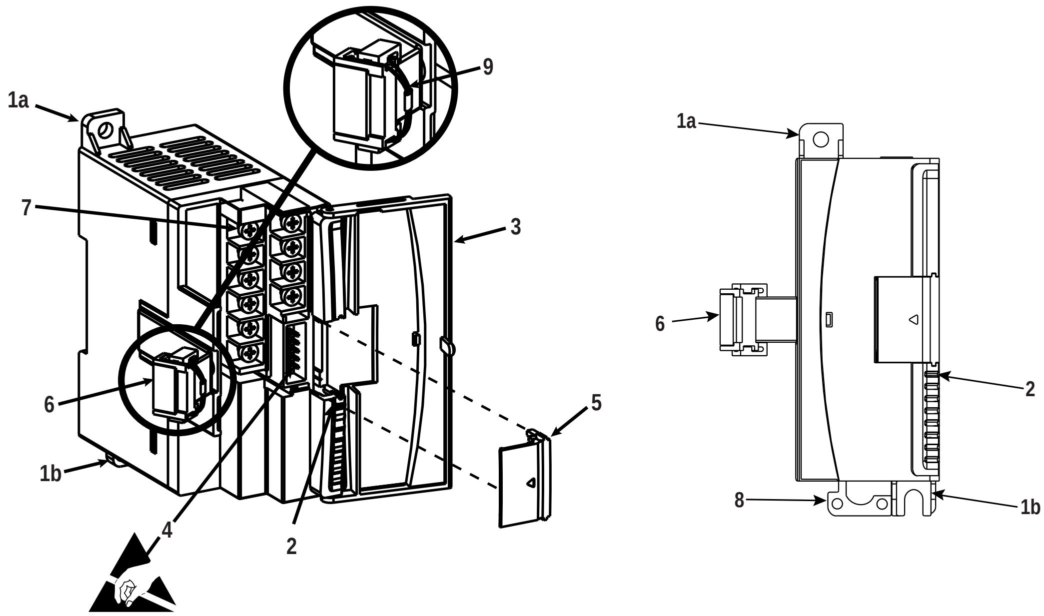
The module uses a digital filter that provides high frequency noise rejection for the input signals. The filter is programmable, allowing you to select from six different filter frequencies for each channel:

- 10 Hz
- 50 Hz
- 60 Hz
- 250 Hz
- 500 Hz
- 1000 Hz

Hardware Features

Channels are wired as differential inputs. A cold junction compensation (CJC) sensor is attached to the terminal block to enable accurate readings from each channel. The sensor compensates for offset voltages introduced into the input signal as a result of the cold-junction where the thermocouple wires are connected to the module.

The illustration below shows the module's hardware features.



Item	Description
1a	upper panel mounting tab
1b	lower panel mounting tab
2	power diagnostic LED
3	module door with terminal identification label
5	bus connector cover
6	flat ribbon cable with bus connector (female)
7	terminal block
8	DIN rail latch
9	pull loop

General Diagnostic Features

The module contains a diagnostic LED that helps you identify the source of problems that may occur during power-up or during normal channel operation. The LED indicates both status and power. Power-up and channel diagnostics are explained in Chapter 4, *Diagnostics and Troubleshooting*.

System Overview

The modules communicate to the controller through the bus interface. The modules also receive 5 and 24V dc power through the bus interface.

System Operation

At power-up, the module performs a check of its internal circuits, memory, and basic functions. During this time, the module status LED remains off. If no faults are found during power-up diagnostics, the module status LED is turned on.

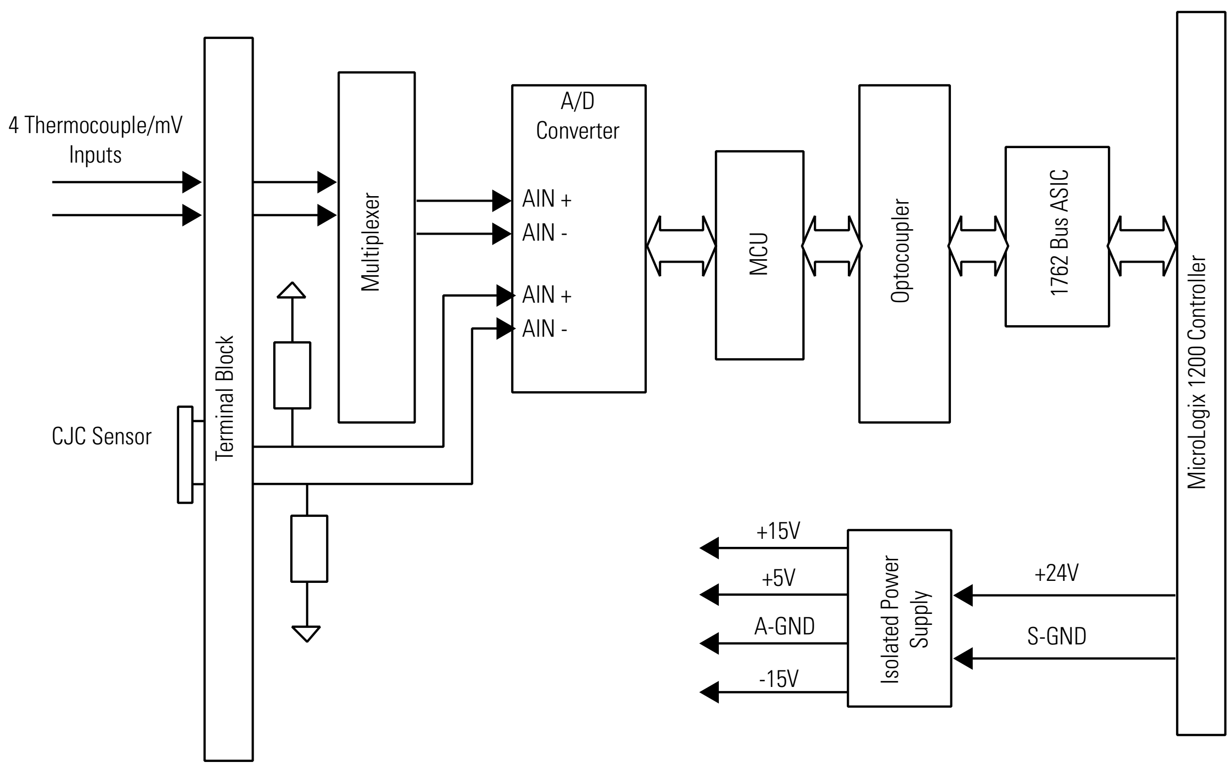
After power-up checks are complete, the module waits for valid channel configuration data. If an invalid configuration is detected, the module generates a configuration error. Once a channel is properly configured and enabled, it continuously converts the thermocouple or millivolt input to a value within the range selected for that channel.

Each time a channel is read by the input module, that data value is tested by the module for an over-range, under-range, open-circuit, or “input data not valid” condition. If such a condition is detected, a unique bit is set in the channel status word. The channel status word is described in Input Data File on page 3-2.

Using the module image table, the controller reads the two’s complement binary converted thermocouple or millivolt data from the module. This typically occurs at the end of the program scan or when commanded by the control program. If the controller and the module determine that the data transfer has been made without error, the data is used in the control program.

Module Operation

When the module receives a differential input from an analog device, the module's circuitry multiplexes the input into an A/D converter. The converter reads the signal and converts it as required for the type of input. The module also continuously samples the CJC sensor and compensates for temperature changes at the terminal block cold junction, between the thermocouple wire and the input channel. See the block diagram below.



Each channel can receive input signals from a thermocouple or millivolt analog input device, depending upon how you configured the channel.

When configured for thermocouple input types, the module converts the analog input voltages into cold-junction compensated and linearized digital temperature readings. The module uses the National Institute of Standards and Technology (NIST) ITS-90 standard for linearization for all thermocouple types (J, K, T, E, R, S, B, N, C).

When configured for millivolt inputs, the module converts the analog values directly into digital counts.

Module Field Calibration

The module provides autocalibration, which compensates for offset and gain drift of the A/D converter caused by a temperature change within the module. An internal, high-precision, low drift voltage and system ground reference is used for this purpose. The input module performs autocalibration when a channel is initially enabled. In addition, you can program the module to perform a calibration cycle once every 5 minutes. See Selecting Enable/Disable Cyclic Calibration (Word 4, Bit 0) on page 3-14 for information on configuring the module to perform periodic autocalibration.

Installation and Wiring

This chapter tells you how to:

- determine the power requirements for the modules
- avoid electrostatic damage
- install the module
- wire the module's terminal block
- wire input devices

Compliance to European Union Directives

This product is approved for installation within the European Union and EEA regions. It has been designed and tested to meet the following directives.

EMC Directive

The 1762-IT4 module is tested to meet Council Directive 89/336/EEC Electromagnetic Compatibility (EMC) and the following standards, in whole or in part, documented in a technical construction file:

- EN 50081-2
  EMC – Generic Emission Standard, Part 2 - Industrial Environment

- EN 50082-2
  EMC – Generic Immunity Standard, Part 2 - Industrial Environment

This product is intended for use in an industrial environment.

Low Voltage Directive

This product is tested to meet Council Directive 73/23/EEC Low Voltage, by applying the safety requirements of EN 61131-2 Programmable Controllers, Part 2 – Equipment Requirements and Tests.

For specific information required by EN61131-2, see the appropriate sections in this publication, as well as the following Allen-Bradley publications:

- *Industrial Automation, Wiring and Grounding Guidelines for Noise Immunity*, publication 1770-4.1
- *Automation Systems Catalog*, publication B113

Power Requirements

The module receives power through the bus interface from the +5V dc/+24V dc system power supply. The maximum current drawn by the module is shown in the table below.

Module Current Draw	at 5V dc	at 24V dc
	40 mA	50 mA

General Considerations

1762 I/O is suitable for use in an industrial environment when installed in accordance with these instructions. Specifically, this equipment is intended for use in clean, dry environments (Pollution degree 2[(1)]) and to circuits not exceeding Over Voltage Category II[(2)] (IEC 60664-1).[(3)]

(1) Pollution Degree 2 is an environment where, normally, only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation shall be expected.

(2) Over Voltage Category II is the load level section of the electrical distribution system. At this level transient voltages are controlled and do not exceed the impulse voltage capability of the product's insulation.

(3) Pollution Degree 2 and Over Voltage Category II are International Electrotechnical Commission (IEC) designations.

Hazardous Location Considerations

This equipment is suitable for use in Class I, Division 2, Groups A, B, C, D or non-hazardous locations only. The following WARNING statement applies to use in hazardous locations.

WARNING

EXPLOSION HAZARD

- Substitution of components may impair suitability for Class I, Division 2.
- Do no replace components or disconnect equipment unless power has been switched off or the area is known to be non-hazardous.
- Do not connect or disconnect components unless power has been switched off or the area is known to be non-hazardous.
- This product must be installed within an enclosure.
- All wiring must comply with N.E.C. article 501-4(b).

Prevent Electrostatic Discharge

ATTENTION

Electrostatic discharge can damage integrated circuits or semiconductors if you touch bus connector pins. Follow these guidelines when you handle the module:

- Touch a grounded object to discharge static potential.
- Wear an approved wrist-strap grounding device.
- Do not touch the bus connector or connector pins.
- Do not touch circuit components inside the module.
- If available, use a static-safe work station.
- When not in use, keep the module in its static-shield box.

Remove Power

ATTENTION

Remove power before removing or installing this module. When you remove or install a module with power applied, an electrical arc may occur. An electrical arc can cause personal injury or property damage by:

- sending an erroneous signal to your system's field devices, causing unintended machine motion
- causing an explosion in a hazardous environment
- causing permanent damage to the module's circuitry

Electrical arcing causes excessive wear to contacts on both the module and its mating connector. Worn contacts may create electrical resistance.

Selecting a Location

Reducing Noise

Most applications require installation in an industrial enclosure to reduce the effects of electrical interference. Analog inputs are highly susceptible to electrical noise. Electrical noise coupled to the analog inputs will reduce the performance (accuracy) of the module.

Group your modules to minimize adverse effects from radiated electrical noise and heat. Consider the following conditions when selecting a location for the analog module. Position the module:

- away from sources of electrical noise such as hard-contact switches, relays, and AC motor drives
- away from modules which generate significant radiated heat. Refer to the module's heat dissipation specification.

In addition, route shielded, twisted-pair analog input wiring away from any high voltage I/O wiring.

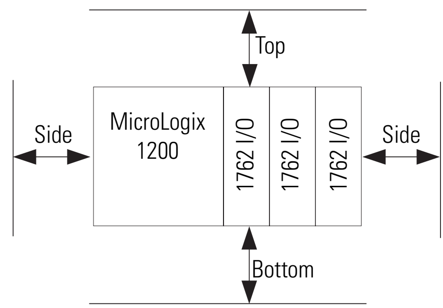
Mounting

ATTENTION

Do not remove protective debris strip until after the module and all other equipment near the module is mounted and wiring is complete. Once wiring is complete and the module is free of debris, carefully remove protective debris strip. Failure to remove strip before operating can cause overheating.

Minimum Spacing

Maintain spacing from enclosure walls, wireways, adjacent equipment, etc. Allow 50.8 mm (2 in.) of space on all sides for adequate ventilation, as shown:



TIP

1762 expansion I/O may be mounted horizontally only.

ATTENTION

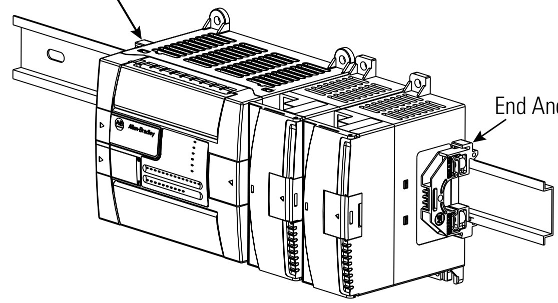
During panel or DIN rail mounting of all devices, be sure that all debris (metal chips, wire strands, etc.) is kept from falling into the module. Debris that falls into the module could cause damage when power is applied to the module.

DIN Rail Mounting

The module can be mounted using the following DIN rails: 35 x 7.5 mm (EN 50 022 - 35 x 7.5) or 35 x 15 mm (EN 50 022 - 35 x 15).

Before mounting the module on a DIN rail, close the DIN rail latch. Press the DIN rail mounting area of the module against the DIN rail. The latch will momentarily open and lock into place.

Use DIN rail end anchors (Allen-Bradley part number 1492-EA35 or 1492-EAH35) for environments with vibration or shock concerns.

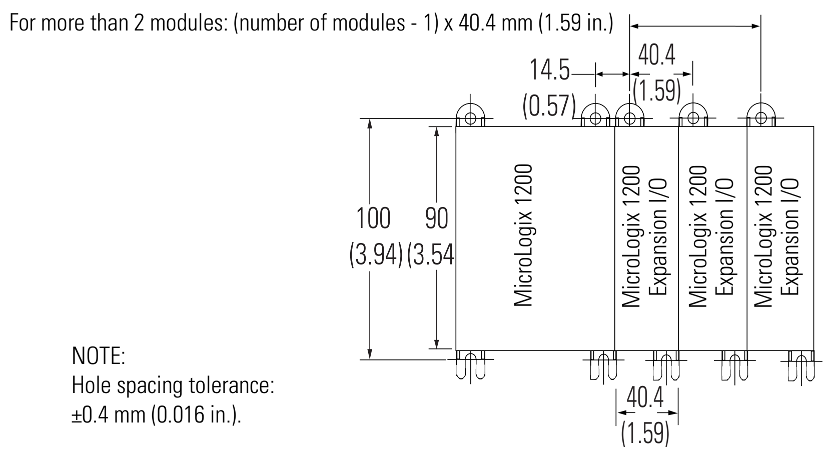


TIP

For environments with extreme vibration and shock concerns, use the panel mounting method described below, instead of DIN rail mounting.

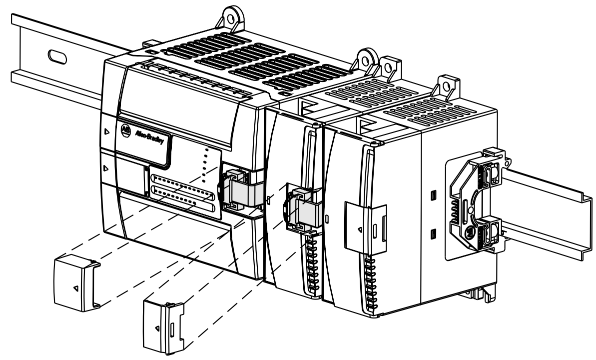
Panel Mounting

Use the dimensional template shown below to mount the module. The preferred mounting method is to use two M4 or #8 panhead screws per module. M3.5 or #6 panhead screws may also be used, but a washer may be needed to ensure a good ground contact. Mounting screws are required on every module.



System Assembly

The expansion I/O module is attached to the controller or another I/O module by means of a ribbon cable *after* mounting as shown below.



TIP

Use the pull loop on the connector to disconnect modules. Do not pull on the ribbon cable.

ATTENTION

EXPLOSION HAZARD

- In Class I, Division 2 applications, the bus connector must be fully seated and the bus connector cover must be snapped in place.
- In Class I, Division 2 applications, all modules must be mounted in direct contact with each other as shown on page 2-5. If DIN rail mounting is used, an end stop must be installed ahead of the controller and after the last 1762 I/O module.

Field Wiring Connections

General

- Power and input wiring must be in accordance with Class 1, Division 2 wiring methods, Article 501-4(b) of the National Electric Code, NFPA 70, and in accordance with the authority having jurisdiction.
- Channels are isolated from one another by ±10 Vdc maximum.
- If multiple power supplies are used with analog millivolt inputs, the power supply commons must be connected.

Terminal Block

- Do not tamper with or remove the CJC sensor on the terminal block. Removal of the sensor reduces accuracy.
- For millivolt sensors, use Belden 8761 shielded, twisted-pair wire (or equivalent) to ensure proper operation and high immunity to electrical noise.
- For a thermocouple, use the shielded, twisted-pair thermocouple extension lead wires specified by the thermocouple manufacturer. Using the incorrect type of thermocouple extension wire or not following the correct polarity will cause invalid readings.
- To ensures optimum accuracy, limit overall cable impedance by keeping a cable as short as possible. Locate the module as close to input devices as the application permits.

Grounding

ATTENTION

The possibility exists that a grounded or exposed thermocouple can become shorted to a potential greater than that of the thermocouple itself. Due to possible shock hazard, take care when wiring grounded or exposed thermocouples. See Appendix D, Using Thermocouple Junctions.

- This product is intended to be mounted to a well-grounded mounting surface such as a metal panel. Additional grounding connections from the module's mounting tabs or DIN rail (if used) are not required unless the mounting surface cannot be grounded.

- Under normal conditions, the drain wire (shield) should be connected to the metal mounting panel (earth ground). Keep shield connection to earth ground as short as possible.

- Ground the shield drain wire at one end only. The typical location is as follows.

  – For grounded thermocouples or millivolt sensors, this is at the sensor end.
  – For insulated/ungrounded thermocouples, this is at the module end. Contact your sensor manufacturer for additional details.

- If it is necessary to connect the shield drain wire at the module end, connect it to earth ground using a panel or DIN rail mounting screw.

- Refer to *Industrial Automation Wiring and Grounding Guidelines*, Allen-Bradley publication 1770-4.1, for additional information.

Noise Prevention

- Route 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 15.2 cm (6 in.) of separation for every 120V of power.

- Routing field wiring in a grounded conduit can reduce electrical noise.

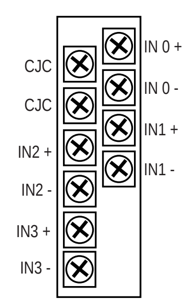
- If field wiring must cross ac or power cables, ensure that they cross at right angles.

- To limit the pickup of electrical noise, keep thermocouple and millivolt signal wires as far as possible from power and load lines.

- If noise persists for a device, try grounding the opposite end of the cable shield. (You can only ground one end at a time.)

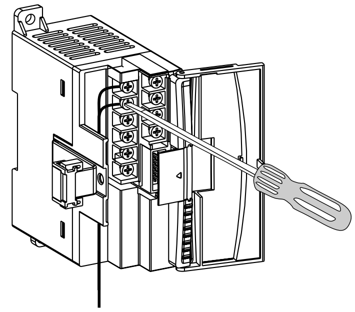
Wiring

Terminal Block Layout



Labeling the Terminals

A write-on label is provided with the module. Mark the identification of each terminal with permanent ink, and slide the label back into the door.



Wiring the Finger-Safe Terminal Block

ATTENTION

Be careful when stripping wires. Wire fragments that fall into a module could cause damage when power is applied. Once wiring is complete, ensure the module is free of all metal fragments.

When wiring the terminal block, keep the finger-safe cover in place.

1. Route the wire under the terminal pressure plate. You can use the stripped end of the wire or a spade lug. The terminals will accept a 6.35 mm (0.25 in.) spade lug.

2. Tighten the terminal screw making sure the pressure plate secures the wire. Recommended torque when tightening terminal screws is 0.904 Nm (8 in-lbs).

3. After wiring is complete, remove the debris shield.

TIP

If you need to remove the finger-safe cover, insert a screw driver into one of the square wiring holes and gently pry the cover off. If you wire the terminal block with the finger-safe cover removed, you will not be able to put it back on the terminal block because the wires will be in the way.

Wire Size and Terminal Screw Torque

Each terminal accepts up to two wires with the following restrictions:

Wire Type		Wire Size	Terminal Screw Torque
Solid	Cu-90°C (194°F)	#14 to #22 AWG	0.904 Nm (8 in-lbs)
Stranded	Cu-90°C (194°F)	#16 to #22 AWG	0.904 Nm (8 in-lbs)

Terminal Door Label

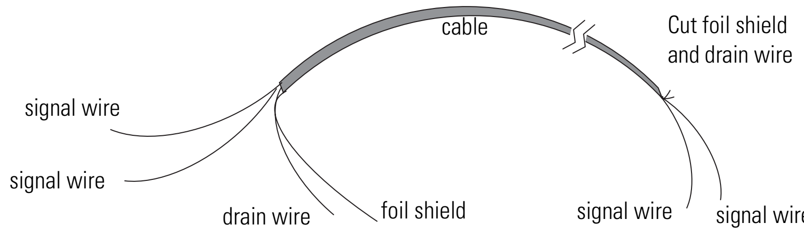
A removable, write-on label is provided with the module. Remove the label from the door, mark your unique identification of each terminal with permanent ink, and slide the label back into the door. Your markings (ID tag) will be visible when the module door is closed.

Wiring the Module

ATTENTION

To prevent shock hazard, care should be taken when wiring the module to analog signal sources. Before wiring any module, disconnect power from the system power supply and from any other source to the module.

After the module is properly installed, follow the wiring procedure on page 2-12, using the proper thermocouple extension cable, or Belden 8761 for non-thermocouple applications.



To wire your module follow these steps.

1. At each end of the cable, strip some casing to expose the individual wires.

2. Trim the signal wires to 2-inch (5 cm) lengths. Strip about 3/16 inch (5 mm) of insulation away to expose the end of the wire.

ATTENTION

Be careful when stripping wires. Wire fragments that fall into a module could cause damage at power up.

3. At one end of the cable, twist the drain wire and foil shield together, bend them away from the cable, and apply shrink wrap. Then earth ground at the preferred location based on the type of sensor you are using. See Grounding on page 2-8.

4. At the other end of the cable, cut the drain wire and foil shield back to the cable and apply shrink wrap.

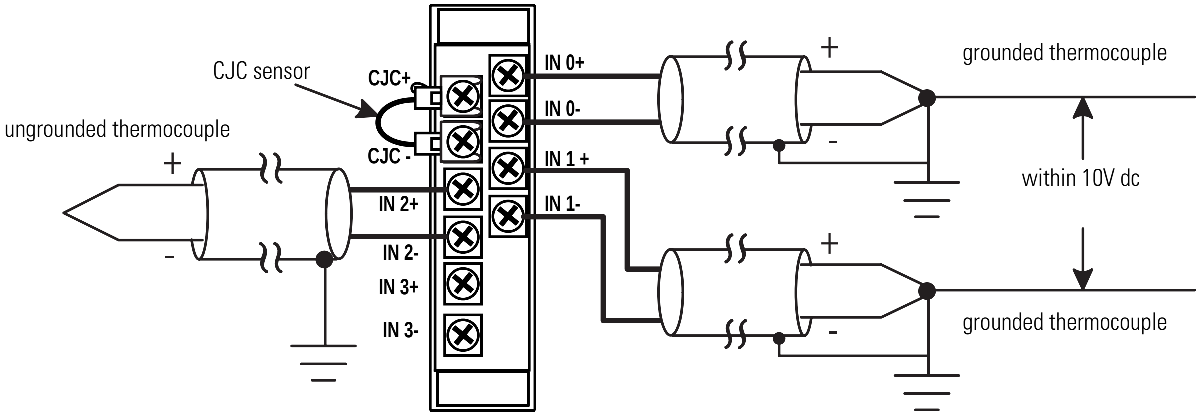
5. Connect the signal wires to the terminal block. Connect the other end of the cable to the analog input device.

6. Repeat steps 1 through 5 for each channel on the module.

TIP

See Appendix D *Using Thermocouple Junctions* for additional information on wiring grounded, ungrounded, and exposed thermocouple types.

Wiring Diagram



TIP

When using an ungrounded thermocouple, the shield must be connected to ground at the module end.

IMPORTANT

When using grounded and/or exposed thermocouples that are touching electrically conductive material, the ground potential between any two channels cannot exceed ±10V dc, or temperature readings will be inaccurate.

Cold Junction Compensation

To obtain accurate readings from each of the channels, the temperature between the thermocouple wire and the input channel must be compensated for. A cold junction compensating thermistor has been integrated in the terminal block. The thermistor must remain installed to retain accuracy.

ATTENTION

Do not remove or loosen the cold junction compensating thermistor assembly. This assembly is critical to ensure accurate thermocouple input readings at each channel. The module will operate in the thermocouple mode, but at reduced accuracy if the CJC sensor is removed. See Determining Open-Circuit Response (Bits 6 and 5) on page 3-9.

If the thermistor assembly is accidentally removed, re-install it by connecting it across the pair of CJC terminals.

Calibration

The thermocouple module is initially calibrated at the factory. The module also has an autocalibration function.

When an autocalibration cycle takes place, the module's multiplexer is set to system ground potential and an A/D reading is taken. The A/D converter then sets its internal input to the module's precision voltage source, and another reading is taken. The A/D converter uses these numbers to compensate for system offset (zero) and gain (span) errors.

Autocalibration of a channel occurs whenever a channel is enabled. You can also program your module to perform cyclic calibration cycles, every five minutes. See Selecting Enable/Disable Cyclic Calibration (Word 4, Bit 0) on page 3-14.

To maintain optimal system accuracy, periodically perform an autocalibration cycle.

IMPORTANT The module does not convert input data while the calibration cycle is in progress following a change in configuration. Module scan times are increased by up to 112 ms during cyclic autocalibration.

Module Data, Status, and Channel Configuration

After installing the 1762-IT4 thermocouple/mV input module, you must configure it for operation using the programming software compatible with the controller (for example, RSLogix 500). Once configuration is complete and reflected in the ladder logic, you need to operate the module and verify its configuration.

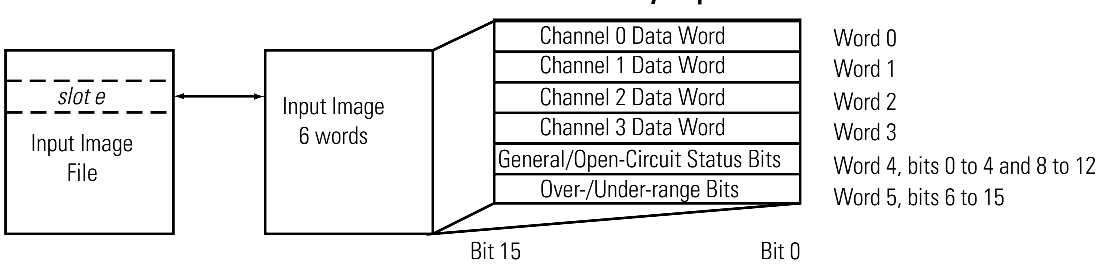
This chapter contains information on the following:

- module memory map
- accessing input image file data
- configuring channels
- determining effective resolution and range
- determining module update time

Module Memory Map

The module uses six input words for data and status bits (input image), and five configuration words.

Memory Map



Accessing Input Image File Data

The input image file represents data words and status words. Input words 0 through 3 hold the input data that represents the value of the analog inputs for channels 0 through 3. These data words are valid only when the channel is enabled and there are no errors. Input words 4 and 5 hold the status bits. To receive valid status information, the channel must be enabled.

You can access the information in the input image file using the programming software data files input screen.

Input Data File

The input data table allows you to access module read data for use in the control program, via word and bit access. The data table structure is shown in table below.

Word/Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	SGN	Analog Input Data Channel 0														
1	SGN	Analog Input Data Channel 1														
2	SGN	Analog Input Data Channel 2														
3	SGN	Analog Input Data Channel 3														
4	Reserved			OC4	OC3	OC2	OC1	OC0	Reserved			S4	S3	S2	S1	S0
5	U0	O0	U1	O1	U2	O2	U3	O3	U4	O4	Reserved					

Input Data Values

Data words 0 through 3 correspond to channels 0 through 3 and contain the converted analog input data from the input device. The most significant bit, bit 15, is the sign bit (SGN).

General Status Bits (S0 to S4)

Bits S0 through S3 of word 4 contain the general status information for channels 0 through 3, respectively. Bit S4 contains general status information for the CJC sensor. If set (1), these bits indicate an error (over- or under-range, open-circuit or input data not valid condition) associated with that channel. The data not valid condition is described below.

Input Data Not Valid Condition

The general status bits S0 to S3 also indicate whether or not the input data for a particular channel, 0 through 3, is being properly converted (valid) by the module. This “invalid data” condition can occur (bit set) when the download of a new configuration to a channel is accepted by the module (proper configuration) but before the A/D converter can provide valid (properly configured) data to the MicroLogix 1200 controller. The following information highlights the bit operation of the Data Not Valid condition.

1. The default and module power-up bit condition is reset (0).

2. The bit condition is set (1) when a new configuration is received and determined valid by the module. The set (1) bit condition

remains until the module begins converting analog data for the previously accepted new configuration. When conversion begins, the bit condition is reset (0). The amount of time it takes for the module to begin the conversion process depends on the number of channels being configured and the amount of configuration data downloaded by the controller.

TIP

If the new configuration is invalid, the bit function remains reset (0) and the module posts a configuration error. See Configuration Errors on page 4-5.

3. If A/D hardware errors prevent the conversion process from taking place, the bit condition is set (1).

Open-Circuit Flag Bits (OC0 to OC4)

Bits OC0 through OC3 of word 4 contain open-circuit error information for channels 0 through 3, respectively. Errors for the CJC sensor are indicated in OC4. The bit is set (1) when an open-circuit condition exists. See Open-Circuit Detection on page 4-4 for more information on open-circuit operation.

Over-Range Flag Bits (O0 to O4)

Over-range bits for channels 0 through 3 and the CJC sensor are contained in word 5, even-numbered bits. They apply to all input types. When set (1), the over-range flag bit indicates an input signal that is at the maximum of its normal operating range for the represented channel or sensor. The module automatically resets (0) the bit when the data value falls below the maximum for that range.

Under-Range Flag Bits (U0 to U4)

Under-range bits for channels 0 through 3 and the CJC sensor are contained in word 5, odd-numbered bits. They apply to all input types. When set (1), the under-range flag bit indicates an input signal that is at the minimum of its normal operating range for the represented channel or sensor. The module automatically resets (0) the bit when the under-range condition is cleared and the data value is within the normal operating range.

Configuring Channels

After module installation, you must configure operation details, such as thermocouple type, temperature units, etc., for each channel. Channel configuration data for the module is stored in the controller configuration file, which is both readable and writable.

The configuration data file is shown below. Bit definitions are provided in Channel Configuration on page 3-4. Detailed definitions of each of the configuration parameters follow the table.

Configuration Data File

The default value of the configuration data is represented by zeros in the data file. The structure of the channel configuration file is shown below.

Word /Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	Enable Channel 0	Data Format Channel 0			Input Type Channel 0				Temperature Units Channel 0	Open-Circuit Condition Channel 0		Not Used	Not Used	Filter Frequency Channel 0		
1	Enable Channel 1	Data Format Channel 1			Input Type Channel 1				Temperature Units Channel 1	Open-Circuit Condition Channel 1		Not Used	Not Used	Filter Frequency Channel 1		
2	Enable Channel 2	Data Format Channel 2			Input Type Channel 2				Temperature Units Channel 2	Open-Circuit Condition Channel 2		Not Used	Not Used	Filter Frequency Channel 2		
3	Enable Channel 3	Data Format Channel 3			Input Type Channel 3				Temperature Units Channel 3	Open-Circuit Condition Channel 3		Not Used	Not Used	Filter Frequency Channel 3		
4	Reserved															Enable/Disable Cyclic Calibration

The structure and bit settings are shown in Channel Configuration on page 3-4.

Channel Configuration

Each channel configuration word consists of bit fields, the settings of which determine how the channel operates. See the table below and the descriptions that follow for valid configuration settings and their meanings.

To Select[1]		Make these bit settings																Decimal Value
		15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
Filter Frequency	10 Hz														1	1	0	6
	60 Hz														0	0	0	0
	50 Hz														0	0	1	1
	250Hz														0	1	1	3
	500 Hz														1	0	0	4
	1 kHz														1	0	1	5
Open Circuit	**Upscale**										0	0						0
	Downscale										0	1						32
	Hold Last State										1	0						64
	Zero										1	1						96
Tempera-ture Units	**Degrees C**									0								0
	Degrees F									1								128
Input Type	**Thermocouple J**					0	0	0	0									0
	Thermocouple K					0	0	0	1									256
	Thermocouple T					0	0	1	0									512
	Thermocouple E					0	0	1	1				Not Used[2]					768
	Thermocouple R					0	1	0	0									1024
	Thermocouple S					0	1	0	1									1280
	Thermocouple B					0	1	1	0									1536
	Thermocouple N					0	1	1	1									1792
	Thermocouple C					1	0	0	0									2048
	-50 to +50 mV					1	0	0	1									2304
	-100 to +100 mV					1	0	1	0									2560
Data Format	**Raw/ Proportional**		0	0	0													0
	Engineering Units		0	0	1													4096
	Engineering Units X 10		1	0	0													16384
	Scaled-for-PID		0	1	0													8192
	Percent Range		0	1	1													12288
Enable Channel	**Disable**	0																0
	Enable	1																-32768

(1) Default values are in bold type and are indicated by zero bit settings. For example, the default filter frequency is 60Hz.

(2) An attempt to write any non-valid (spare) bit configuration into any selection field results in a module configuration error.

Enabling or Disabling a Channel (Bit 15)

You can enable or disable each of the four channels individually using bit 15. The module only scans enabled channels. Enabling a channel forces it to be recalibrated before it measures input data. Disabling a channel sets the channel data word to zero.

TIP

When a channel is not enabled (0), no input is provided to the controller by the A/D converter. This speeds up the response of the active channels, improving performance.

Selecting Data Formats (Bits 14 through 12)

This selection configures channels 0 through 3 to present analog data in any of the following formats:

- Raw/Proportional Data
- Engineering Units x 1
- Engineering Units x 10
- Scaled for PID
- Percent Range

Table 3.1 Channel Data Word Format

Input Type	Data Format						
	Engineering Units x1		Engineering Units x10		Scaled-for-PID	Raw/Proportional Data	Percent Range
	°C	°F	°C	°F			
J	-2100 to +12000	-3460 to +21920	-210 to +1200	-346 to +2192	0 to +16383	-32767 to +32767	0 to +10000
K	-2700 to +13700	-4540 to +24980	-270 to +1370	-454 to +2498	0 to +16383	-32767 to +32767	0 to +10000
T	-2700 to +4000	-4540 to +7520	-270 to +400	-454 to +752	0 to +16383	-32767 to +32767	0 to +10000
E	-2700 to +10000	-4540 to +18320	-270 to +1000	-454 to +1832	0 to +16383	-32767 to +32767	0 to +10000
R	0 to +17680	+320 to 32140	0 to +1768	+32 to 3214	0 to +16383	-32767 to +32767	0 to +10000
S	0 to +17680	+320 to 32140	0 to +1768	+32 to 3214	0 to +16383	-32767 to +32767	0 to +10000
B	+3000 to 18200	+5720 to 32767(1)	+300 to 1820	+572 to 3308	0 to +16383	-32767 to +32767	0 to +10000
N	-2100 to +13000	-3460 to +23720	-210 to +1300	-346 to +2372	0 to +16383	-32767 to +32767	0 to +10000
C	0 to +23150	+320 to 32767(1)	0 to +2315	+32 to 4199	0 to +16383	-32767 to +32767	0 to +10000
±50 mV	-5000 to +5000(2)		-500 to +500(2)		0 to +16383	-32767 to +32767	0 to +10000
±100 mV	-10000 to 10000(2)		-1000 to 1000(2)		0 to +16383	-32767 to +32767	0 to +10000

(1) Type B and C thermocouples cannot be represented in engineering units x1 (°F) above 3276.7 °F; therefore, it will be treated as an over-range error.

(2) When millivolts are selected, the temperature setting is ignored. Analog input date is the same for °C or °F selection.

TIP

The engineering units data formats represent real engineering temperature units provided by the module to the controller. The raw/proportional counts, scaled-for-PID and percent of full-scale data formats may yield the highest effective resolutions, but may also require that you convert channel data to real engineering units in your control program.

Raw/Proportional Data

The value presented to the controller is proportional to the selected input and scaled into the maximum data range allowed by the bit resolution of the A/D converter and filter selected. The raw/proportional data format also provides the best resolution of all the data formats.

If you select the raw/proportional data format for a channel, the data word will be a number between -32767 and +32767. For example, if a type J thermocouple is selected, the lowest temperature of -210°C corresponds to -32767 counts. The highest temperature of 1200°C corresponds to +32767. See Determining Effective Resolution and Range on page 3-14.

Engineering Units x 1

When using this data format for a thermocouple or millivolt input, the module scales the thermocouple or millivolt input data to the actual engineering values for the selected millivolt input or thermocouple type. It expresses temperatures in 0.1°C or 0.1°F units. For millivolt inputs, the module expresses voltages in 0.01 mV units.

TIP

Use the engineering units x 10 setting to produce temperature readings in whole degrees Celsius or Fahrenheit.

The resolution of the engineering units x 1 data format is dependent on the range selected and the filter selected. See Determining Effective Resolution and Range on page 3-14.

Engineering Units x 10

When using a thermocouple input with this data format, the module scales the input data to the actual temperature values for the selected thermocouple type. With this format, the module expresses temperatures in 1°C or 1°F units. For millivolt inputs, the module expresses voltages in 0.1 mV units.

The resolution of the engineering units x 10 data format is dependent on the range selected and the filter selected. See Determining Effective Resolution and Range on page 3-14.

Scaled-for-PID

The value presented to the controller is a signed integer with 0 representing the lower input range and +16383 representing the upper input range.

To obtain the value, the module scales the input signal range to a 0 to +16383 range, which is standard to the PID algorithm for the MicroLogix 1200 and other Allen-Bradley controllers (e.g. SLC). For example, if type J thermocouple is used, the lowest temperature for the thermocouple is -210°C, which corresponds to 0 counts. The highest temperature in the input range, 1200°C, corresponds to +16383 counts.

Percent Range

Input data is presented to the user as a percent of the specified range. The module scales the input signal range to a 0 to +10000 range. For example, using a type J thermocouple, the range -210°C to +1200°C is represented as 0% to 100%. See Determining Effective Resolution and Range on page 3-14.

Selecting Input Type (Bits 11 through 8)

Bits 11 through 8 in the channel configuration word indicate the type of thermocouple or millivolt input device. Each channel can be individually configured for any type of input.

Selecting Temperature Units (Bit 7)

The module supports two different linearized/scaled ranges for thermocouples, degrees Celsius (°C) and degrees Fahrenheit (°F). Bit 7 is ignored for millivolt input types, or when raw/proportional, scaled-for-PID, or percent data formats are used.

IMPORTANT If you are using engineering units x 1 data format and degrees Fahrenheit temperature units, thermocouple types B and C cannot achieve full-scale temperature with 16-bit signed numerical representation. An over-range error will occur for the configured channel if it tries to represent the full-scale value. The maximum representable temperature is 3276.7°F.

Determining Open-Circuit Response (Bits 6 and 5)

An open-circuit condition occurs when an input device or its extension wire is physically separated or open. This can happen if the wire is cut or disconnected from the terminal block.

TIP If the CJC sensor is removed from the module terminal block, its open-circuit bit is set (1) and the module continues to calculate thermocouple readings at reduced accuracy. If an open CJC circuit is detected at power-up, the module uses 25°C as the sensed temperature at that location. If an open CJC circuit is detected during normal operation, the last valid CJC reading is used. An input channel configured for millivolt input is not affected by CJC open-circuit conditions. See Open-Circuit Detection on page 4-4 for additional details.

Bits 6 and 5 define the state of the channel data word when an open-circuit condition is detected for the corresponding channel. The module overrides the actual input data depending on the option that you specify when it detects an open circuit. The open-circuit options are explained in the table on page 3-10.

Table 3.2 Open-Circuit Response Definitions

Response Option	Definition
Upscale	Sets the input data value to full upper scale value of channel data word. The full-scale value is determined by the selected input type and data format.
Downscale	Sets the input data value to full lower scale value of channel data word. The low scale value is determined by the selected input type and data format.
Last State	Sets the input data value to the last input value prior to the detection of the open-circuit.
Zero	Sets the input data value to 0 to force the channel data word to 0.

Selecting Input Filter Frequency (Bits 2 through 0)

The input filter selection field allows you to select the filter frequency for each channel and provides system status of the input filter setting for channels 0 through 3. The filter frequency affects the following, as explained later in this chapter:

- noise rejection characteristics for module inputs
- channel step response
- channel cut-off frequency
- effective resolution
- module update time

Effects of Filter Frequency on Noise Rejection

The filter frequency that you choose for a module channel determines the amount of noise rejection for the inputs. A lower frequency (50 Hz versus 500 Hz) provides better noise rejection and increases effective resolution, but also increases channel update time. A higher filter frequency provides lower noise rejection, but decreases the channel update time and effective resolution.

When selecting a filter frequency, be sure to consider cut-off frequency and channel step response to obtain acceptable noise rejection. Choose a filter frequency so that your fastest-changing signal is below that of the filter’s cut-off frequency.

Common Mode Rejection is better than 115 dB at 50 and 60 Hz, with the 50 and 60 Hz filters selected, respectively, or with the 10Hz filter selected. The module performs well in the presence of common mode noise as long as the signals applied to the user positive and negative input terminals do not exceed the common mode voltage rating (±10V) of the module.

TIP

Improper earth ground may be a source of common mode noise.

Transducer power supply noise, transducer circuit noise, or process variable irregularities may also be sources of normal mode noise.

TIP

The filter frequency of the module's CJC sensors is the lowest filter frequency of any enabled thermocouple type to maximize the trade-offs between effective resolution and channel update time.

Effects of Filter Frequency on Channel Step Response

The selected channel filter frequency determines the channel's step response. The step response is the time required for the analog input signal to reach 100% 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. The channel step response is calculated by a settling time of 3 x (1/filter frequency).

Filter Frequency	Step Response
10 Hz	303 ms
50 Hz	63 ms
60 Hz	53 ms
250 Hz	15 ms
500 Hz	9 ms
1 kHz	7 ms

Channel Cut-Off Frequency

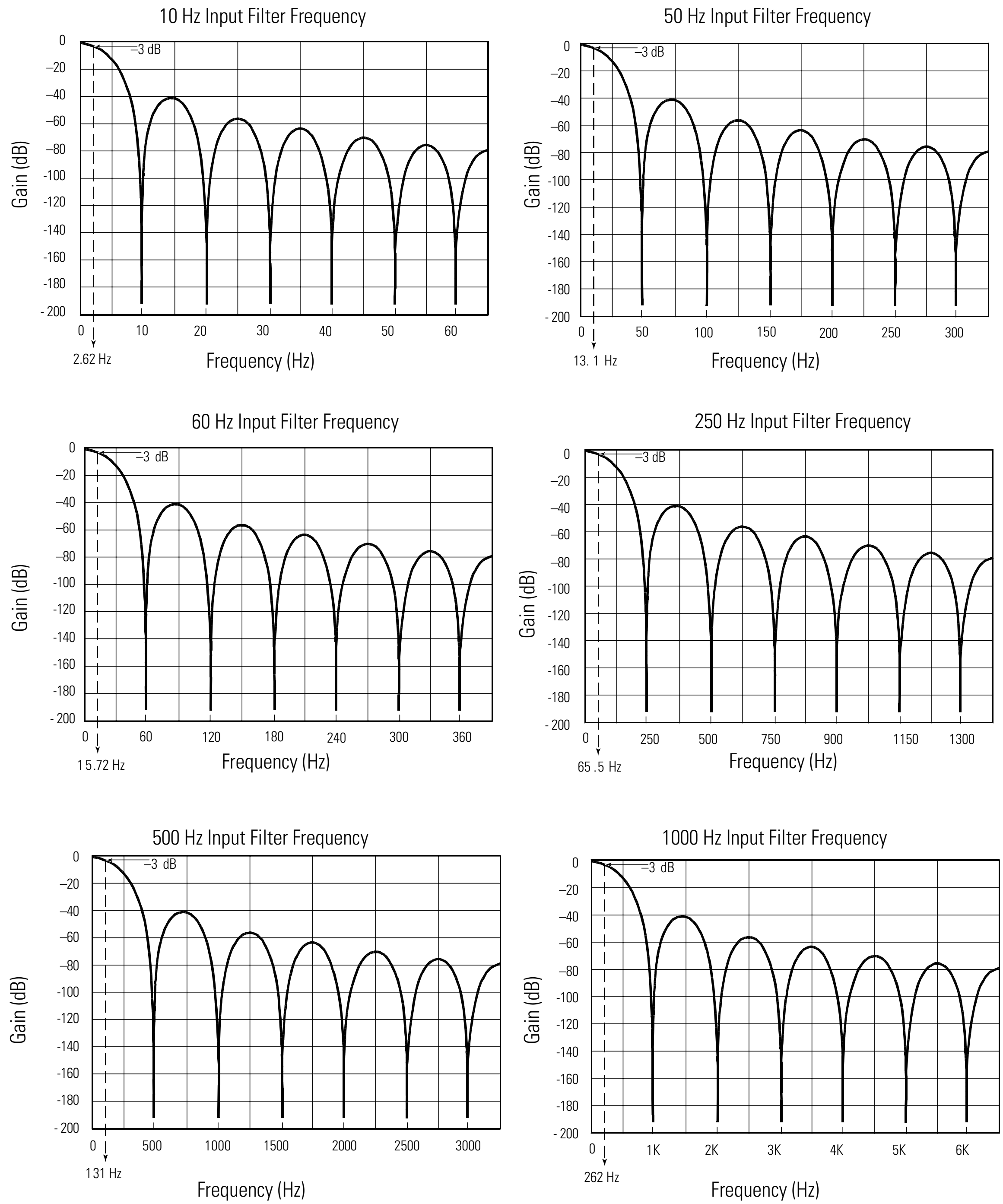
The filter cut-off frequency, -3 dB, is the point on the frequency response curve where frequency components of the input signal are passed with 3 dB of attenuation. The following table shows cut-off frequencies for the supported filters.

Table 3.3 Filter Frequency versus Channel Cut-off Frequency

Filter Frequency	Cut-off Frequency
10 Hz	2.62 Hz
50 Hz	13.1 Hz
60 Hz	15.7 Hz
250 Hz	65.5 Hz
500 Hz	131 Hz
1 kHz	262 Hz

All input 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 on page 3-13.

Figure 3.1 Frequency Response Graphs



The cut-off frequency for each channel is defined by its filter frequency selection. 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 the update time. The cut-off frequency relates to 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 is updated.

Selecting Enable/Disable Cyclic Calibration (Word 4, Bit 0)

Cyclic calibration functions to reduce offset and gain drift errors due to temperature changes within the module. By setting word 4, bit 0 to 0, you can configure the module to perform calibration on all enabled channels. Setting this bit to 1 disables cyclic calibration.

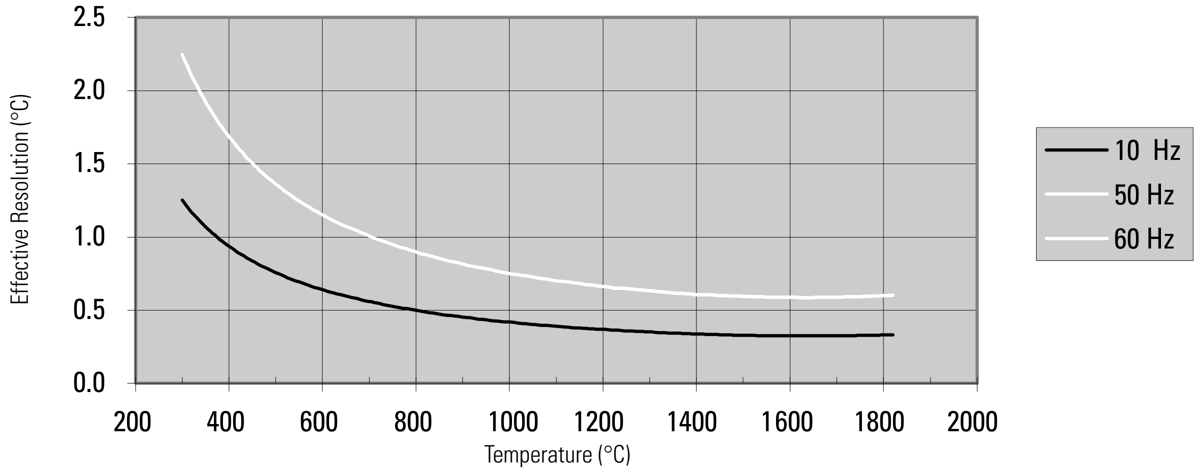
You can program the calibration cycle to occur whenever you desire for systems that allow modifications to the state of this bit via the ladder program. When the calibration function is enabled (bit = 0), a calibration cycle occurs once for all enabled channels. If the function remains enabled, a calibration cycle occurs every five minutes thereafter. The calibration cycle of each enabled channel is staggered over several module scan cycles within the five minute period to limit impact on the system response speed.

See Effects of Autocalibration on Module Update Time on page 3-34.

Determining Effective Resolution and Range

The effective resolution for an input channel depends upon the filter frequency selected for that channel. The following graphs provide the effective resolution for each of the range selections at the six available frequencies. These graphs do not include the affects of unfiltered input noise. Choose the frequency that most closely matches your requirements.

Figure 3.2 Effective Resolution Versus Input Filter Selection for Type B Thermocouples Using 10, 50, and 60 Hz Filters



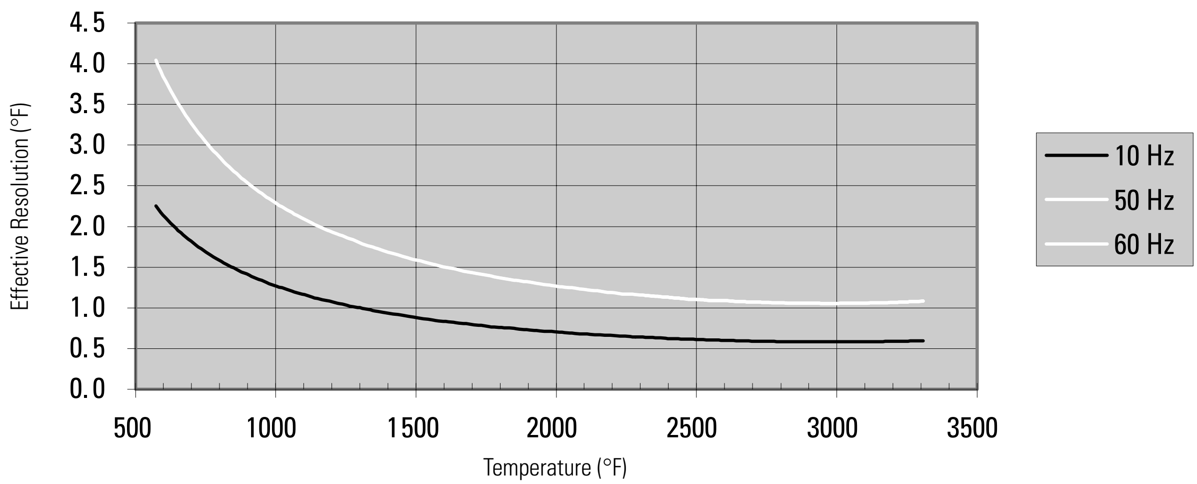
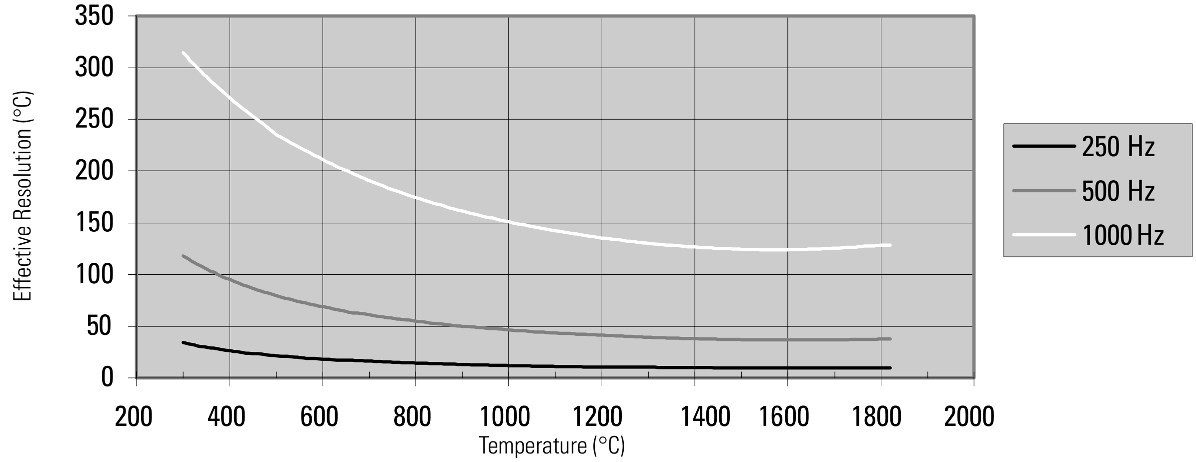


Figure 3.3 Effective Resolution Versus Input Filter Selection for Type B Thermocouples Using 250, 500, and 1k Hz Filters



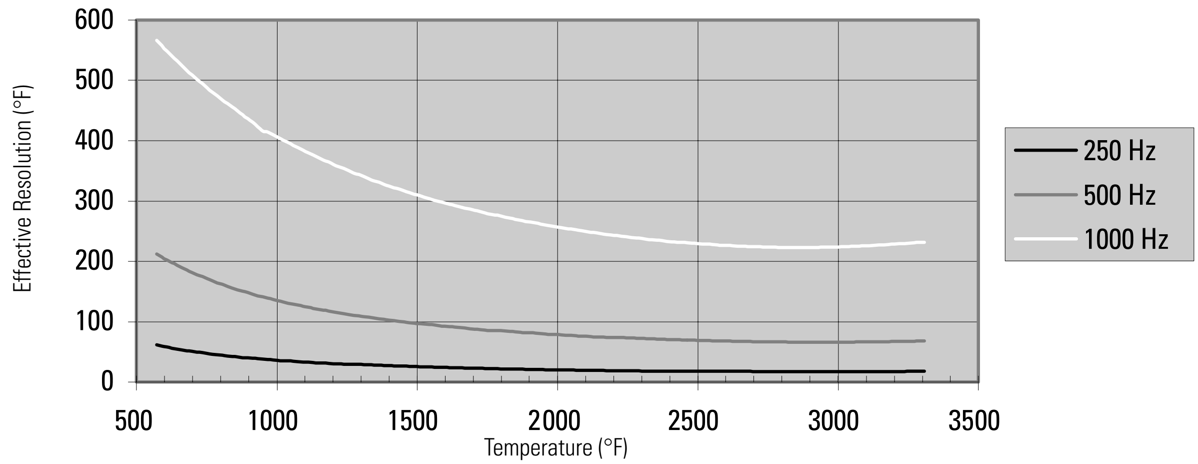
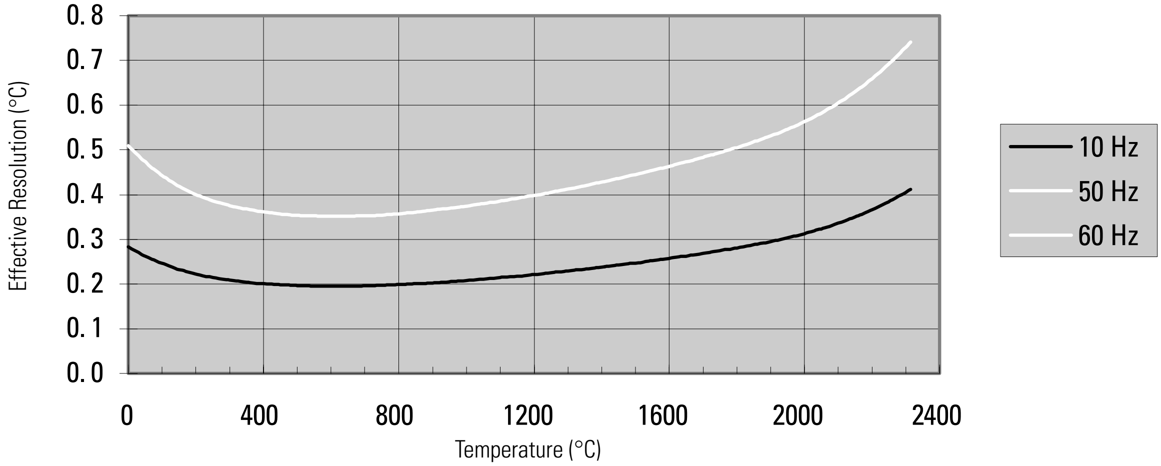


Figure 3.4 Effective Resolution Versus Input Filter Selection for Type C Thermocouples Using 10, 50, and 60 Hz Filters



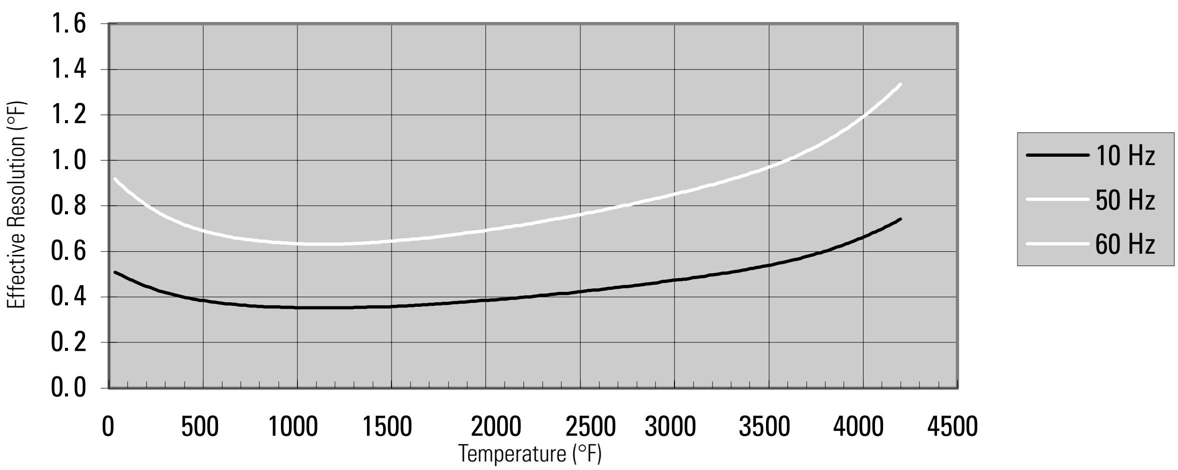
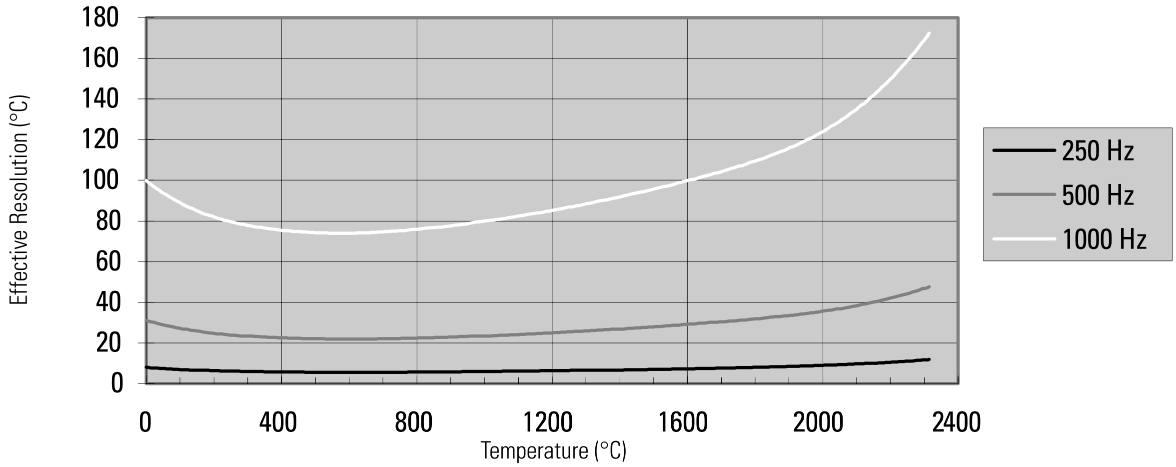


Figure 3.5 Effective Resolution Versus Input Filter Selection for Type C Thermocouples Using 250, 500, and 1k Hz Filters



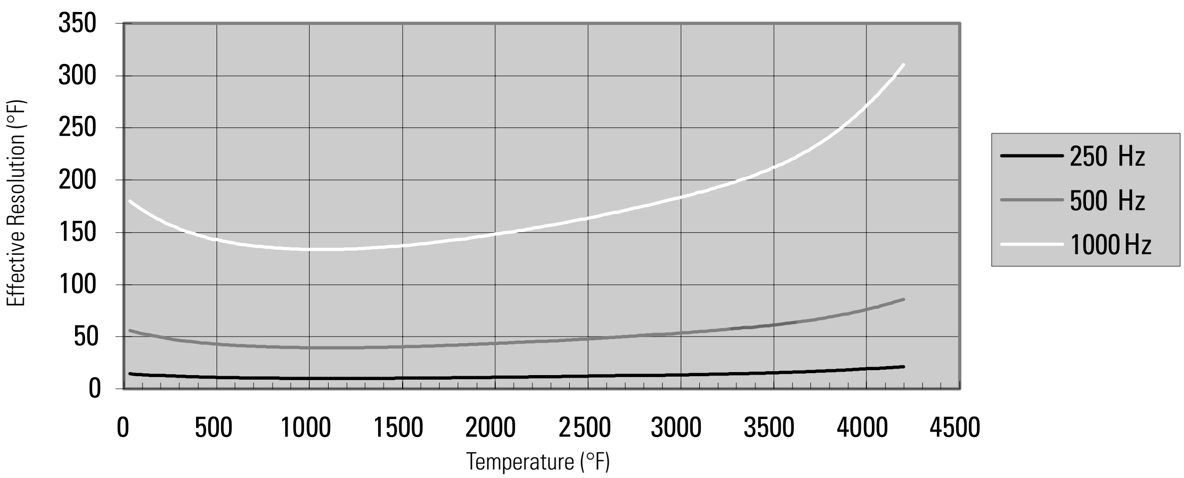
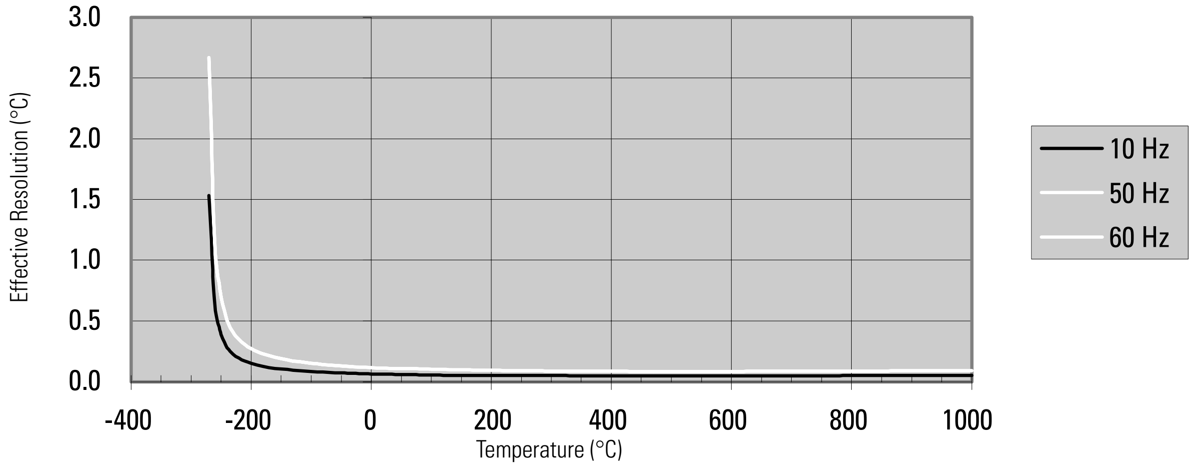


Figure 3.6 Effective Resolution Versus Input Filter Selection for Type E Thermocouples Using 10, 50, and 60 Hz Filters



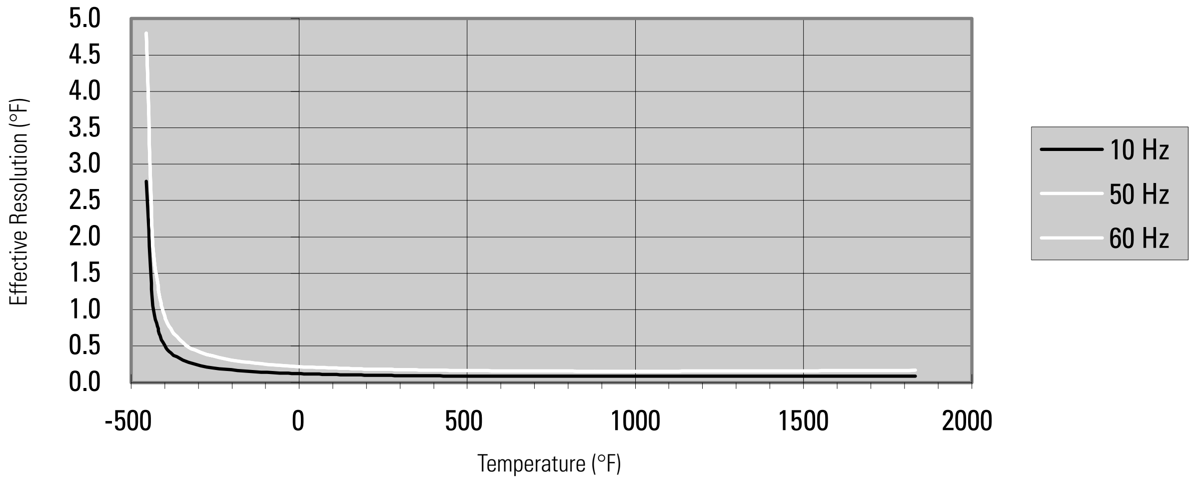
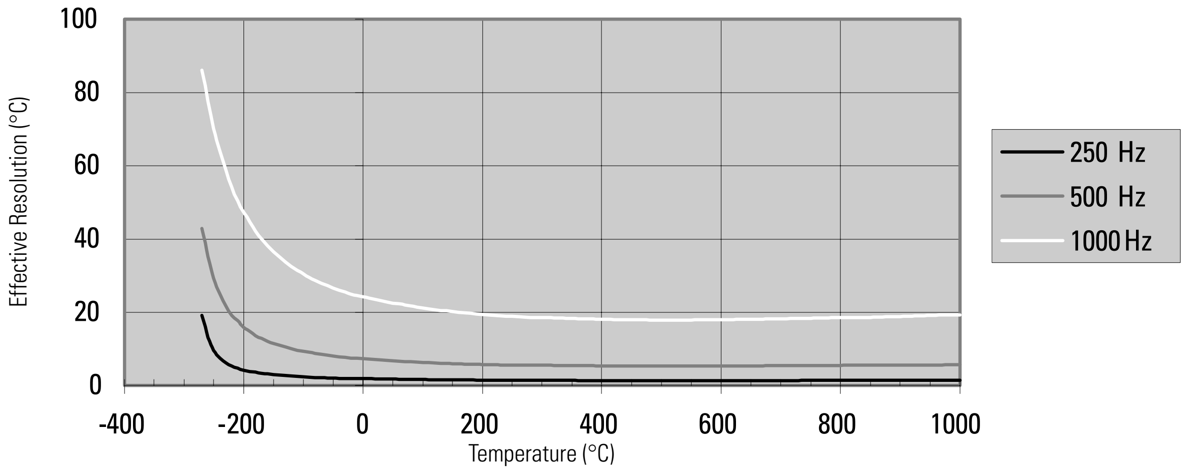


Figure 3.7 Effective Resolution Versus Input Filter Selection for Type E Thermocouples Using 250, 500, and 1k Hz Filters



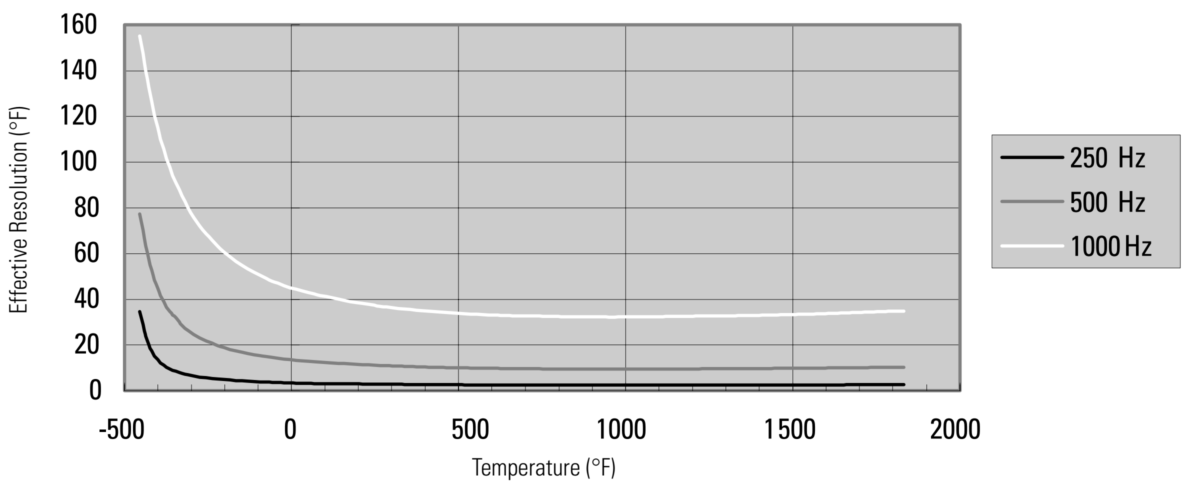


Figure 3.8 Effective Resolution Versus Input Filter Selection for Type J Thermocouples Using 10, 50, and 60 Hz Filters

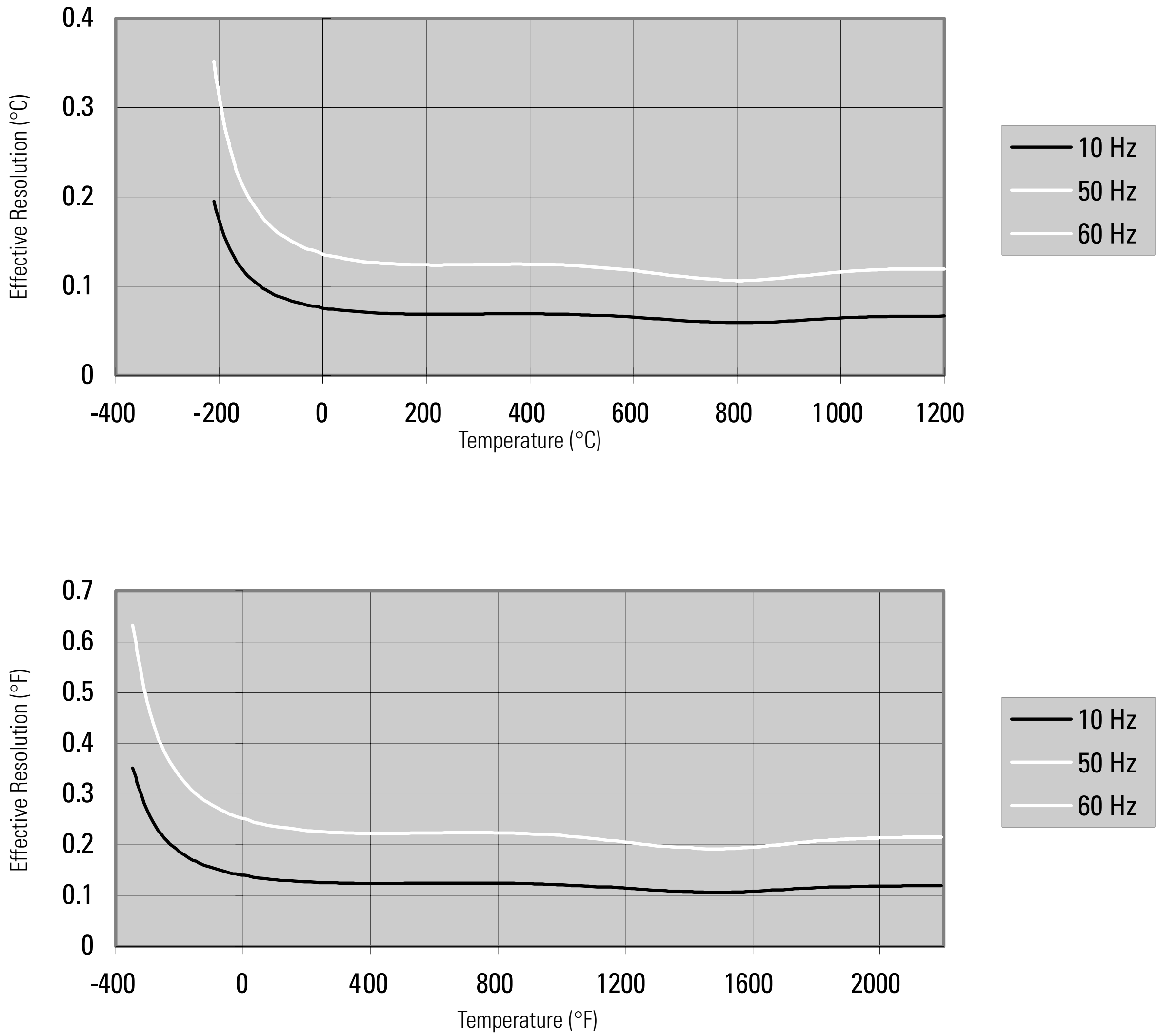
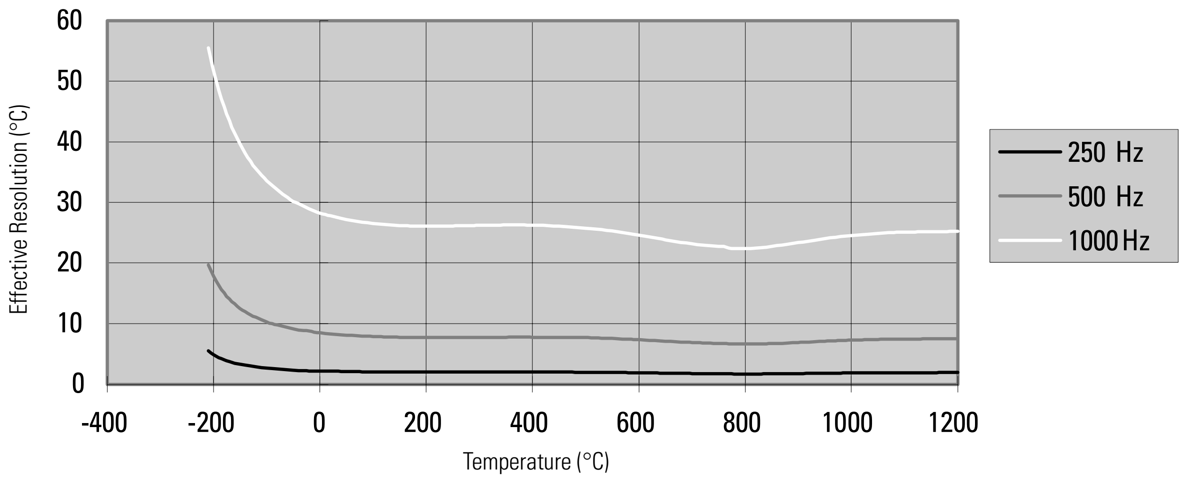


Figure 3.9 Effective Resolution Versus Input Filter Selection for Type J Thermocouples Using 250, 500, and 1k Hz Filters



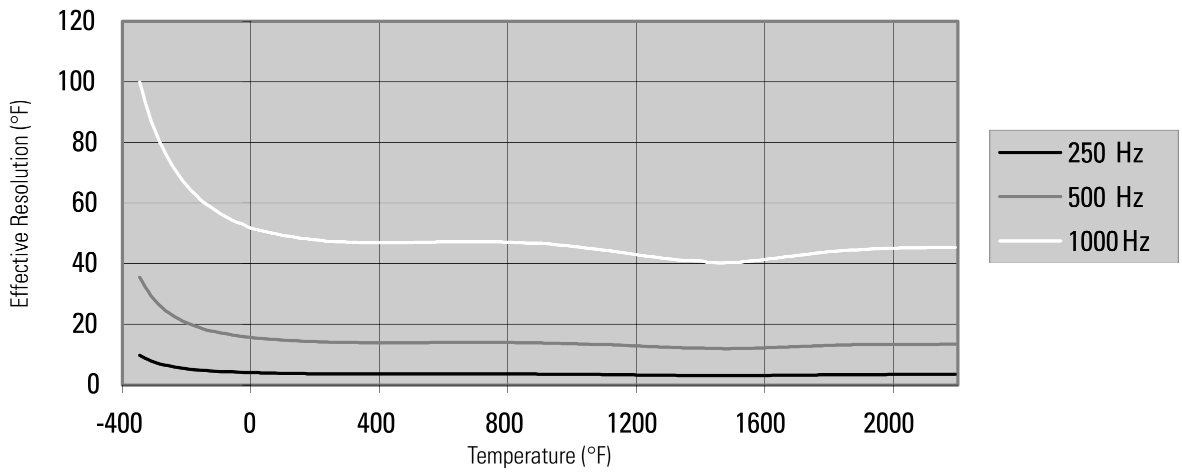
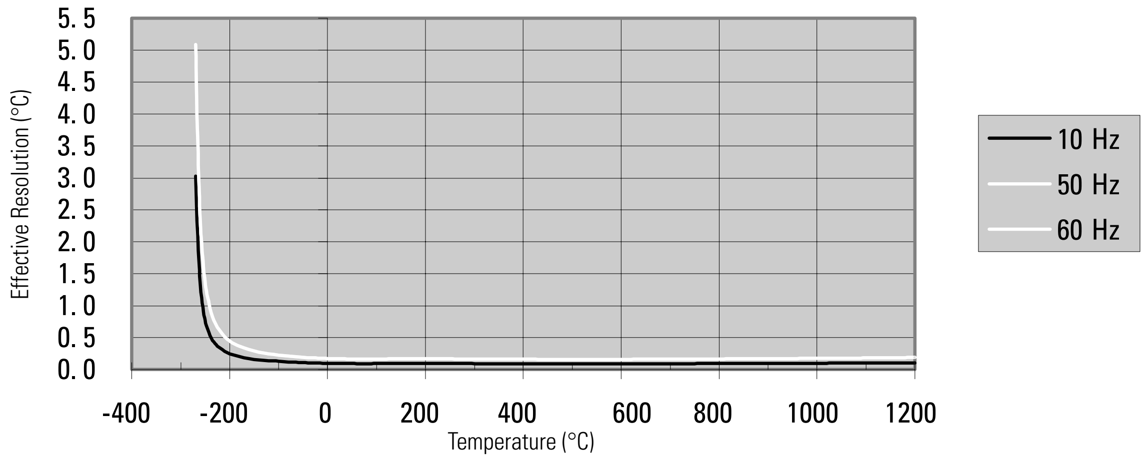


Figure 3.10 Effective Resolution Versus Input Filter Selection for Type K Thermocouples Using 10, 50, and 60 Hz Filters



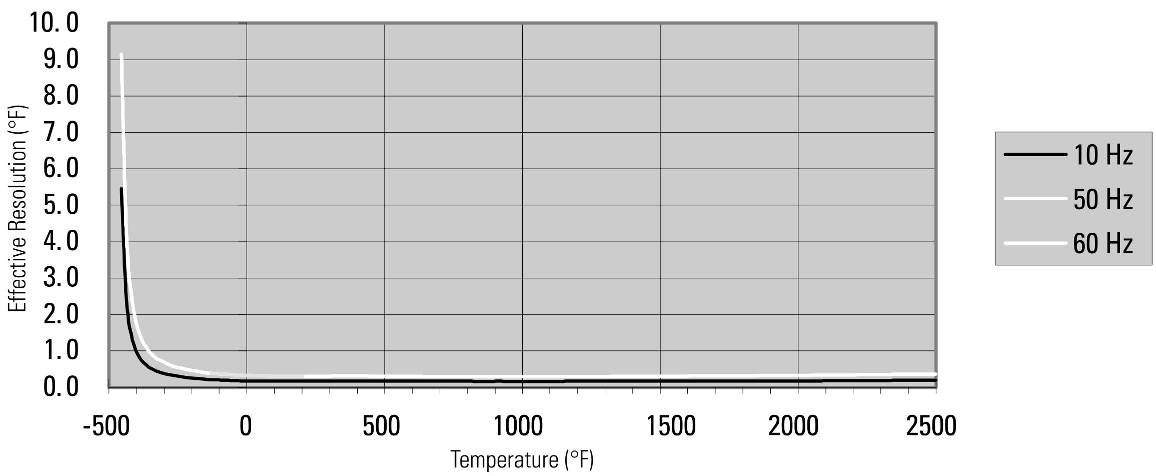
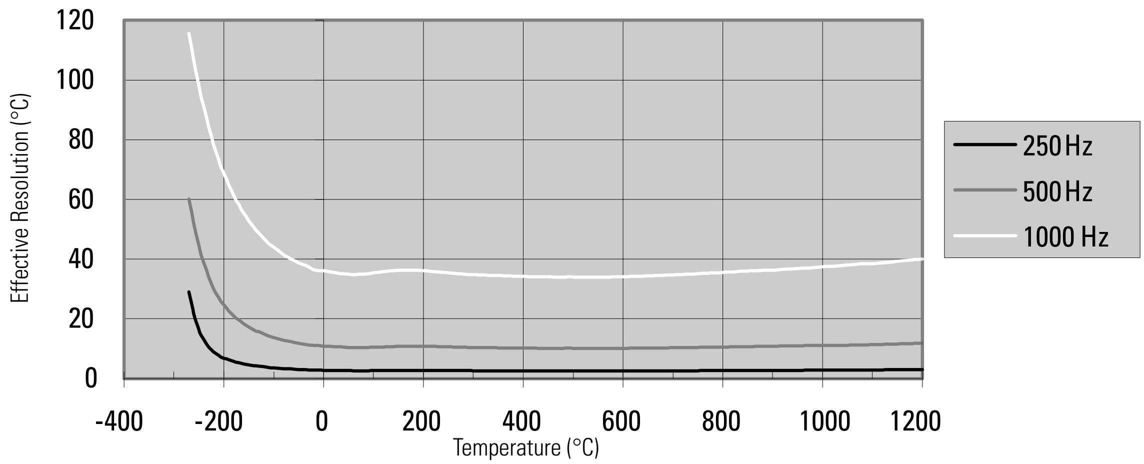


Figure 3.11 Effective Resolution Versus Input Filter Selection for Type K Thermocouples Using 250, 500, and 1k Hz Filters



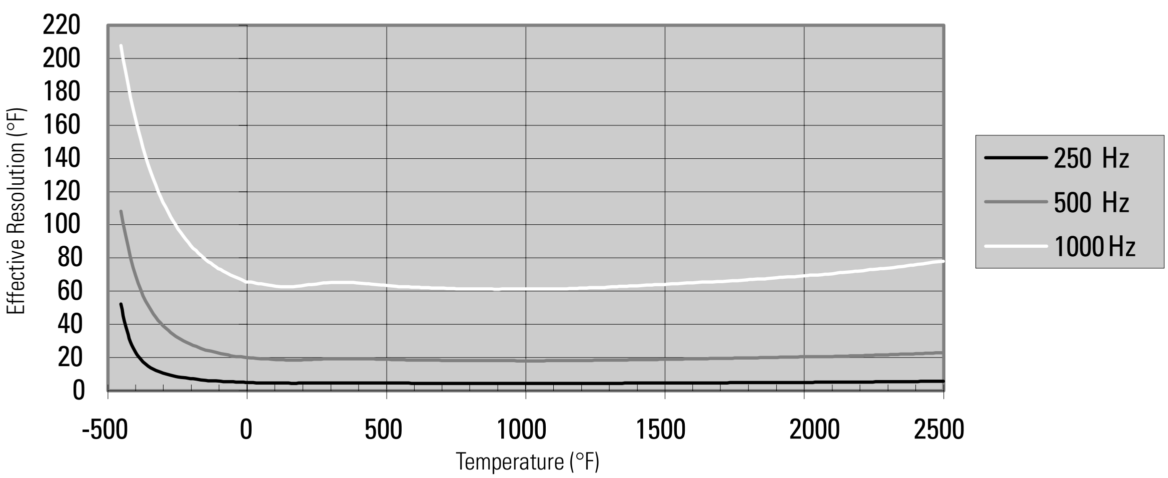
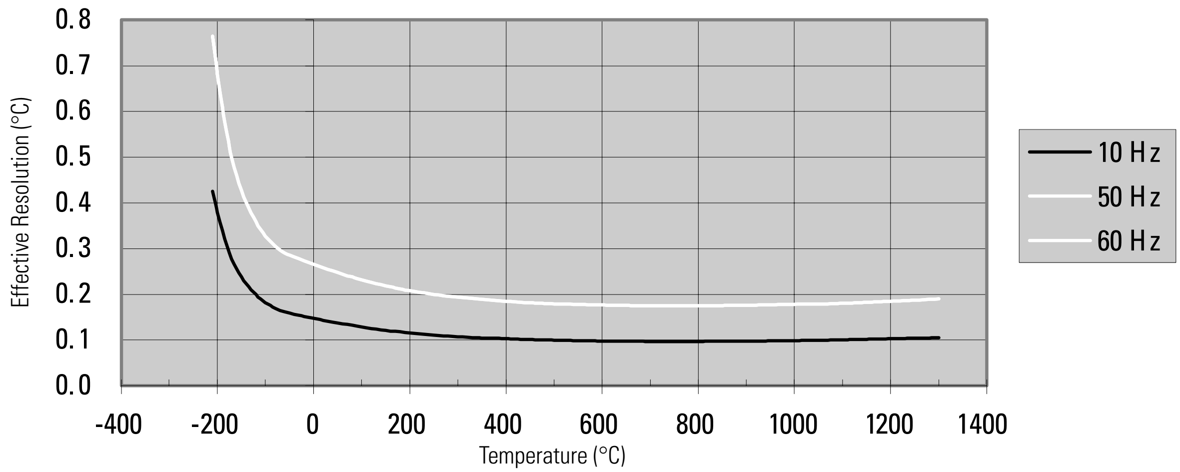


Figure 3.12 Effective Resolution Versus Input Filter Selection for Type N Thermocouples Using 10, 50, and 60 Hz Filters



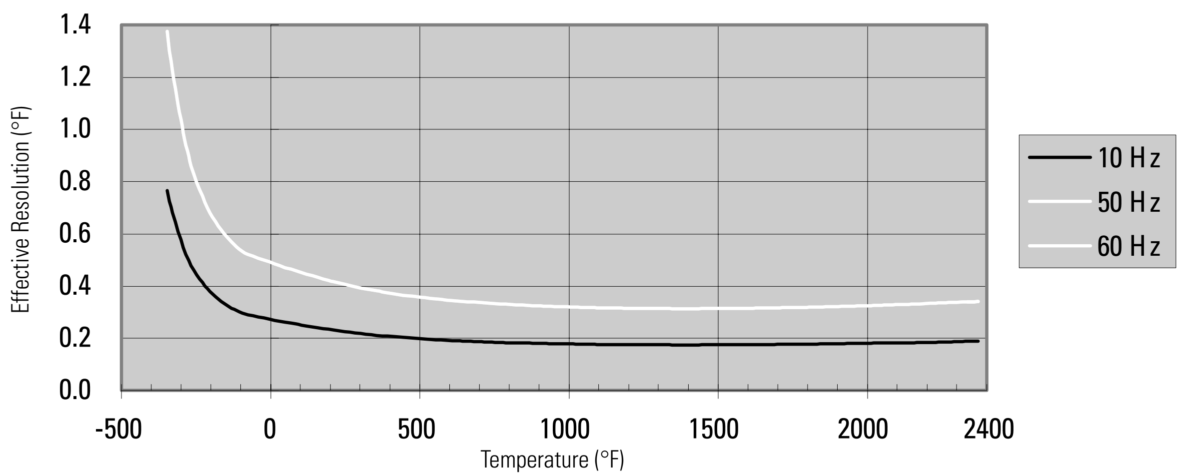
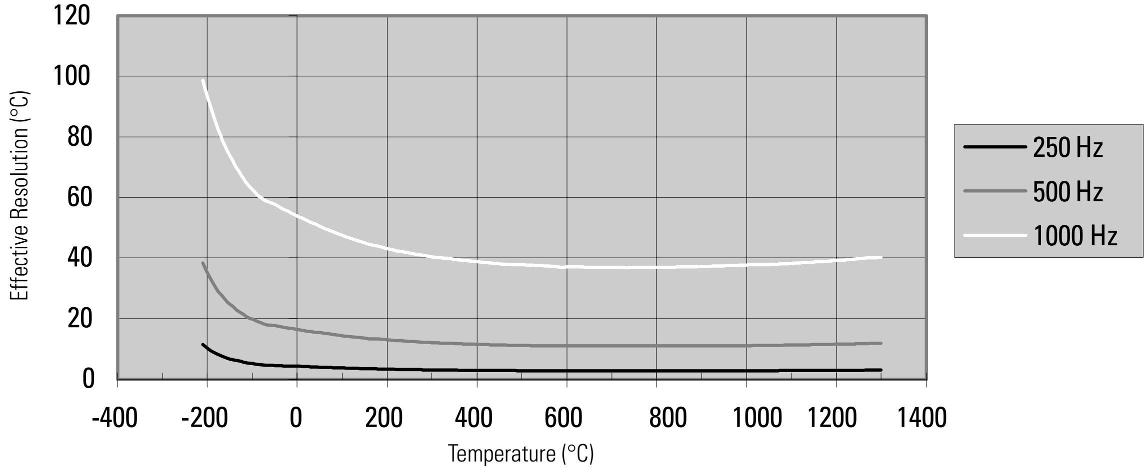


Figure 3.13 Effective Resolution Versus Input Filter Selection for Type N Thermocouples Using 250, 500, and 1k Hz Filters



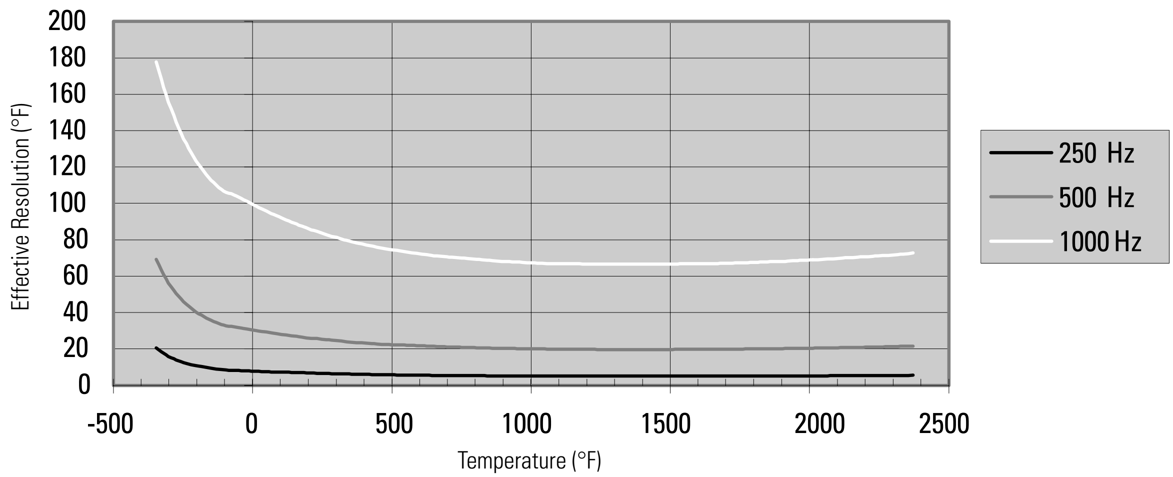
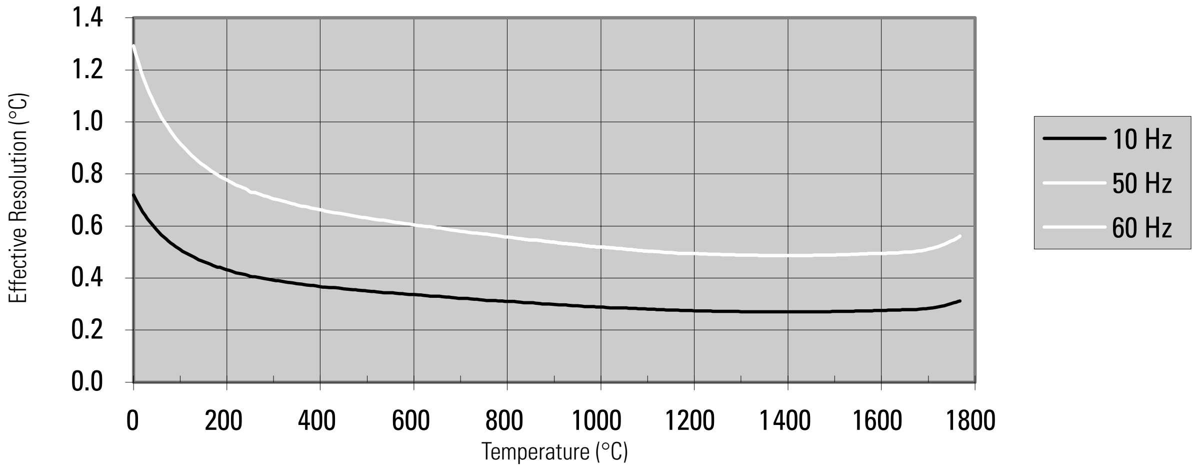


Figure 3.14 Effective Resolution Versus Input Filter Selection for Type R Thermocouples Using 10, 50, and 60 Hz Filters



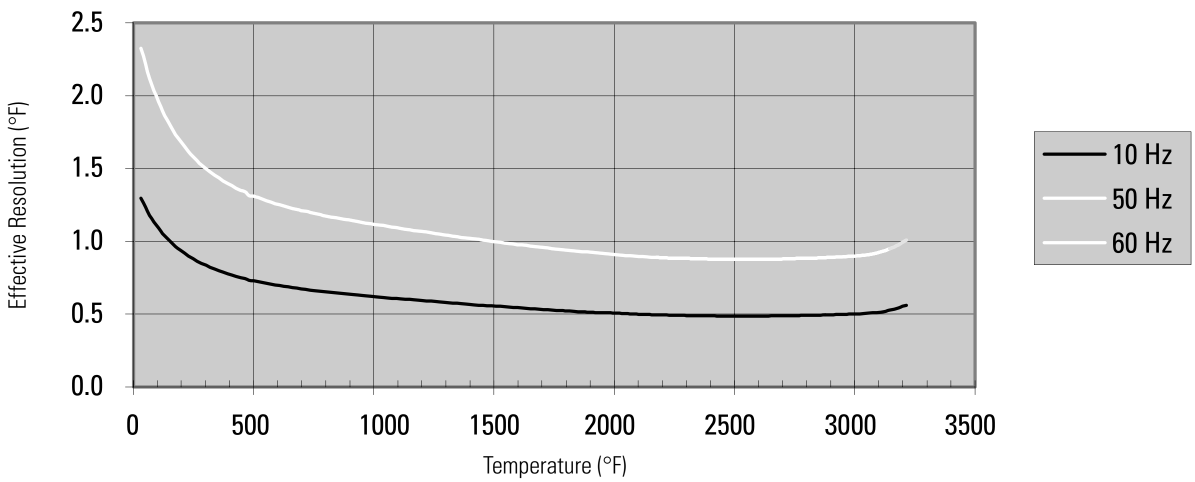
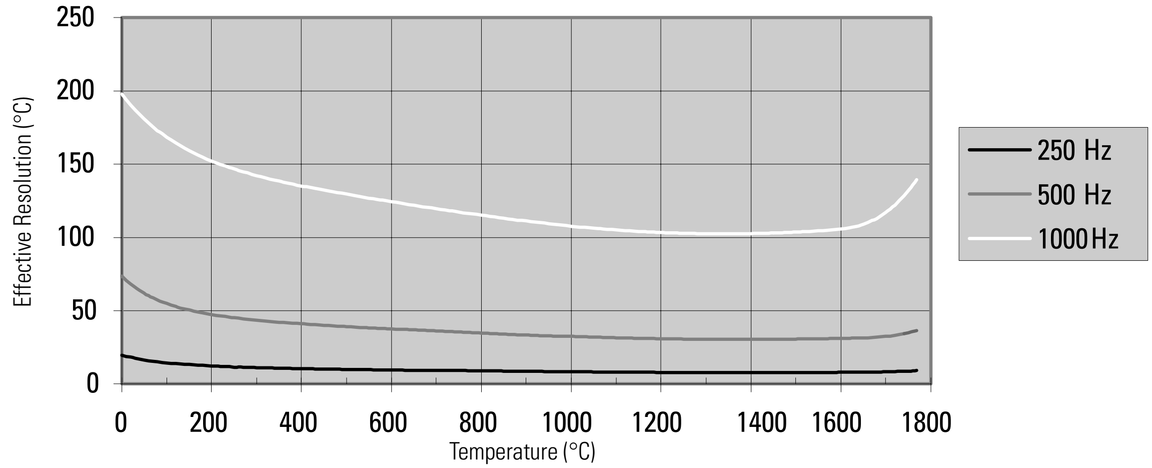


Figure 3.15 Effective Resolution Versus Input Filter Selection for Type R Thermocouples Using 250, 500, and 1k Hz Filters



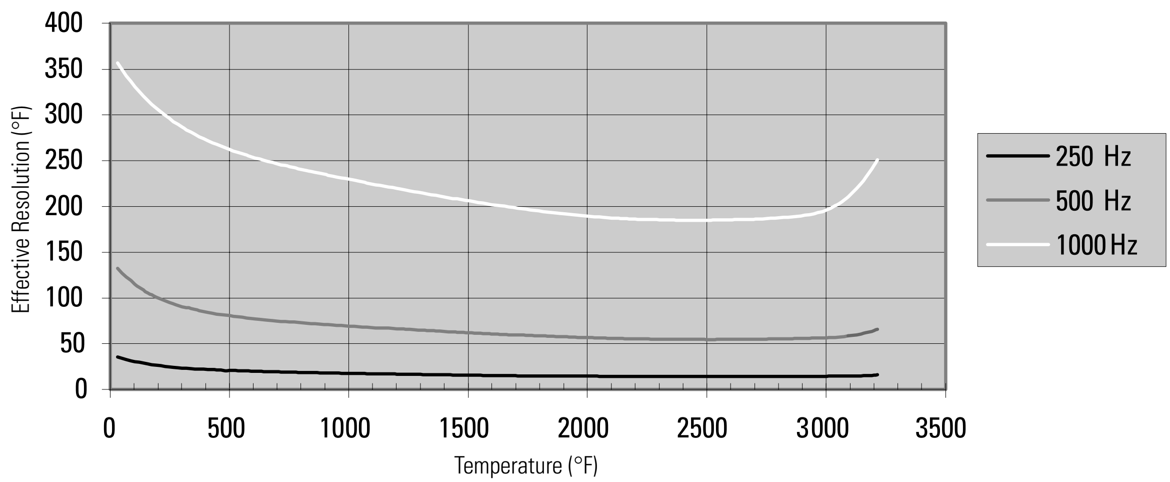
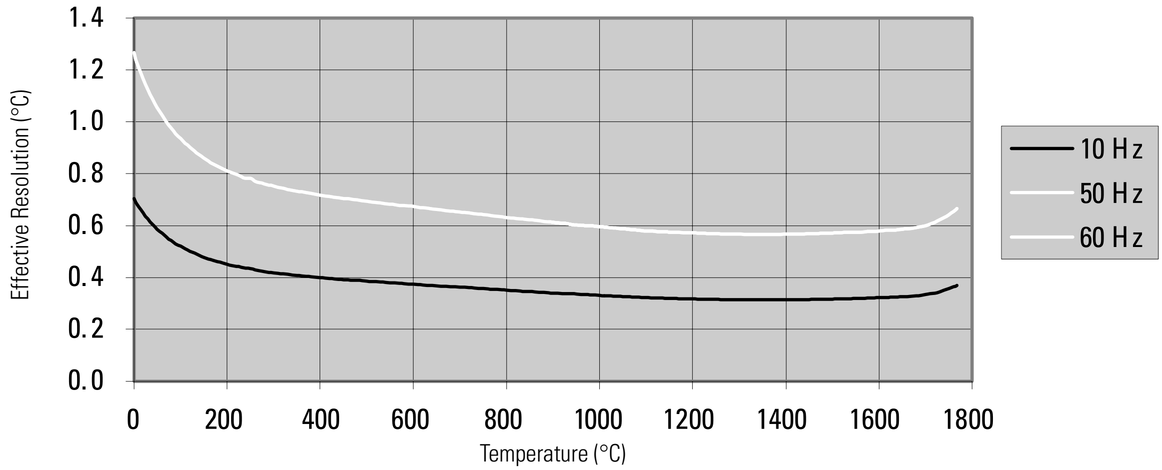


Figure 3.16 Effective Resolution Versus Input Filter Selection for Type S Thermocouples Using 10, 50, and 60 Hz Filters



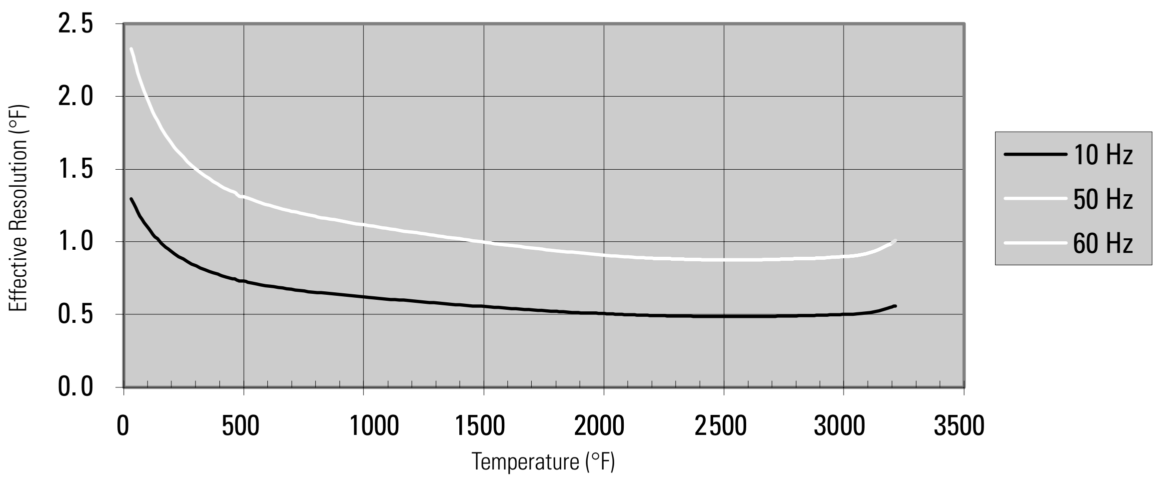


Figure 3.17 Effective Resolution Versus Input Filter Selection for Type S Thermocouples Using 250, 500, and 1k Hz Filters

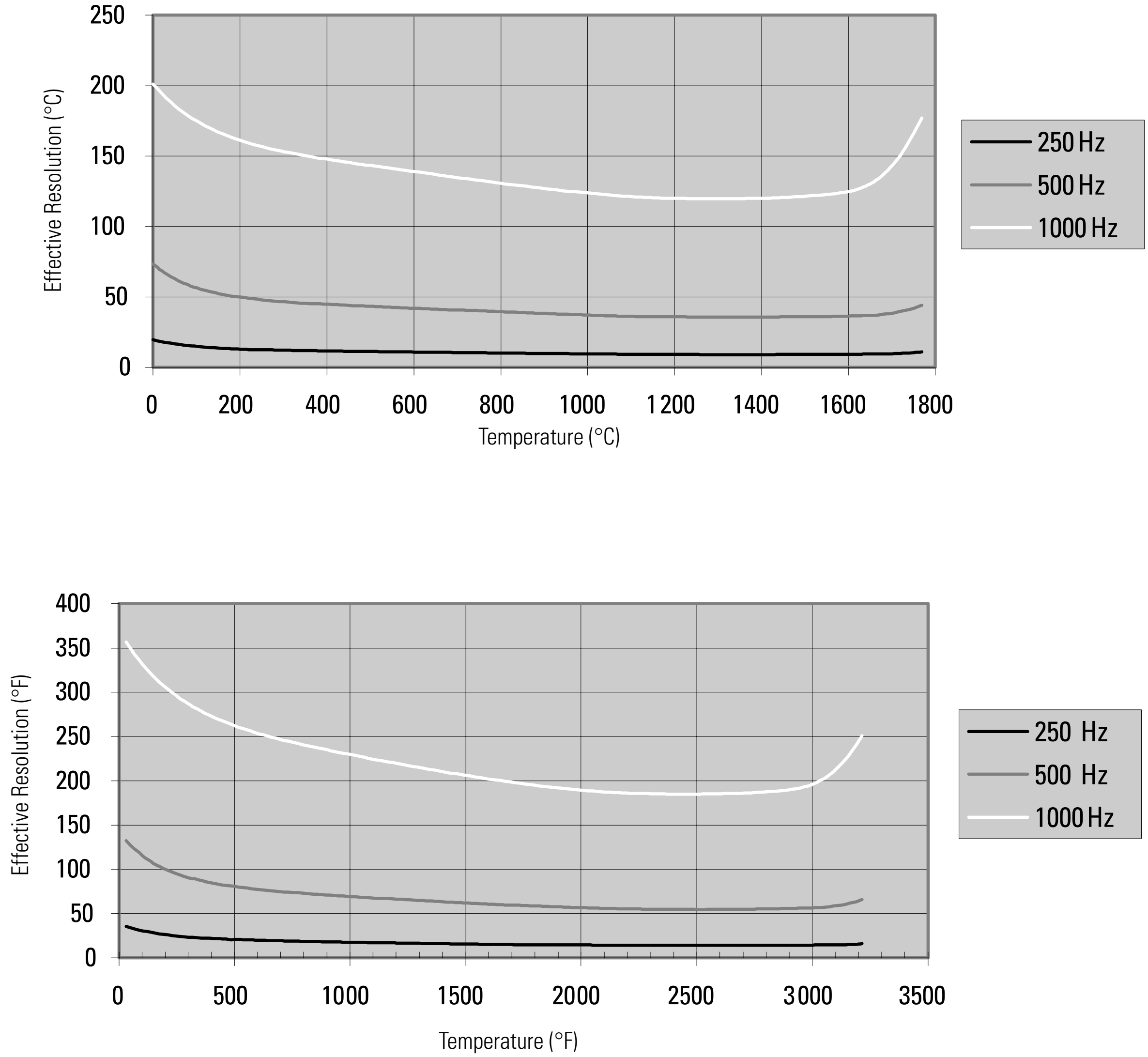
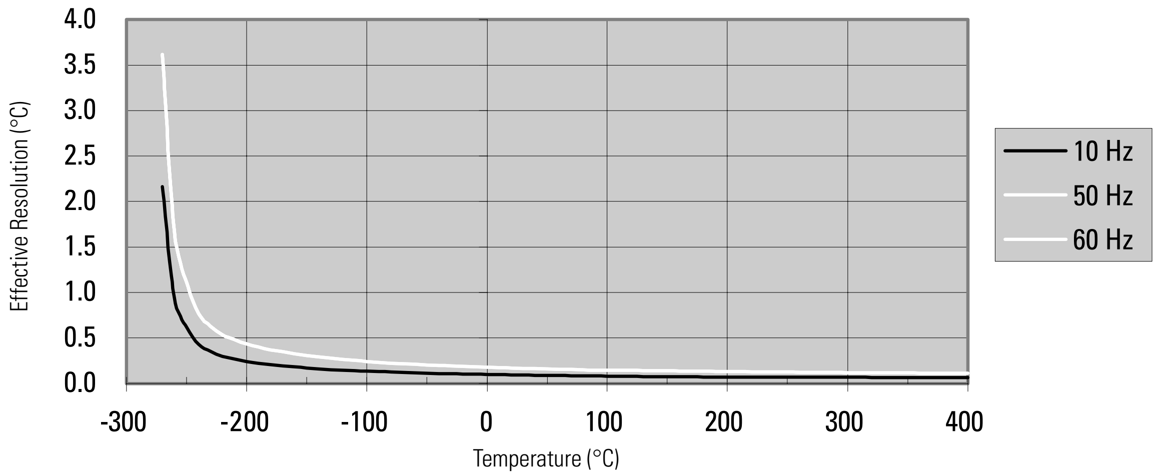


Figure 3.18 Effective Resolution Versus Input Filter Selection for Type T Thermocouples Using 10, 50, and 60 Hz Filters



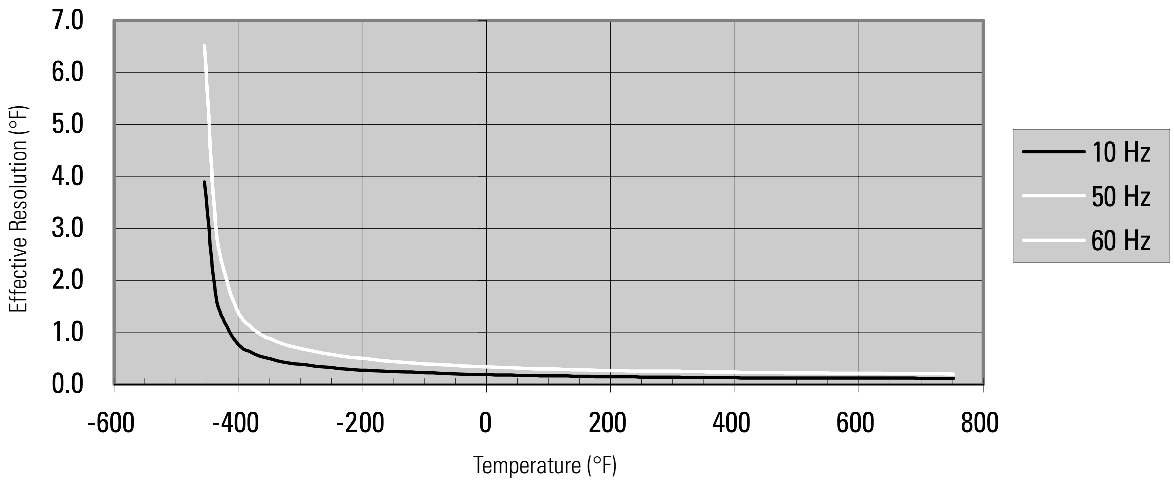
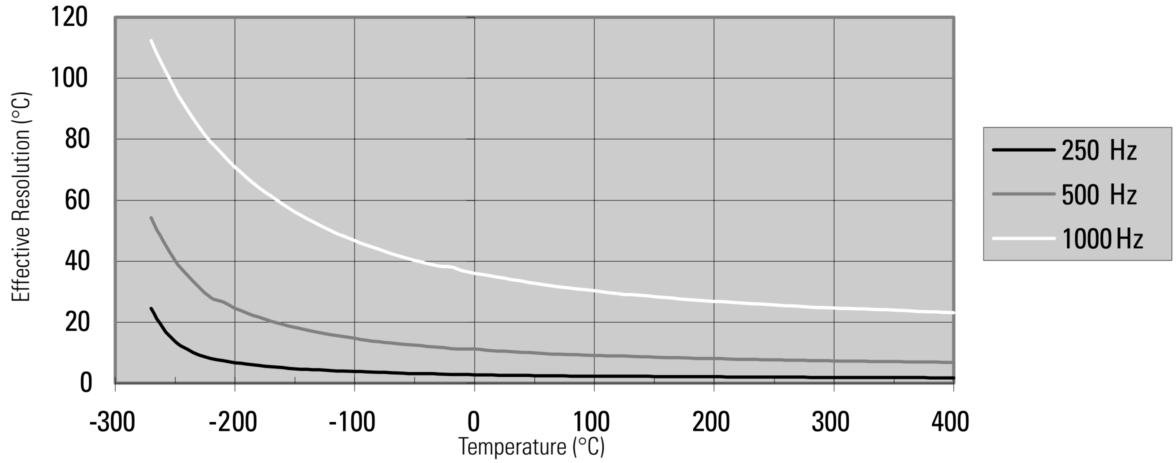


Figure 3.19 Effective Resolution Versus Input Filter Selection for Type T Thermocouples Using 250, 500, and 1k Hz Filters



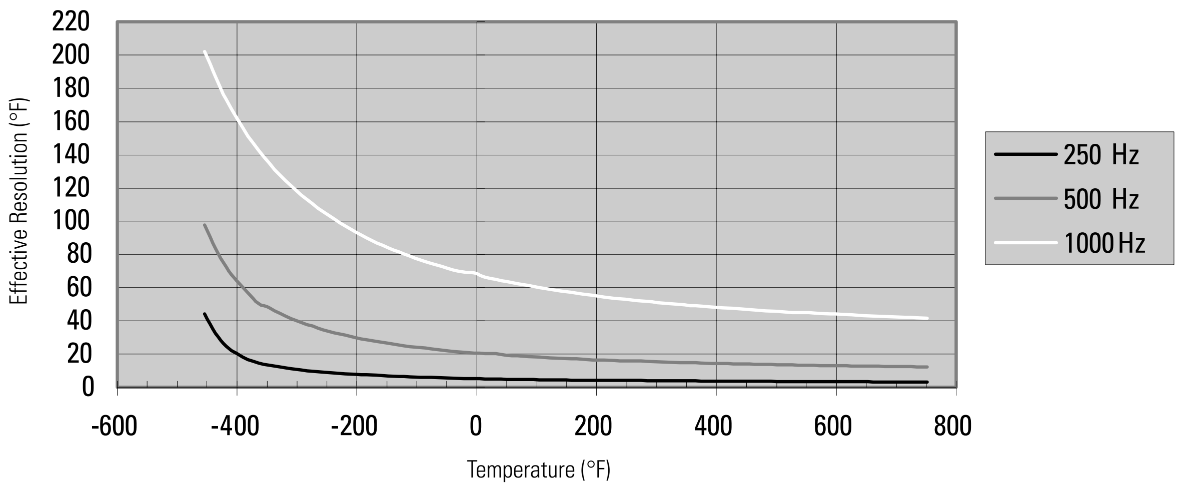


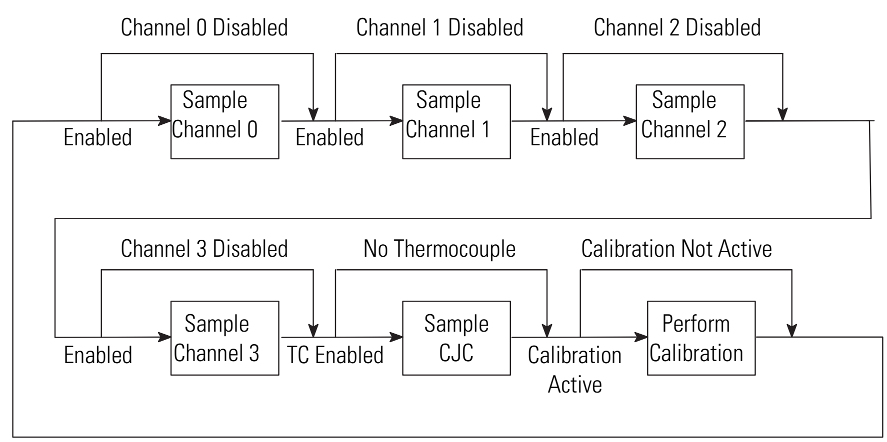
Table 3.4 Effective Resolution vs. Input Filter Selection for Millivolt Inputs

Filter Frequency	±50mV	±100mV
10 Hz	6 µV	6 µV
50 Hz	9 µV	12 µV
60 Hz	9 µV	12 µV
250 Hz	125 µV	150 µV
500 Hz	250 µV	300 µV
1 kHz	1000 µV	1300 µV

TIP The resolutions provided by the filters apply to the raw/proportional data format only.

Determining Module Update Time

The 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 provide the resulting data values to the processor. Module update time can be calculated by adding the sum of all enabled channel's times. The module sequentially samples the enabled channels in a continuous loop as shown below.



Channel update time is dependent upon the input filter selection. The following table shows the channel update times.

Table 3.5 Channel Update Time

Filter Frequency	Channel Update Time
10 Hz	303 ms
50 Hz	63 ms
60 Hz	53 ms
250 Hz	15 ms
500 Hz	9 ms
1 kHz	7 ms

The CJC input is only sampled if one or more channels are enabled for any thermocouple type. The CJC update time is equal to the largest channel update time of any of the enabled thermocouple inputs types. In that case, a single CJC update is done per scan. See the scan diagram on the previous page. The cyclic calibration time only applies when cyclic calibration is enabled and active. If enabled, the cyclic calibration is staggered over several scan cycles once every five minutes to limit the overall impact to module update time.

Effects of Autocalibration on Module Update Time

The module's autocalibration feature allows it to correct for accuracy errors caused by temperature drift over the module operating temperature range (0 to 55°C). Autocalibration occurs automatically on a system mode change from Program-to-Run for all configured channels or if any online(1) configuration change is made to a channel. In addition, you can configure the module to perform autocalibration every 5 minutes during normal operation, or you can disable this feature using the Enable/Disable Cyclic Calibration function (default is enabled). This feature allows you to implement a calibration cycle anytime, at your command, by enabling and then disabling this bit.

If you enable the cyclic autocalibration function, the module update time increases when the autocalibration occurs. To limit its impact on the module update time, the autocalibration function is divided over multiple module scans. The first enabled channel receives an A/D converter (ADC) self-calibration and a channel offset calibration over the course of two module scans. The time added to the module update time depends on the filter selected for the channel, as shown in Table 3.6 on page 3-35. Each additional enabled channel receives

(1) During an online configuration change, input data for the affected channel is not updated by the module.

separate ADC self-calibration and offset calibration cycles only if their filter configurations are different than those of previously calibrated channels.

Following all input channel calibration cycles, the CJC sensor channel receives a separate ADC self-calibration cycle. The time added to this cycle is determined by the filter setting for the CJC, which is set to the lowest filter setting of any input configured as a thermocouple. If no enabled input channel is configured for a thermocouple, no CJC calibration cycle occurs. See Table 3.6 below for channel and CJC sensor ADC self-calibration times as well as channel offset calibration times.

Table 3.6 Calibration Time

Type of Calibration	10 Hz	50 Hz	60 Hz	250 Hz	500 Hz	1 kHz
ADC self-calibration (Channels 0 through 3)	603	123	103	27	15	9
Offset calibration (Channels 0 through 3)	303	63	53	15	9	6
ADC self-calibration (CJC sensor)	603	123	103	27	15	9

Calculating Module Update Time

To determine the module update time, add the individual channel update times for each enabled channel and the CJC update time if any of the channels are enabled as thermocouple inputs.

EXAMPLE

1. Two Channels Enabled for Millivolt Inputs

Channel 0 Input: ±50 mV with 60 Hz filter
Channel 1 Input: ±50 mV with 500 Hz filter

From Table 3.5, Channel Update Time, on page 3-34:

Module Update Time
= Ch 0 Update Time + Ch 1 Update Time
= 53 ms + 9 ms
= 62 ms

EXAMPLE

2.Three Channels Enabled for Different Inputs

Channel 0 Input: Type J Thermocouple with 10 Hz filter
Channel 1 Input: Type J Thermocouple with 60 Hz filter
Channel 2 Input: ±100 mV with 250 Hz filter

From Table 3.5, Channel Update Time, on page 3-34:

Module Update Time
= Ch 0 Update Time + Ch 1 Update Time
+ Ch 2 Update Time + CJC Update Time (uses lowest thermocouple filter selected)
= 303 ms + 53 ms + 15 ms + 303 ms
= 674 ms

EXAMPLE

3.Three Channels Enabled for Different Inputs with Cyclic Calibration Enabled

Channel 0 Input: Type T Thermocouple with 60 Hz Filter
Channel 1 Input: Type T Thermocouple with 60 Hz Filter
Channel 2 Input: Type J Thermocouple with 60 Hz Filter

From Table 3.5, Channel Update Time, on page 3-34:

Module Update Time *without* an Autocalibration Cycle
= Ch 0 Update Time + Ch 1 Update Time + Ch 2 Update Time
+ CJC Update Time (uses lowest thermocouple filter selected)
= 53 ms + 53 ms + 53 ms + 53 ms = 212 ms

Module Update Time *during* an Autocalibration Cycle

Module Scan 1
= Ch 0 Update Time + Ch 1 Update Time + Ch 2 Update Time
+ CJC Update Time + *Ch 0 ADC Self-Calibration Time*
= 53 ms + 53 ms + 53 ms + 53 ms + *103* ms = 315 ms

Module Scan 2
= Ch 0 Update Time + Ch 1 Update Time + Ch 2 Update Time
+ CJC Update Time + *Ch 0 Offset Time*
= 53 ms + 53 ms + 53 ms + 53 ms + *53* ms = 265 ms

Channel 1 and Channel 2: (no scan impact)
No autocalibration cycle is required for Channels 1 and 2 because they are configured to use the same Input Filter as Channel 0.

Module Scan 3
= Ch 0 Update Time + Ch 1 Update Time + Ch 2 Update Time
+ CJC Update Time + *CJC ADC Self-Calibration Time*
= 53 ms + 53 ms + 53 ms + 53 ms + *103* ms = 315 ms

After the above cycles are complete, the module returns to scans without autocalibration for approximately 5 minutes. At that time, the autocalibration cycle repeats.

Impact of Autocalibration on Module Startup During Mode Change

Regardless of the selection of the Enable/Disable Cyclic Calibration function, an autocalibration cycle occurs automatically on a mode change from Program-to-Run and on subsequent module startups/initialization for all configured channels. During module startup, input data is not updated by the module and the General Status bits (S0 to S5) are set to 1, indicating a Data Not Valid condition. The amount of time it takes the module to startup is dependent on channel filter frequency selections as indicated in Table 3.5, Channel Update Time, on page 3-34. The following is an example calculation of module startup time.

EXAMPLE

1.Two Channels Enabled for Different Inputs

Channel 0 Input: Type T Thermocouple with 60 Hz filter
Channel 1 Input: Type J Thermocouple with 60 Hz filter

Module Startup Time
= Ch 0ADC Self-Calibration Time + Ch 0 Offset Time
+ CJC Self-Calibration Time
= 103 ms + 53 ms + 103 ms = 259 ms

2.Three Channels Enabled; Two with Different Inputs

Channel 0 Input: Type T Thermocouple with 60 Hz filter
Channel 1 Input: Type J Thermocouple with 60 Hz filter
Channel 2 Input: Type K Thermocouple with 50 Hz filter

Module Startup Time
= Channel 0 ADC Self-Calibration Time + Channel 0 Offset Time
+ Channel 2 ADC Self-Calibration Time + Channel 2 Offset Time
+ CJC Self-Calibration Time
= 103 ms + 53 ms + 123 ms + 63 ms + 103 ms = 445 ms

Diagnostics and Troubleshooting

This chapter describes troubleshooting the thermocouple/mV input module. This chapter contains information on:

- safety considerations while troubleshooting
- internal diagnostics during module operation
- module errors
- contacting Rockwell Automation for technical assistance

Safety Considerations

Safety considerations are an important element of proper troubleshooting procedures. Actively thinking about the safety of yourself and others, as well as the condition of your equipment, is of primary importance.

The following sections describe several safety concerns you should be aware of when troubleshooting your control system.

ATTENTION

Never reach into a machine to actuate a switch because unexpected motion can occur and cause injury.

Remove all electrical power at the main power disconnect switches before checking electrical connections or inputs/outputs causing machine motion.

Indicator Lights

When the green LED on the module is illuminated, it indicates that power is applied to the module and that it has passed its internal tests.

Stand Clear of Equipment

When troubleshooting any system problem, have all personnel remain clear of the equipment. The problem could be intermittent, and sudden unexpected machine motion could occur. Have someone ready to operate an emergency stop switch in case it becomes necessary to shut off power.

Program Alteration

There are several possible causes of alteration to the user program, including extreme environmental conditions, Electromagnetic Interference (EMI), improper grounding, improper wiring connections, and unauthorized tampering. If you suspect a program has been altered, check it against a previously saved master program.

Safety Circuits

Circuits installed on the machine for safety reasons, like over-travel limit switches, stop push buttons, and interlocks, should always be hard-wired to the master control relay. These devices must be wired in series so that when any one device opens, the master control relay is de-energized, thereby removing power to the machine. Never alter these circuits to defeat their function. Serious injury or machine damage could result.

Module Operation vs. Channel Operation

The module performs diagnostic operations at both the module level and the channel level. Module-level operations include functions such as power-up, configuration, and communication with a MicroLogix 1200 controller.

Channel-level operations describe channel related functions, such as data conversion and over- or under-range detection.

Internal diagnostics are performed at both levels of operation. When detected, module error conditions are immediately indicated by the module status LED. Both module hardware and channel configuration error conditions are reported to the controller. Channel over-range or under-range and open-circuit conditions are reported in the module's input data table. Module hardware errors are typically reported in the controller's I/O status file. Refer to your controller manual for details.

Power-up Diagnostics

At module power-up, a series of internal diagnostic tests are performed. If these diagnostic tests are not successfully completed, the module status LED remains off and a module error is reported to the controller.

If module status LED is:	Indicated condition:	Corrective action:
On	Proper Operation	No action required.
Off	Module Fault	Cycle power. If condition persists, replace the module. Call your local distributor or Rockwell Automation for assistance.

Channel Diagnostics

When an input channel is enabled, the module performs a diagnostic check to see that the channel has been properly configured. In addition, the channel is tested on every scan for configuration errors, over-range and under-range, and open-circuit conditions.

Invalid Channel Configuration Detection

Whenever a channel configuration word is improperly defined, the module reports an error. See pages 4-4 to 4-6 for a description of module errors.

Over- or Under-Range Detection

Whenever the data received at the channel word is out of the defined operating range, an over-range or under-range error is indicated in input data word 5.

Possible causes of an out-of-range condition include:

- The temperature is too hot or too cold for the type of thermocouple being used.
- The wrong thermocouple is being used for the input type selected, or for the configuration that was programmed.
- The input device is faulty.
- The signal input from the input device is beyond the scaling range.

Open-Circuit Detection

On each scan, the module performs an open-circuit test on all enabled channels. Whenever an open-circuit condition occurs, the open-circuit bit for that channel is set in input data word 6.

Possible causes of an open circuit include:

- the input device is broken
- a wire is loose or cut
- the input device is not installed on the configured channel
- A thermocouple is installed incorrectly

Non-critical vs. Critical Module Errors

Non-critical module errors are typically recoverable. Channel errors (over-range or under-range errors) are non-critical. Non-critical error conditions are indicated in the module input data table.

Critical module errors are conditions that may prevent normal or recoverable operation of the system. When these types of errors occur, the system typically leaves the run or program mode of operation until the error can be dealt with. Critical module errors are indicated in Table 4.3 Extended Error Codes on page 4-6.

Module Error Definition Table

Analog module errors are expressed in two fields as four-digit Hex format with the most significant digit as “don’t care” and irrelevant. The two fields are “Module Error” and “Extended Error Information”. The structure of the module error data is shown below.

Table 4.1 Module Error Table

“Don’t Care” Bits				Module Error			Extended Error Information								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hex Digit 4				Hex Digit 3				Hex Digit 2				Hex Digit 1			

Module Error Field

The purpose of the module error field is to classify module errors into three distinct groups, as described in the table below. The type of error determines what kind of information exists in the extended error information field. These types of module errors are typically reported in the controller's I/O status file. Refer to your controller manual for details.

Table 4.2 Module Error Types

Error Type	Module Error Field Value Bits 11 through 9 (binary)	Description
No Errors	000	No error is present. The extended error field holds no additional information.
Hardware Errors	001	General and specific hardware error codes are specified in the extended error information field.
Configuration Errors	010	Module-specific error codes are indicated in the extended error field. These error codes correspond to options that you can change directly. For example, the input range or input filter selection.

Extended Error Information Field

Check the extended error information field when a non-zero value is present in the module error field. Depending upon the value in the module error field, the extended error information field can contain error codes that are module-specific or common to all 1769 analog modules.

TIP

If no errors are present in the module error field, the extended error information field is set to zero.

Hardware Errors

General or module-specific hardware errors are indicated by module error code 001. See Table 4.3 Extended Error Codes on page 4-6.

Configuration Errors

If you set the fields in the configuration file to invalid or unsupported values, the module generates a critical error.

Table 4.3 Extended Error Codes on page 4-6 lists the possible module-specific configuration error codes defined for the modules.

Error Codes

The table below explains the extended error code.

Table 4.3 Extended Error Codes

Error Type	Hex Equivalent(1)	Module Error Code	Extended Error Information Code	Error Description
		Binary	Binary	
No Error	X000	000	0 0000 0000	No Error
General Common Hardware Error	X200	001	0 0000 0000	General hardware error; no additional information
	X201	001	0 0000 0001	Power-up reset state
Hardware-Specific Error	X300	001	1 0000 0000	General hardware error; no additional information
	X301	001	1 0000 0001	Microprocessor hardware error
	X302	001	1 0000 0010	A/D Converter error
	X303	001	1 0000 0011	Calibration error
Module-Specific Configuration Error	X400	010	0 0000 0000	General configuration error; no additional information
	X401	010	0 0000 0001	Invalid input type selected (channel 0)
	X402	010	0 0000 0010	Invalid input type selected (channel 1)
	X403	010	0 0000 0011	Invalid input type selected (channel 2)
	X404	010	0 0000 0100	Invalid input type selected (channel 3)
	X405	010	0 0000 0101	Invalid filter selected (channel 0)
	X406	010	0 0000 0110	Invalid filter selected (channel 1)
	X407	010	0 0000 0111	Invalid filter selected (channel 2)
	X408	010	0 0000 1000	Invalid filter selected (channel 3)
	X409	010	0 0000 1001	Invalid format selected (channel 0)
	X40A	010	0 0000 1010	Invalid format selected (channel 1)
	X40B	010	0 0000 1011	Invalid format selected (channel 2)
	X40C	010	0 0000 1100	Invalid format selected (channel 3)
	X40D	010	0 0000 1101	An unused bit has been set for channel 0
	X40E	010	0 0000 1110	An unused bit has been set for channel 1
	X40F	010	0 0000 1111	An unused bit has been set for channel 2
	X410	010	0 0001 0000	An unused bit has been set for channel 3
	X411	010	0 0001 0001	Invalid module configuration register

(1) X represents the “Don’t Care” digit.

Contacting Rockwell Automation

If you need to contact Rockwell Automation for assistance, please have the following information available when you call:

- a clear statement of the problem, including a description of what the system is actually doing. Note the LED state; also note data and configuration words for the module.
- a list of remedies you have already tried
- processor type and firmware number (See the label on the processor.)
- hardware types in the system, including all I/O modules
- fault code if the processor is faulted

Specifications

General Specifications

Specification	Value
Dimensions	90 mm (height) x 87 mm (depth) x 40 mm (width) height including mounting tabs is 110 mm 3.54 in. (height) x 3.43 in. (depth) x 1.58 in. (width) height including mounting tabs is 4.33 in.
Approximate Shipping Weight (with carton)	220g (0.53 lbs.)
Storage Temperature	-40°C to +85°C (-40°F to +185°F)
Operating Temperature	0°C to +55°C (32°F to +131°F)
Operating Humidity	5% to 95% non-condensing
Operating Altitude	2000 meters (6561 feet)
Vibration	Operating: 10 to 500 Hz, 5G, 0.030 in. peak-to-peak Relay Operation: 2G
Shock	Operating: 30G, 11 ms panel mounted (20G, 11 ms DIN rail mounted) Relay Operation: 7.5G panel mounted (5G DIN rail mounted) Non-Operating: 40G panel mounted (30G DIN rail mounted)
Recommended Cable	Belden™ 8761 (shielded) for millivolt inputs Shielded thermocouple extension wire for the specific type of thermocouple you are using. Follow thermocouple manufacturer's recommendations.
Agency Certification	• C-UL certified (under CSA C22.2 No. 142) • UL 508 listed • CE compliant for all applicable directives • C-Tick marked for all applicable acts
Hazardous Environment Class	Class I, Division 2, Hazardous Location, Groups A, B, C, D (UL 1604, C-UL under CSA C22.2 No. 213)
Radiated and Conducted Emissions	EN50081-2 Class A

Specification	Value
Electrical /EMC:	*The module has passed testing at the following levels:*
• ESD Immunity (EN61000-4-2)	• 4 kV contact, 8 kV air, 4 kV indirect
• Radiated Immunity (EN61000-4-3)	• 10 V/m , 80 to 1000 MHz, 80% amplitude modulation, +900 MHz keyed carrier
• Fast Transient Burst (EN61000-4-4)	• 2 kV, 5kHz
• Surge Immunity (EN61000-4-5)	• 1kV galvanic gun
• Conducted Immunity (EN61000-4-6)	• 10V, 0.15 to 80MHz[1] [2]

(1) Conducted Immunity frequency range may be 150 kHz to 30 MHz if the Radiated Immunity frequency range is 30 to 1000 MHz.
(2) For grounded thermocouples, the 10V level is reduced to 3V.

Input Specifications

Specification	Value
Number of Inputs	4 input channels plus 1 CJC sensor
Resolution	15 bits plus sign
Bus Current Draw (max.)	40 mA at 5V dc 50 mA at 24V dc
Heat Dissipation	1.5 Total Watts (The Watts per point, plus the minimum Watts, with all points energized.)
Converter Type	Delta Sigma
Response Speed per Channel	Input filter and configuration dependent. See “Effects of Filter Frequency on Noise Rejection” on page 3-10
Rated Working Voltage[1]	30V ac/30V dc
Common Mode Voltage Range[2]	±10V maximum per channel
Common Mode Rejection	115 dB (minimum) at 50 Hz (with 10 Hz or 50 Hz filter) 115 dB (minimum) at 60 Hz (with 10 Hz or 60 Hz filter)
Normal Mode Rejection Ratio	85 dB (minimum) at 50 Hz (with 10 Hz or 50 Hz filter) 85 dB (minimum) at 60 Hz (with 10 Hz or 60 Hz filter)
Maximum Cable Impedance	25 Ω (for specified accuracy)
Input Impedance	>10M Ω
Open-circuit Detection Time	7 ms to 1.515 seconds[3]
Calibration	The module performs autocalibration upon power-up and whenever a channel is enabled. You can also program the module to calibrate every five minutes.

(1) Rated working voltage is the maximum continuous voltage that can be applied at the input terminal, including the input signal and the value that floats above ground potential (for example, 30V dc input signal and 20V dc potential above ground).
(2) For proper operation, both the plus and minus input terminals must be within ±10V dc of analog common.
(3) Open-circuit detection time is equal to the module scan time, which is based on the number of enabled channels, the filter frequency of each channel, and whether cyclic calibration is enabled..

Specification	Value
Module Error over Full Temperature Range (0 to +55°C [+32°F to +131°F])	See "Accuracy" on page A-4.
CJC Accuracy	±1.3°C (±2.34°F)
Maximum Overload at Input Terminals	±35V dc continuous(1)
Input Group to Bus Isolation	720V dc for 1 minute (qualification test) 30V ac/30V dc working voltage
Input Channel Configuration	via configuration software screen or the user program (by writing a unique bit pattern into the module's configuration file).
Module OK LED	On: module has power, has passed internal diagnostics, and is communicating over the bus. Off: Any of the above is not true.
Channel Diagnostics	Over- or under-range and open-circuit by bit reporting
Vendor I.D. Code	1
Product Type Code	10
Product Code	64

(1) Maximum current input is limited due to input impedance.

Repeatability at 25°C (77°F)(1) (2)

Input Type	Repeatability for 10 Hz Filter
Thermocouple J	±0.1°C [±0.18°F]
Thermocouple N (-110°C to +1300°C [-166°F to +2372°F])	±0.1°C [±0.18°F]
Thermocouple N (-210°C to -110°C [-346°F to -166°F])	±0.25°C [±0.45°F]
Thermocouple T (-170°C to +400°C [-274°F to +752°F])	±0 .1°C [±0.18°F]
Thermocouple T (-270°C to -170°C [-454°F to -274°F])	±1.5°C [±2.7°F]
Thermocouple K (-270°C to +1370°C [-454°F to +2498°F])	±0.1°C [±0.18°F]
Thermocouple K (-270°C to -170°C [-454°F to -274°F])	±2.0°C [±3.6°F]
Thermocouple E (-220°C to +1000°C [-364°F to +1832°F])	±0.1°C [±0.18°F]
Thermocouple E (-270°C to -220°C [-454°F to -364°F])	±1.0°C [±1.8°F]
Thermocouples S and R	±0.4°C [±0.72°F]
Thermocouple C	±0.2°C [±0.36°F]
Thermocouple B	±0.7°C [±1.26°F]
±50 mV	±6 μV
±100 mV	±6 μV

(1) Repeatability is the ability of the input module to register the same reading in successive measurements for the same input signal.

(2) Repeatability at any other temperature in the 0 to 60°C (32 to 140°F) range is the same as long as the temperature is stable.

Accuracy

Input Type[1]	With Autocalibration Enabled		Without Autocalibration
	Accuracy[2] [3] for 10 Hz, 50 Hz and 60 Hz Filters (max.)		Maximum Temperature Drift[2] [4]
	at 25°C [77°F] Ambient	at 0 to 60°C [32 to 140°F] Ambient	at 0 to 60°C [32 to 140°F] Ambient
Thermocouple J (-210°C to 1200°C [-346°F to 2192°F])	±0.6°C [± 1.1°F]	±0.9°C [± 1.7°F]	±0.0218°C/°C [±0.0218°F/°F]
Thermocouple N (-200°C to +1300°C [-328°F to 2372°F])	±1°C [± 1.8°F]	±1.5°C [±2.7°F]	±0.0367°C/°C [±0.0367°F/°F]
Thermocouple N (-210°C to -200°C [-346°F to -328°F])	±1.2°C [±2.2°F]	±1.8°C [±3.3°F]	±0.0424°C/°C [±0.0424°F/°F]
Thermocouple T (-230°C to +400°C [-382°F to +752°F])	±1°C [± 1.8°F]	±1.5°C [±2.7°F]	±0.0349°C/°C [±0.0349°F/°F]
Thermocouple T (-270°C to -230°C [-454°F to -382°F])	±5.4°C [± 9.8°F]	±7.0°C [±12.6°F]	±0.3500°C/°C [±0.3500°F/°F]
Thermocouple K (-230°C to +1370°C [-382°F to +2498°F])	±1°C [± 1.8°F]	±1.5°C [±2.7°F]	±0.4995°C/°C [±0.4995°F/°F]
Thermocouple K (-270°C to -225°C [-454°F to -373°F])	±7.5°C [± 13.5°F]	±10°C [± 18°F]	±0.0378°C/°C [±0.0378°F/°F]
Thermocouple E (-210°C to +1000°C [-346°F to +1832°F])	±0.5°C [± 0.9°F]	±0.8°C [±1.5°F]	±0.0199°C/°C [±0.0199°F/°F]
Thermocouple E (-270°C to -210°C [-454°F to -346°F])	±4.2°C [± 7.6°F]	±6.3°C [±11.4°F]	±0.2698°C/°C [±0.2698°F/°F]
Thermocouple R	±1.7°C [± 3.1°F]	±2.6°C [± 4.7°F]	±0.0613°C/°C [±0.0613°F/°F]
Thermocouple S	±1.7°C [± 3.1°F]	±2.6°C [± 4.7°F]	±0.0600°C/°C [±0.0600°F/°F]
Thermocouple C	±1.8°C [±3.3°F]	±3.5°C [±6.3°F]	±0.0899°C/°C [±0.0899°F/°F]
Thermocouple B	±3.0°C [±5.4°F]	±4.5°C [±8.1°F]	±0.1009°C/°C [±0.1009°F/°F]
±50 mV	±15 µV	±25 µV	±0.44µV/°C [±0.80µV/°F]
±100 mV	±20 µV	±30 µV	±0.69µV/°C [±01.25µV/°F]

(1) The module uses the National Institute of Standards and Technology (NIST) ITS-90 standard for thermocouple linearization.
(2) Accuracy and temperature drift information does not include the affects of errors or drift in the cold junction compensation circuit.
(3) Accuracy is dependent upon the analog/digital converter output rate selection, data format, and input noise.
(4) Temperature drift with autocalibration is slightly better than without autocalibration.

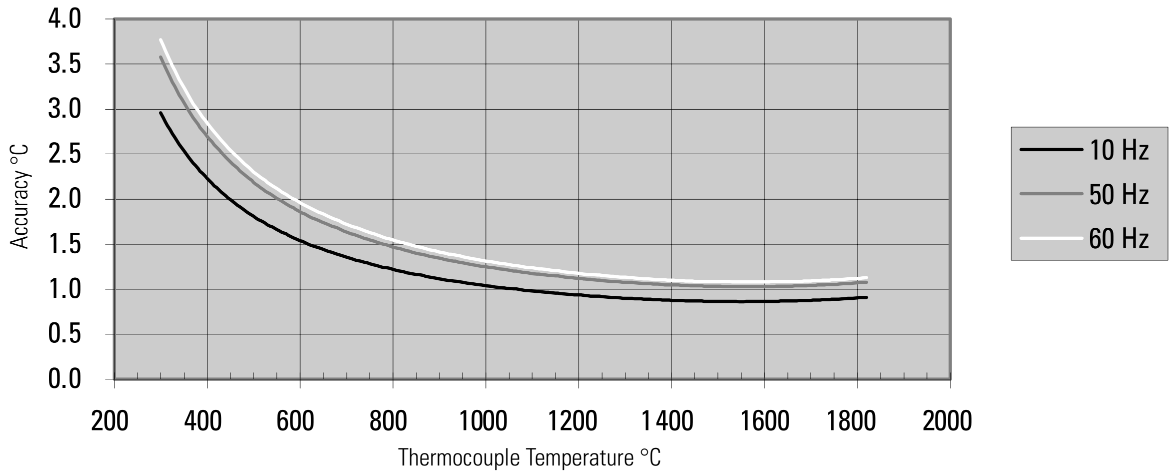
TIP

For more detailed accuracy information, see the accuracy graphs on pages A-5 through A-21.

Accuracy Versus Thermocouple Temperature and Filter Frequency

The following graphs show the module's accuracy when operating at 25°C for each thermocouple type over the thermocouple's temperature range for each frequency. The effect of errors in cold junction compensation is not included.

Figure A.1 Module Accuracy at 25°C (77°F) Ambient for Type B Thermocouple Using 10, 50, and 60 Hz Filter



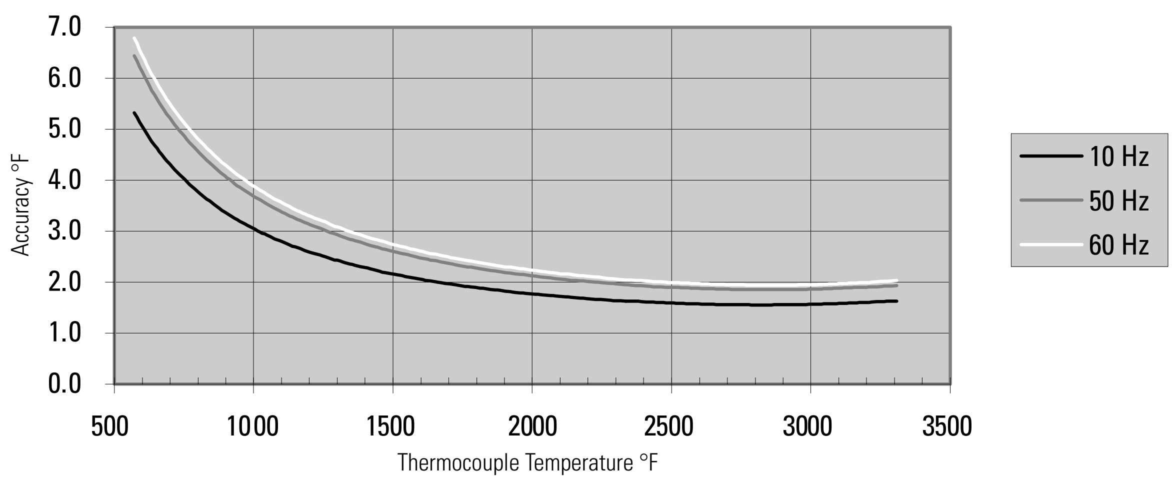


Figure A.2 Module Accuracy at 25°C (77°F) Ambient for Type B Thermocouple Using 250, 500, and 1 kHz Filter

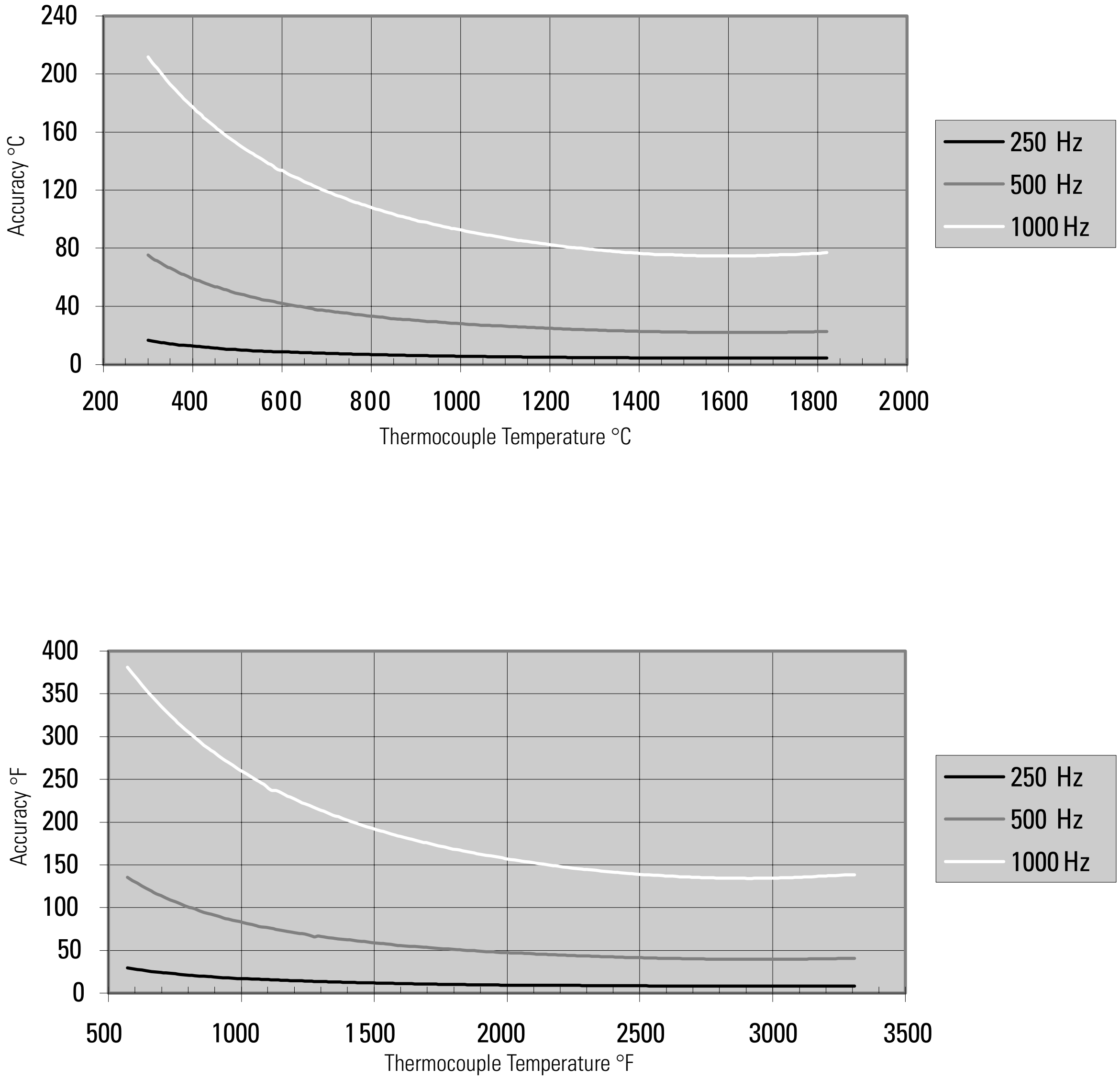
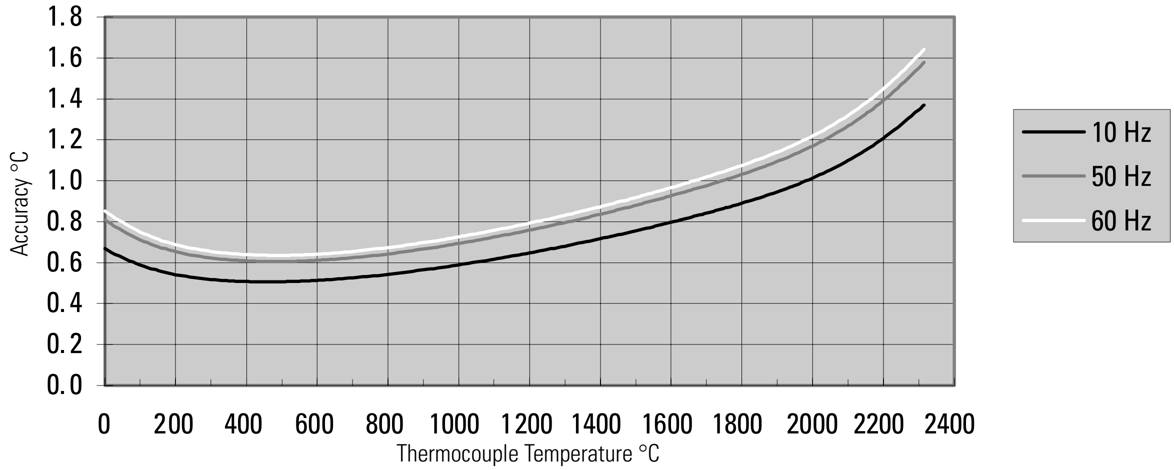


Figure A.3 Module Accuracy at 25°C (77°F) Ambient for Type C Thermocouple Using 10, 50, and 60 Hz Filter



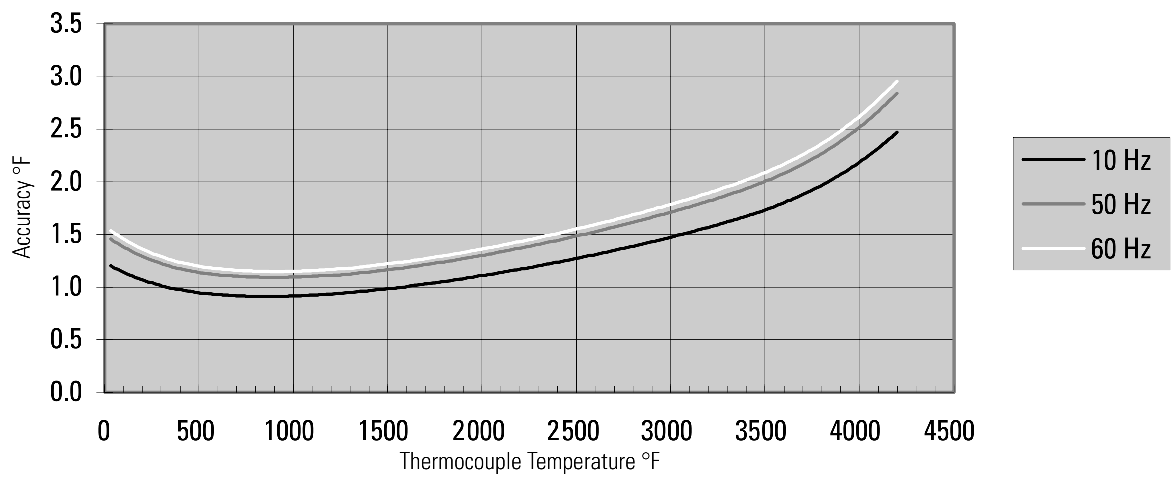
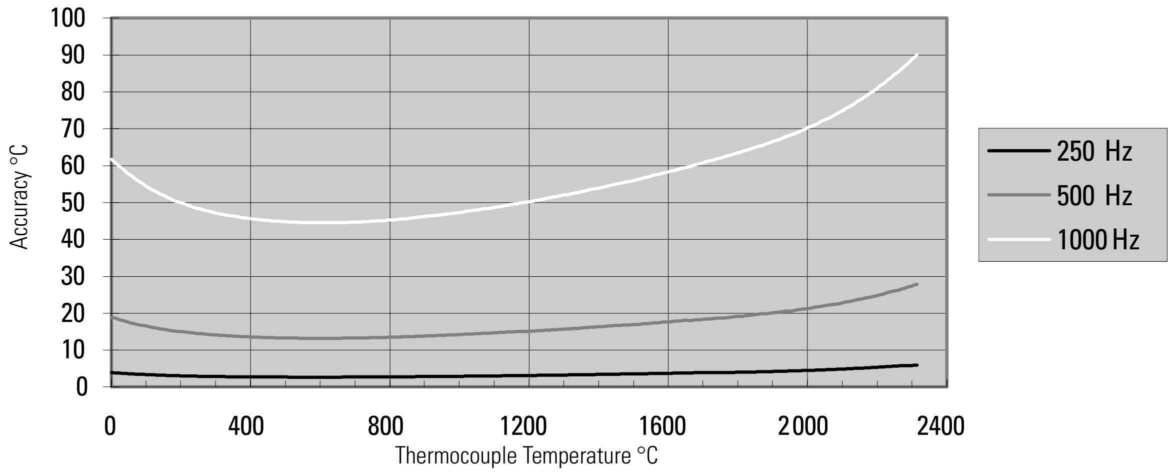


Figure A.4 Module Accuracy at 25°C (77°F) Ambient for Type C Thermocouple Using 250, 500, and 1 kHz Filter



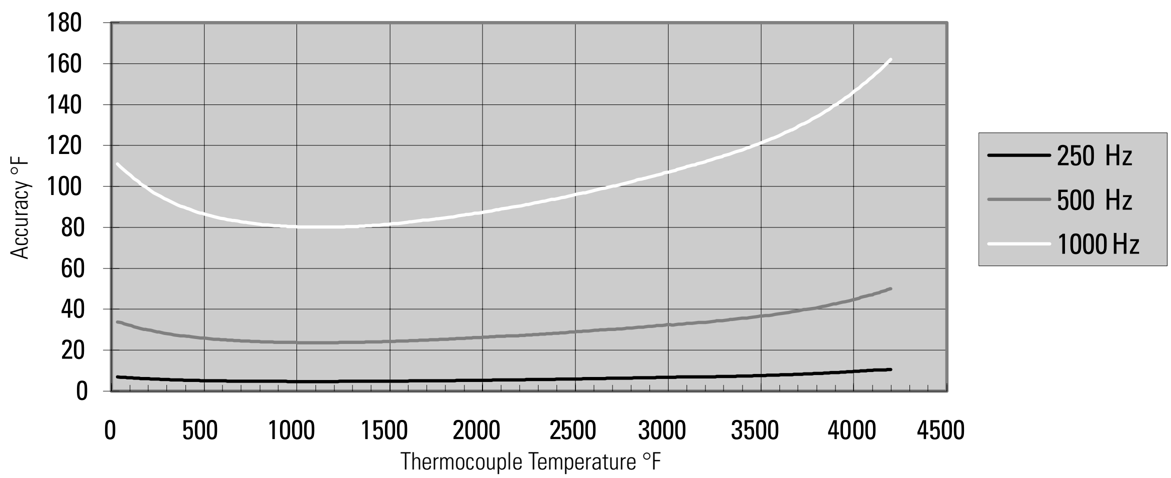
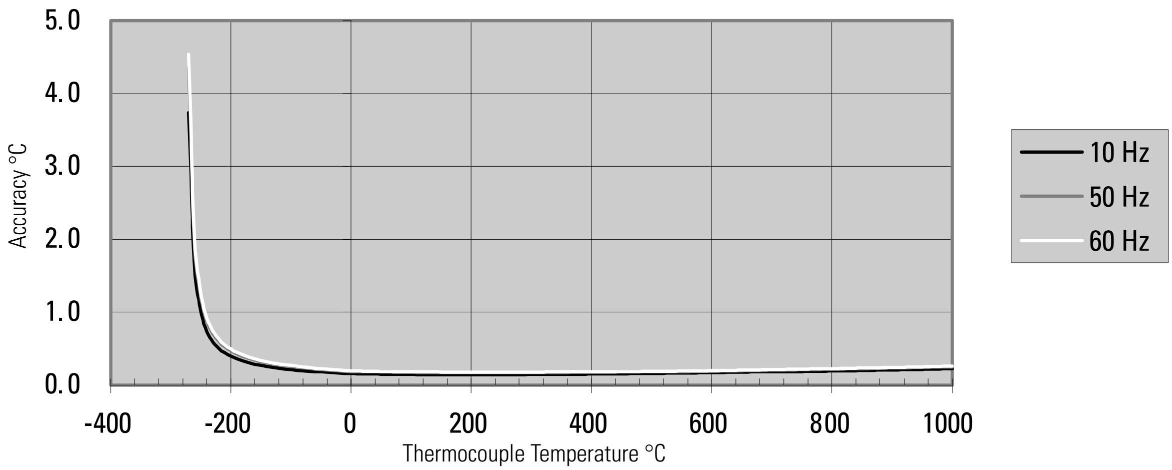


Figure A.5 Module Accuracy at 25°C (77°F) Ambient for Type E Thermocouple Using 10, 50, and 60 Hz Filter



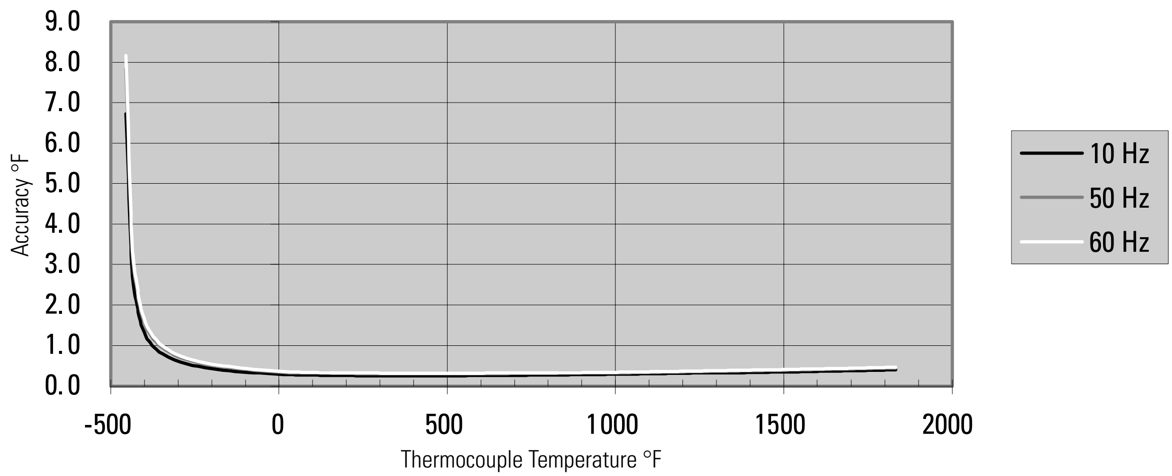
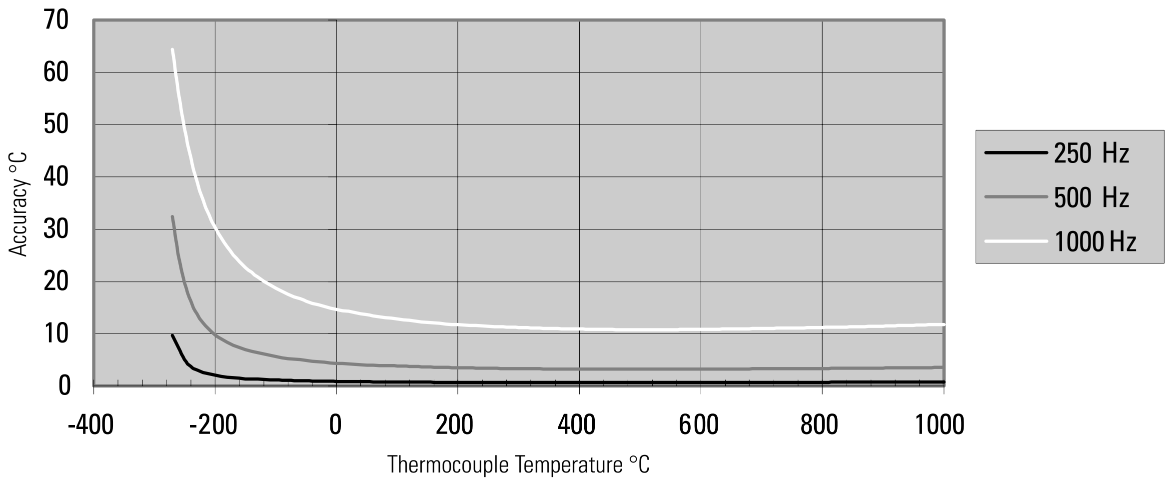


Figure A.6 Module Accuracy at 25°C (77°F) Ambient for Type E Thermocouple Using 250, 500, and 1 kHz Filter



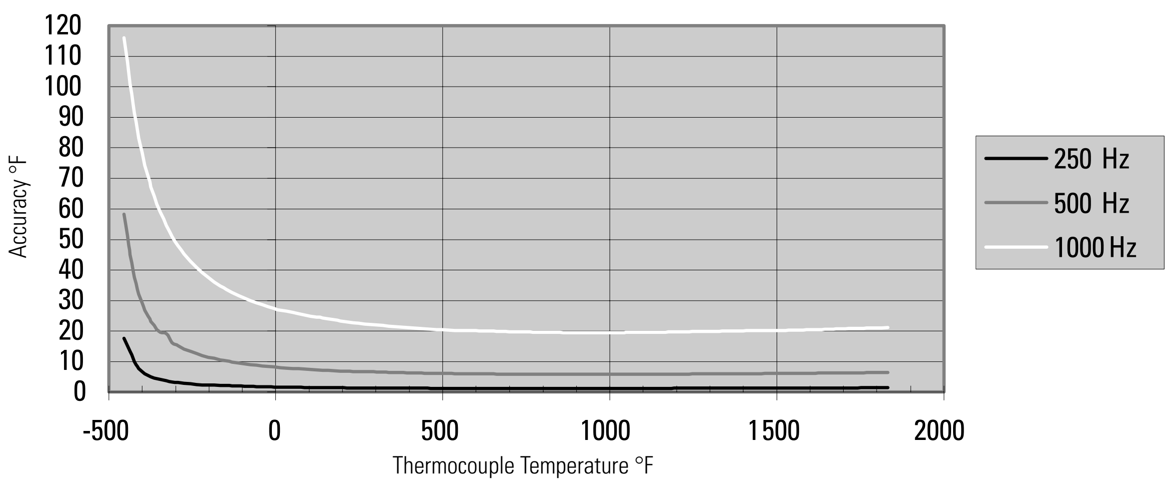
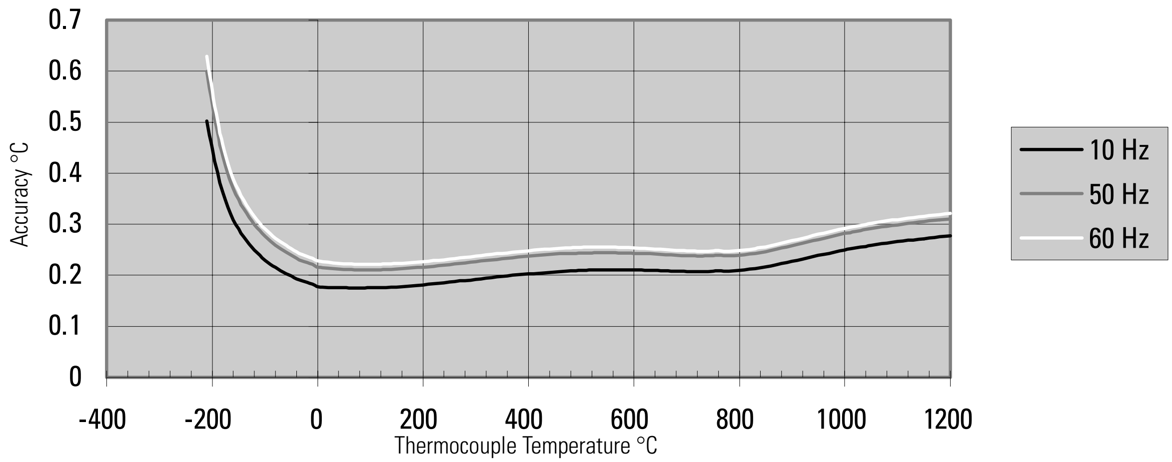


Figure A.7 Module Accuracy at 25°C (77°F) Ambient for Type J Thermocouple Using 10, 50, and 60 Hz Filter



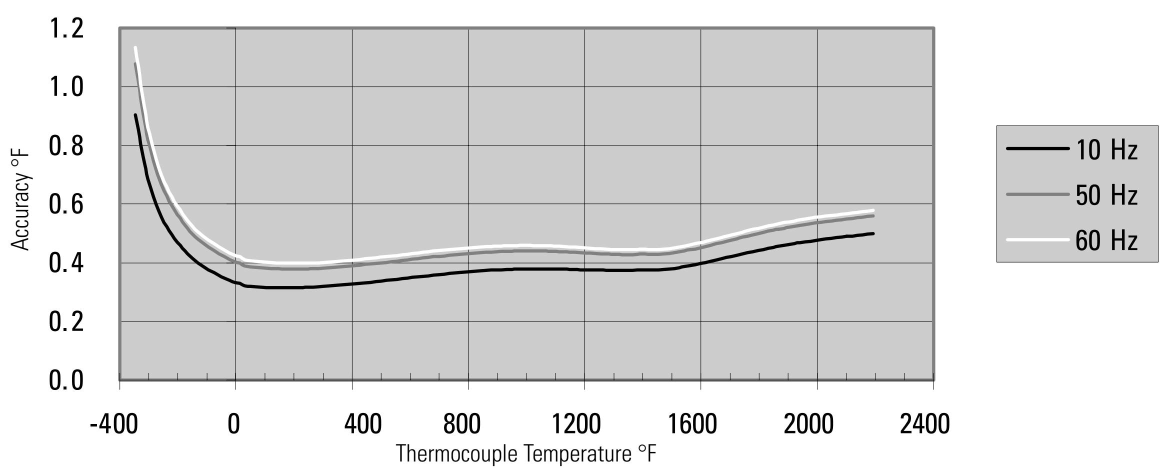
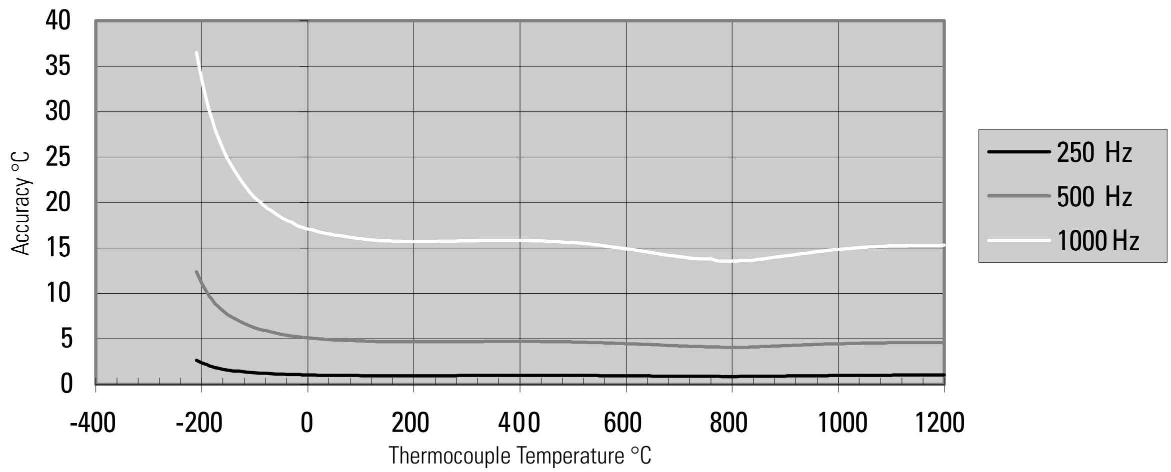


Figure A.8 Module Accuracy at 25°C (77°F) Ambient for Type J Thermocouple Using 250, 500, and 1 kHz Filter



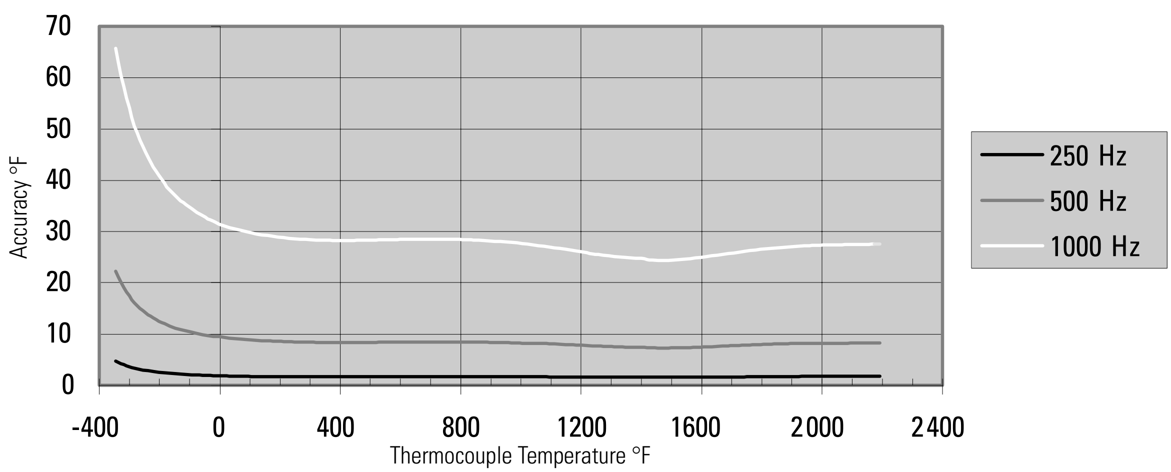
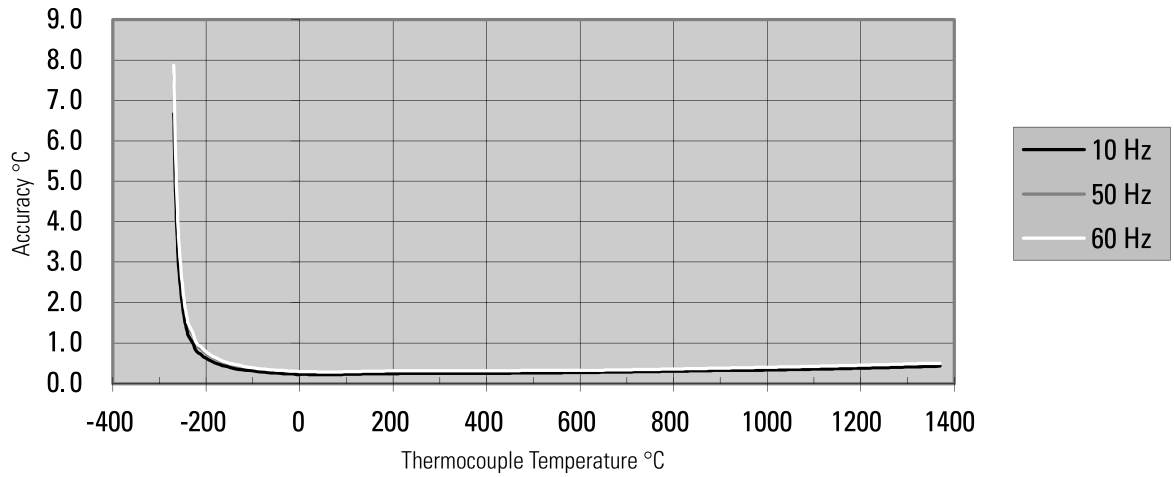


Figure A.9 Module Accuracy at 25°C (77°F) Ambient for Type K Thermocouple Using 10, 50, and 60 Hz Filter



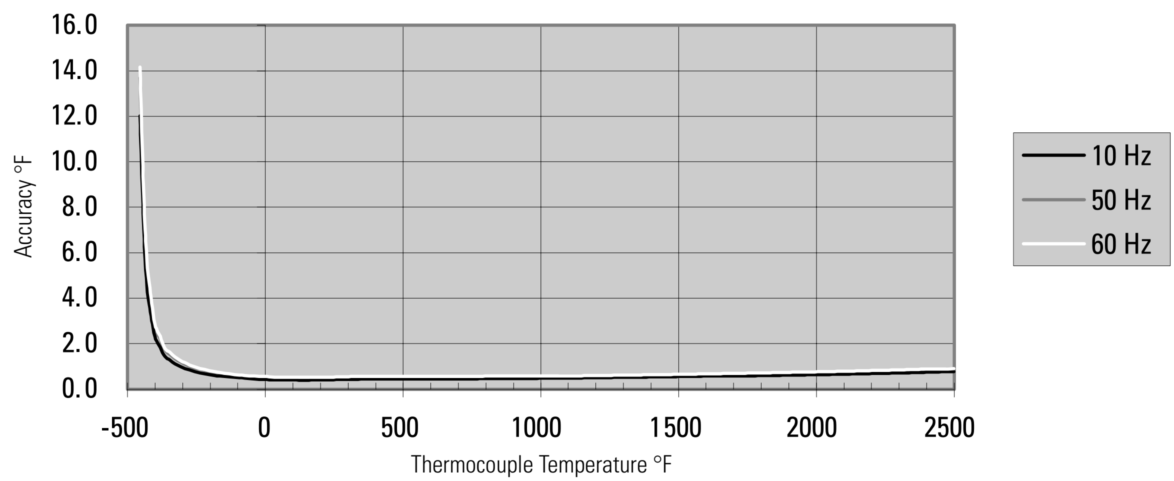
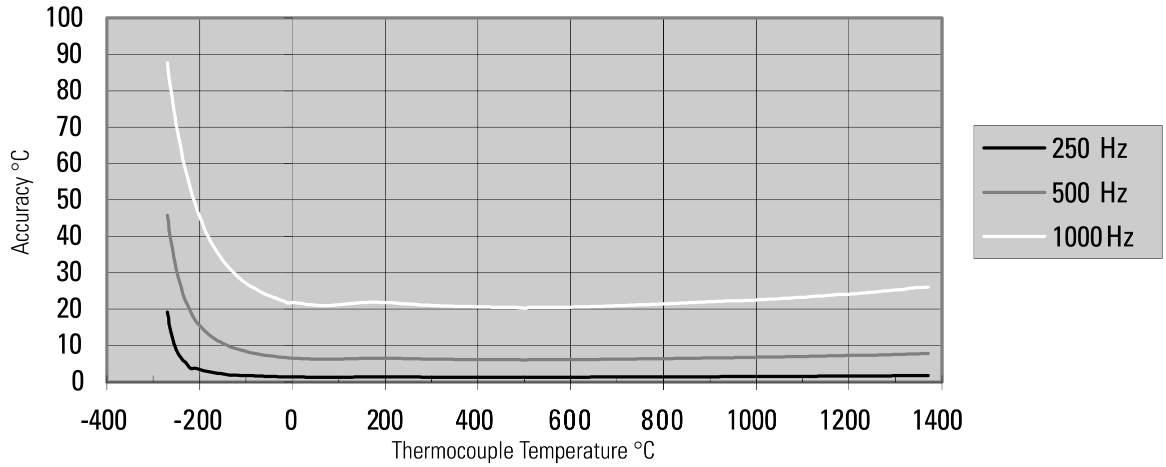


Figure A.10 Module Accuracy at 25°C (77°F) Ambient for Type K Thermocouple Using 250, 500, and 1 kHz Filter



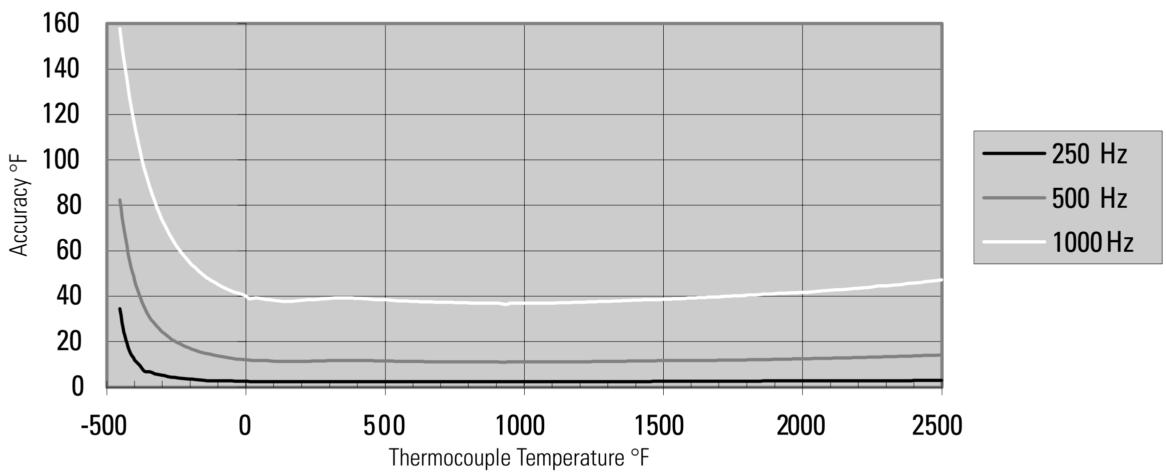
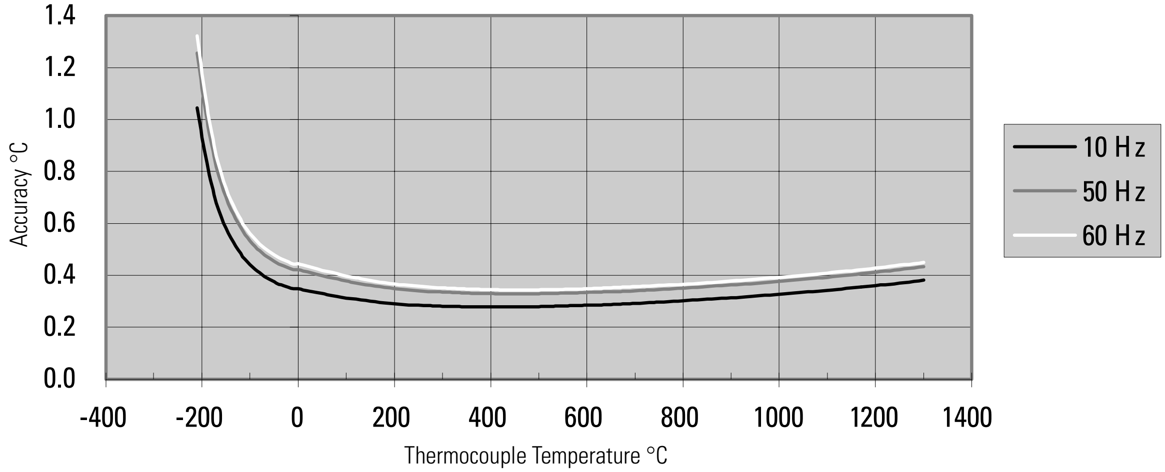


Figure A.11 Module Accuracy at 25°C (77°F) Ambient for Type N Thermocouple Using 10, 50, and 60 Hz Filter



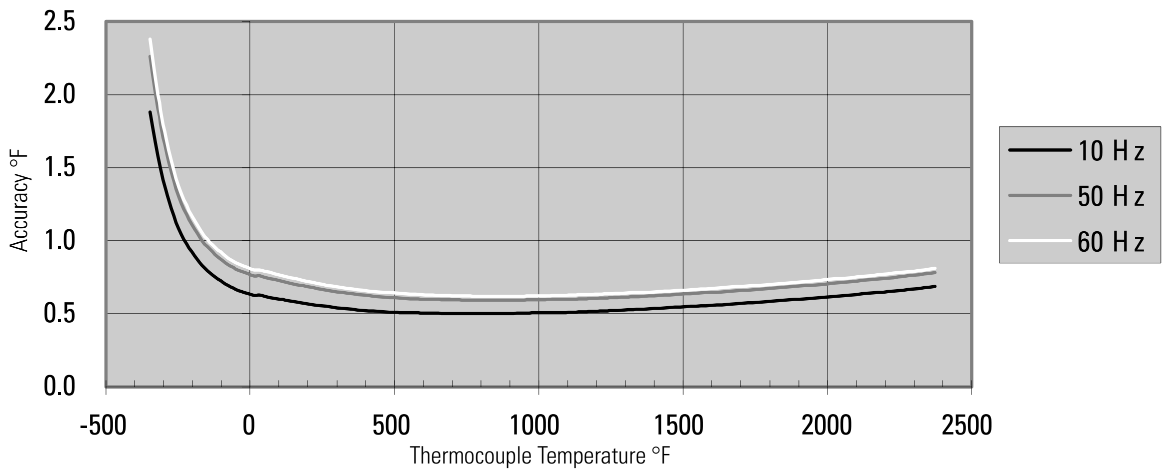
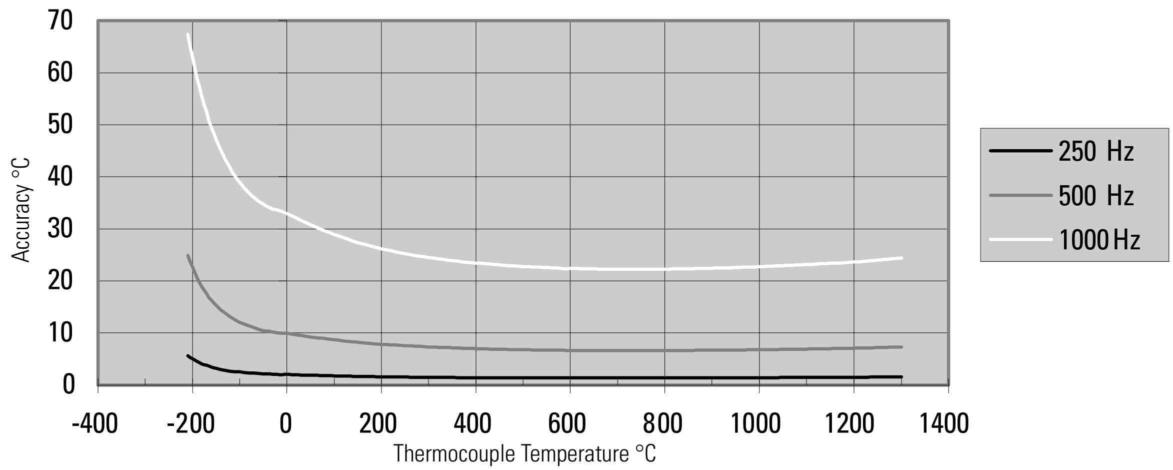


Figure A.12 Module Accuracy at 25°C (77°F) Ambient for Type N Thermocouple Using 250, 500, and 1 kHz Filter



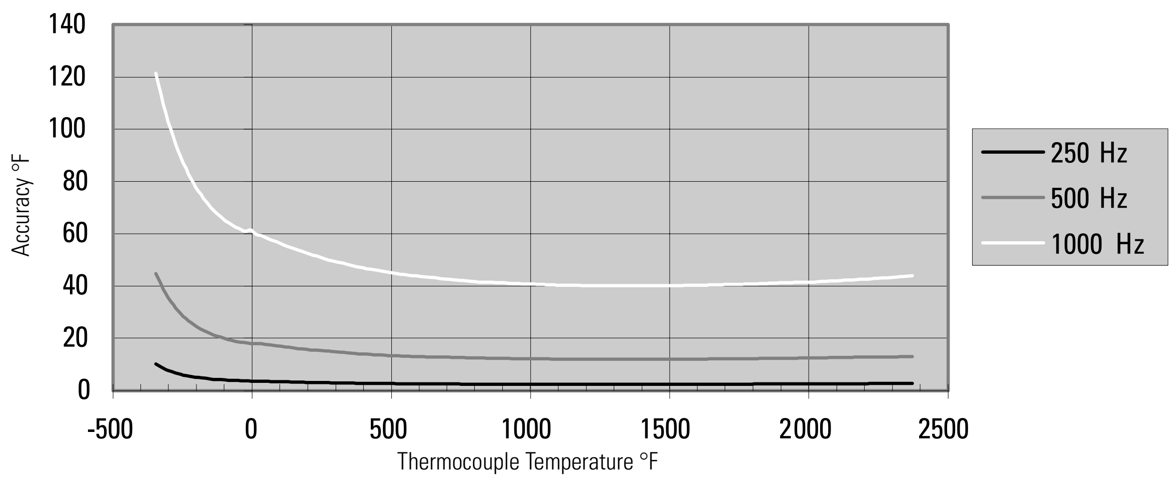
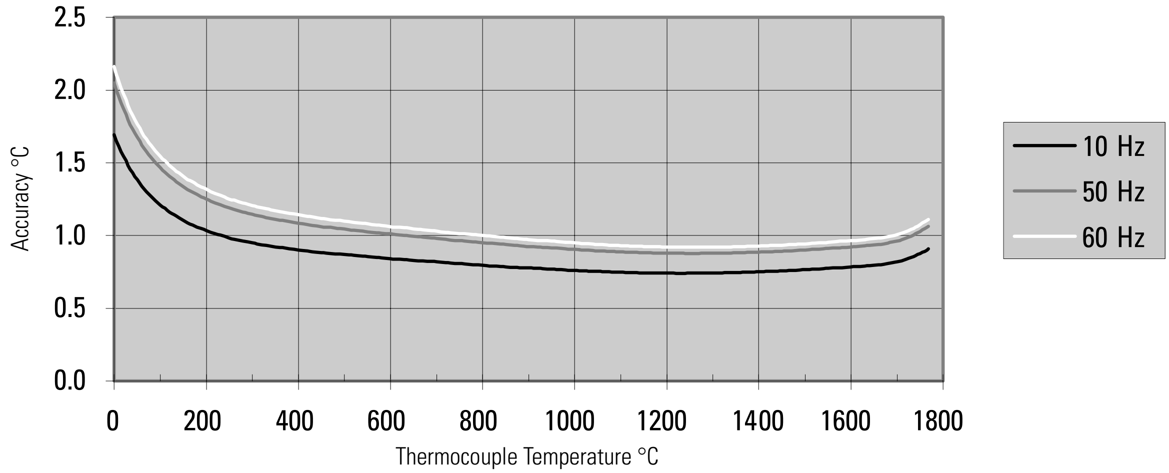


Figure A.13 Module Accuracy at 25°C (77°F) Ambient for Type R Thermocouple Using 10, 50, and 60 Hz Filter



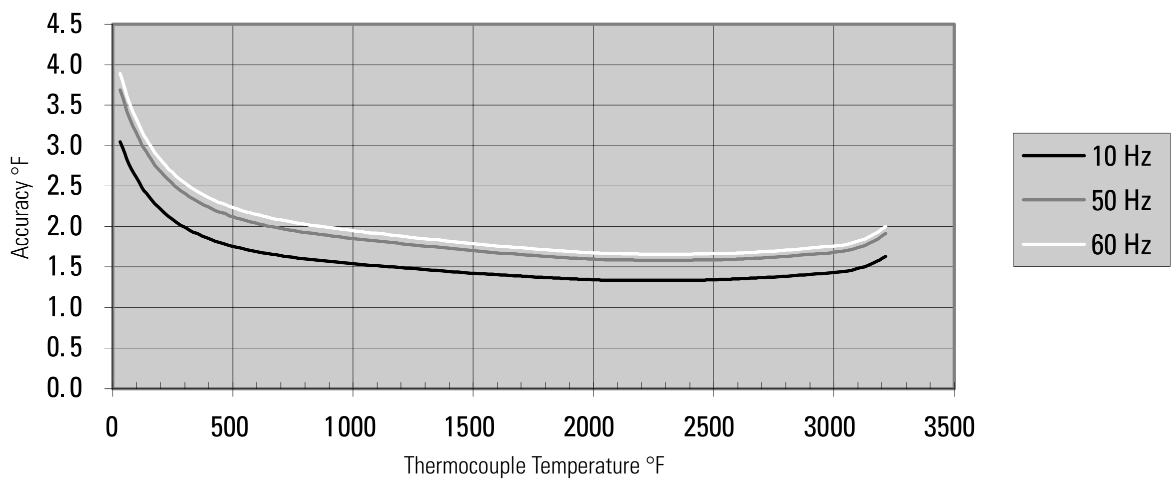
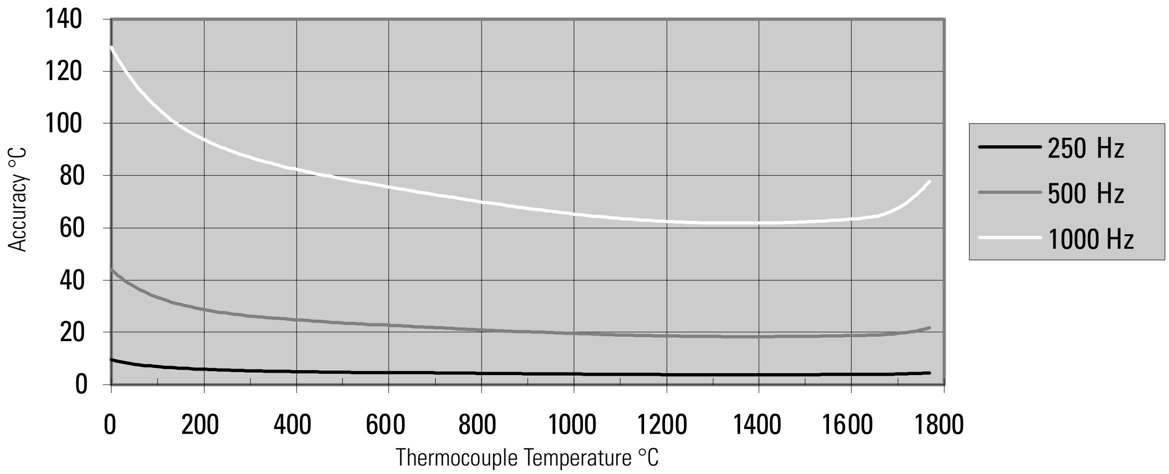


Figure A.14 Module Accuracy at 25°C (77°F) Ambient for Type R Thermocouple Using 250, 500, and 1 kHz Filter



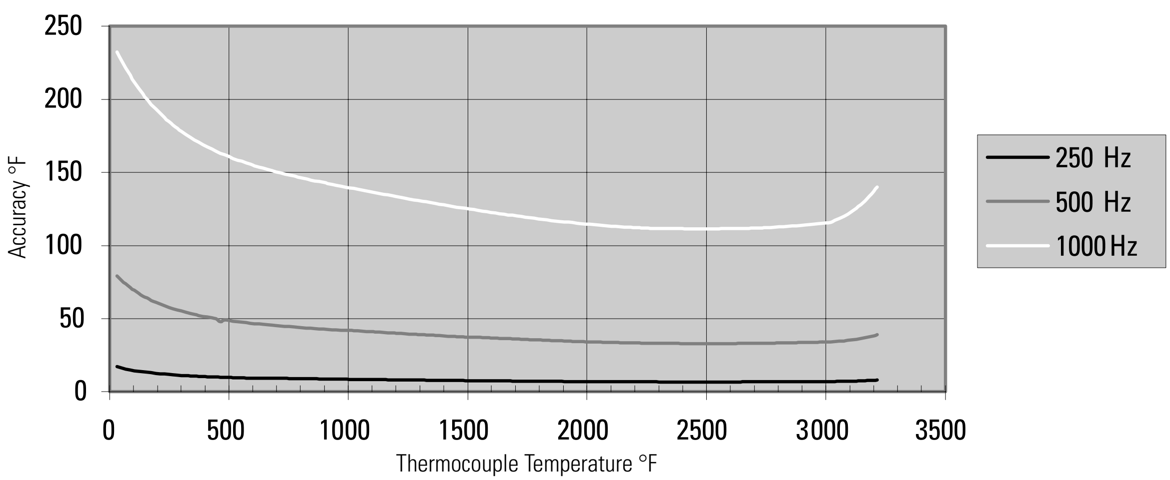
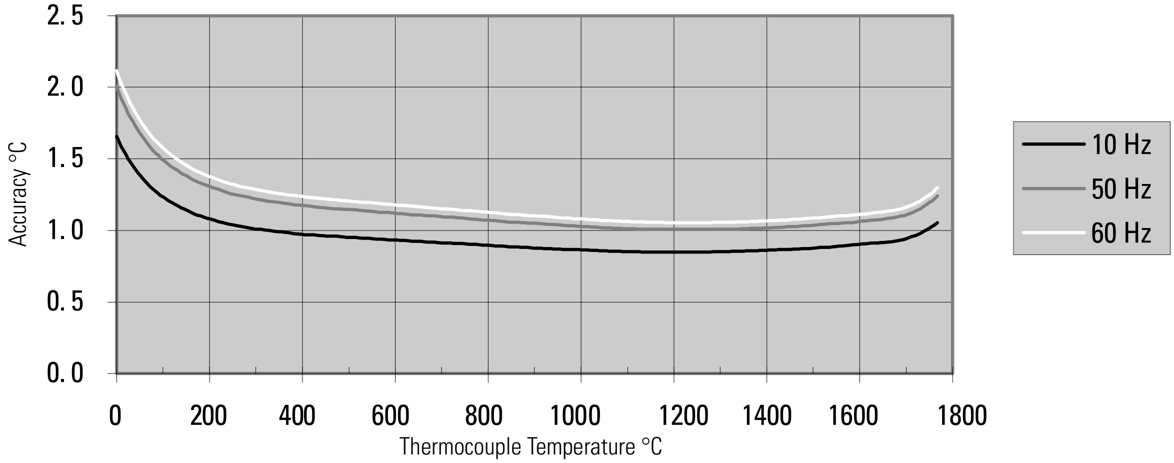


Figure A.15 Module Accuracy at 25°C (77°F) Ambient for Type S Thermocouple Using 10, 50, and 60 Hz Filter



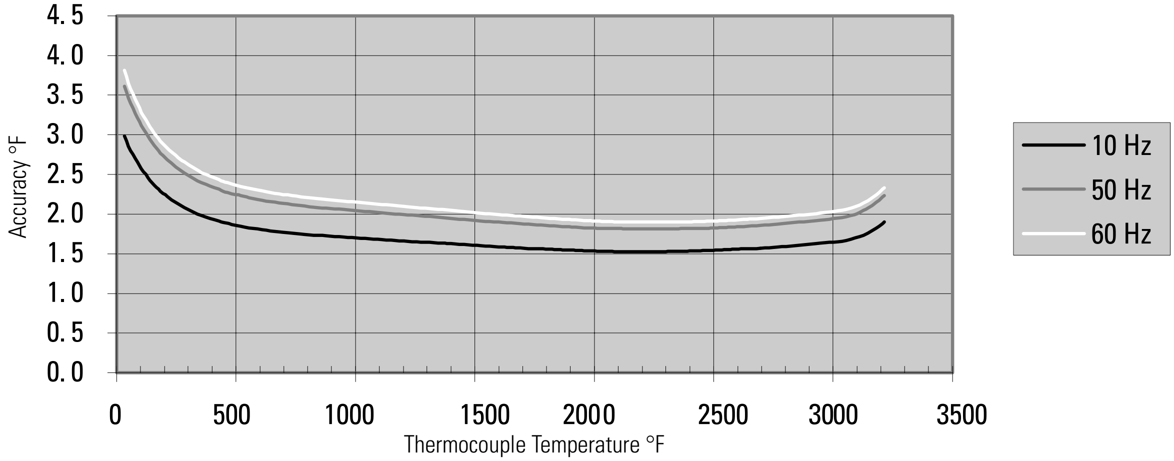
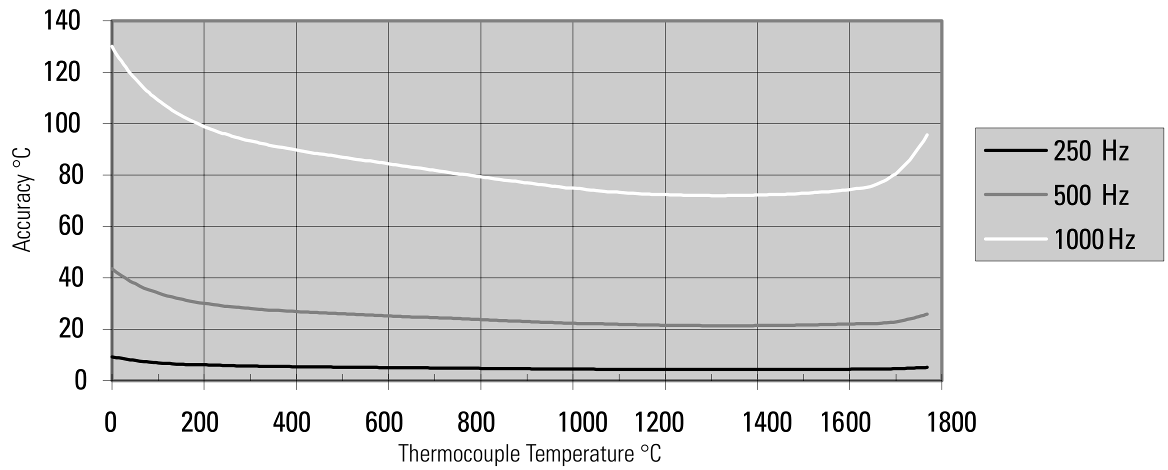


Figure A.16 Module Accuracy at 25°C (77°F) Ambient for Type S Thermocouple Using 250, 500, and 1 kHz Filter



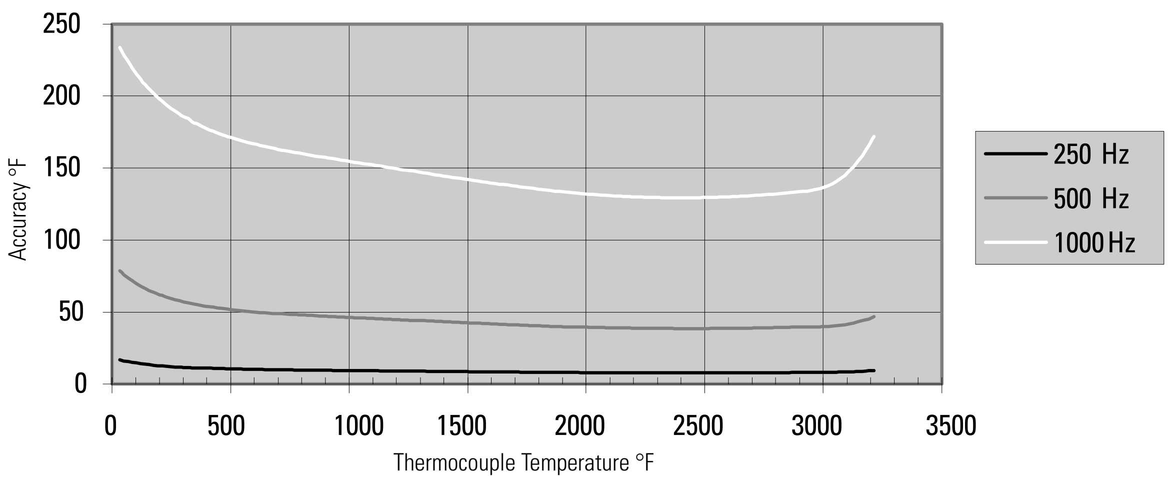
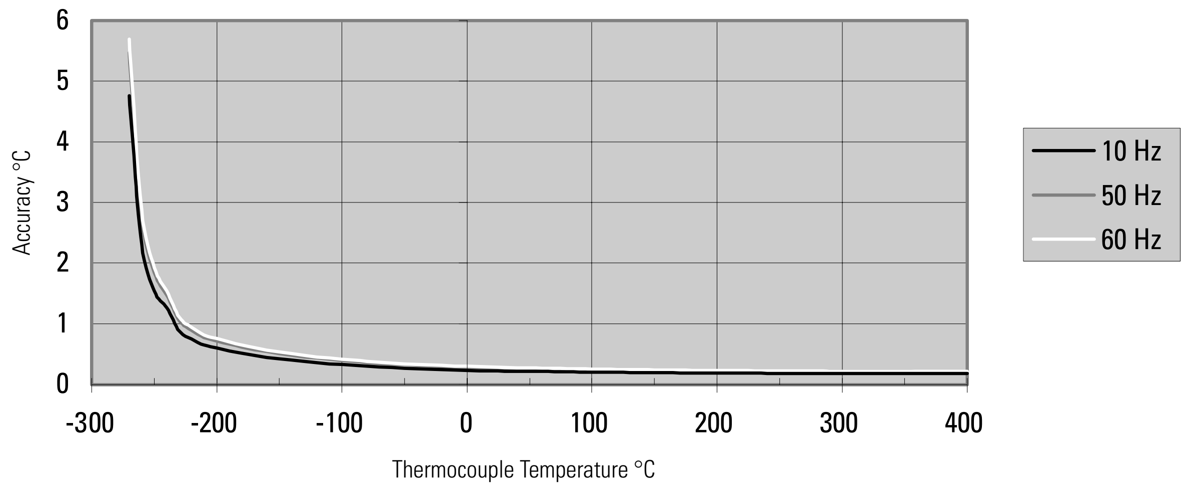


Figure A.17 Module Accuracy at 25°C (77°F) Ambient for Type T Thermocouple Using 10, 50, and 60 Hz Filter



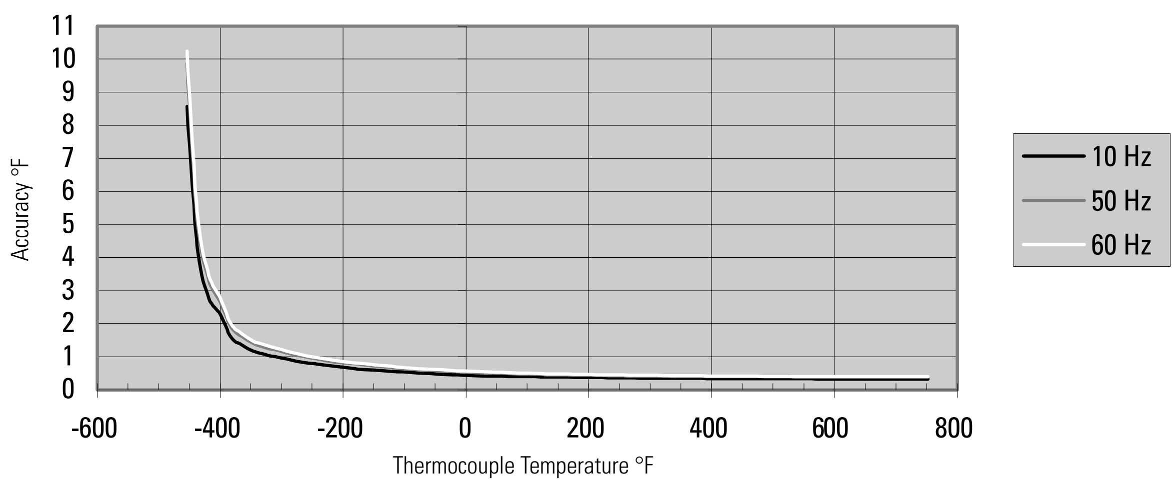
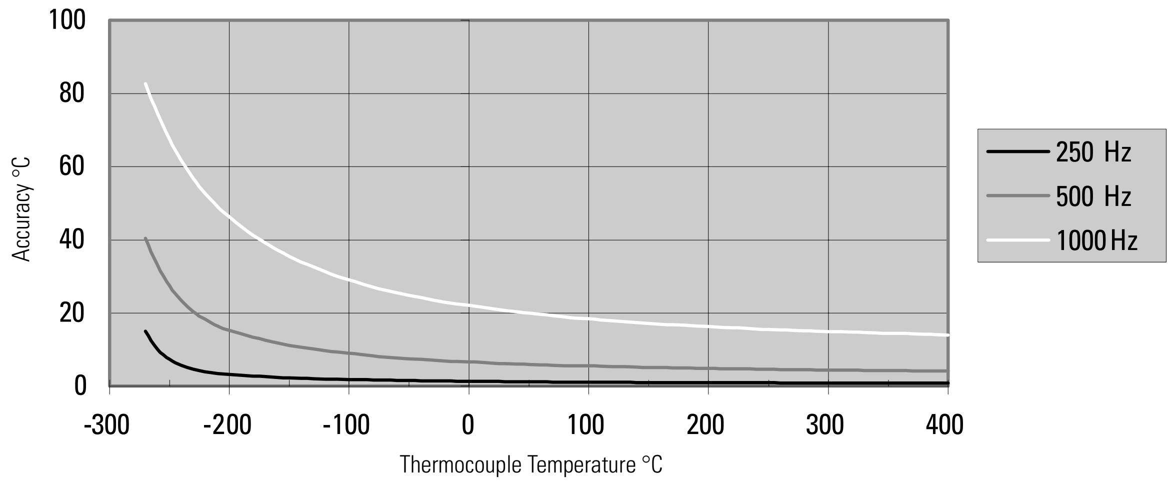
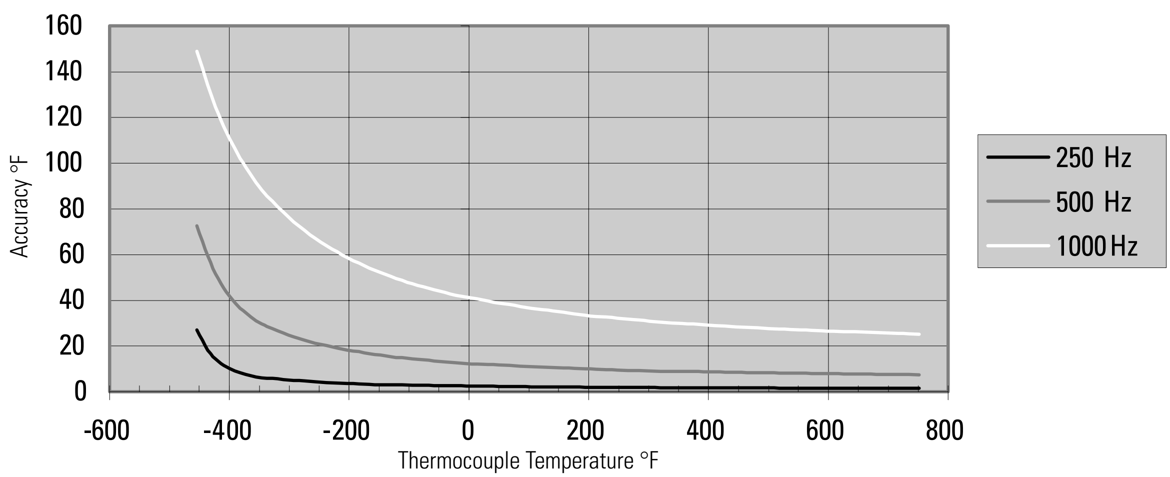


Figure A.18 Module Accuracy at 25°C (77°F) Ambient for Type T Thermocouple Using 250, 500, and 1 kHz Filter





Two's Complement Binary Numbers

The processor memory stores 16-bit binary numbers. Two's complement binary is used when performing mathematical calculations internal to the processor. Analog input values from the analog modules are returned to the processor in 16-bit two's complement binary format. For positive numbers, the binary notation and two's complement binary notation are identical.

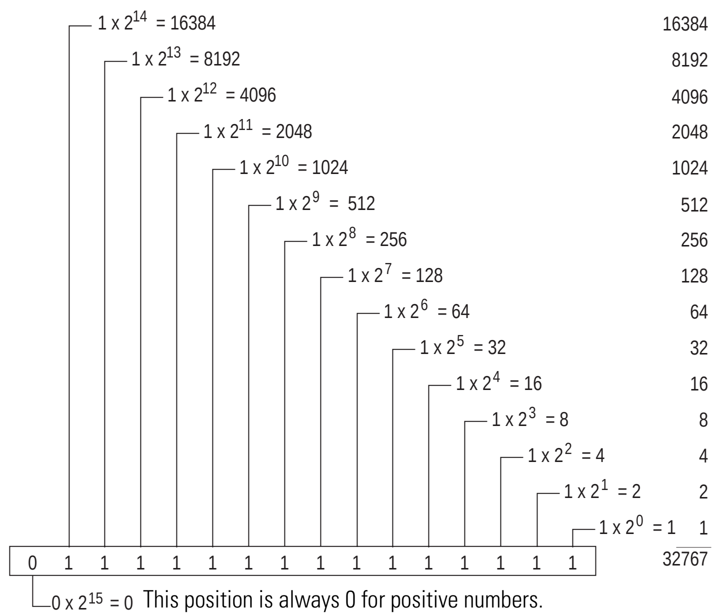
As indicated in the figure on the next page, each position in the number has a decimal value, beginning at the right with 2^0 and ending at the left with 2^{15}. Each position can be 0 or 1 in the processor memory. A 0 indicates a value of 0; a 1 indicates the decimal value of the position. The equivalent decimal value of the binary number is the sum of the position values.

Positive Decimal Values

The far left position is always 0 for positive values. As indicated in the figure below, this limits the maximum positive decimal value to 32767 (all positions are 1 except the far left position). For example:

0000 1001 0000 1110 = $2^{11}+2^{8}+2^{3}+2^{2}+2^{1}$ = 2048+256+8+4+2 = 2318

0010 0011 0010 1000 = $2^{13}+2^{9}+2^{8}+2^{5}+2^{3}$ = 8192+512+256+32+8 = 9000

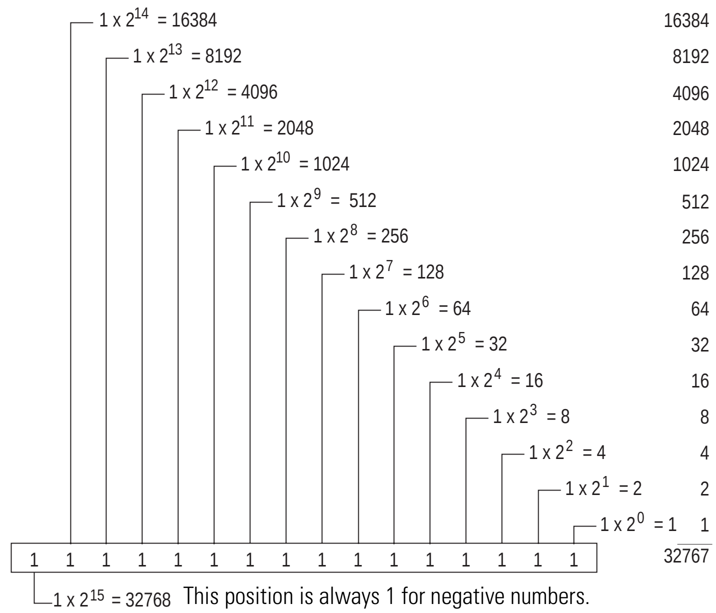


Negative Decimal Values

In two's complement notation, the far left position is always 1 for negative values. The equivalent decimal value of the binary number is obtained by subtracting the value of the far left position, 32768, from the sum of the values of the other positions. In the figure below (all positions are 1), the value is 32767 - 32768 = -1. For example:

$$1111\ 1000\ 0010\ 0011 = (2^{14}+2^{13}+2^{12}+2^{11}+2^{5}+2^{1}+2^{0}) - 2^{15} =$$

$$(16384+8192+4096+2048+32+2+1) - 32768 = 30755 - 32768 = -2013$$



Thermocouple Descriptions

The information in this appendix 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 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.

Type B Thermocouples

This section discusses Platinum-30 percent Rhodium Alloy Versus Platinum-6 percent Rhodium Alloy thermocouples, commonly called type B thermocouples. This type is sometimes referred to by the nominal chemical composition of its thermoelements: platinum - 30 percent rhodium versus platinum - 6 percent rhodium or “30-6”. The positive (BP) thermoelement typically contains 29.60 ± 0.2 percent rhodium and the negative (BN) thermoelement usually contains 6.12 ± 0.02 percent 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 percent shall be alloyed with platinum of 99.99 percent 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 percent 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 -2.6μV near 21°C to a maximum of 2.3μV 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 3μV. At temperatures above

1100°C, an additional measurement error of 3μV (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 percent between 870°C and 1700°C. Type B thermocouples can also be supplied to meet special tolerances of ±0.25 percent. 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 (0.51 mm) 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.

Type E Thermocouples

This section describes Nickel-Chromium Alloy Versus Copper-Nickel Alloy thermocouples, known as type E 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 20.3K) where their Seebeck coefficient is about 8mV/°C. They may even be used down to liquid helium temperatures (4.2°K) although their Seebeck coefficient becomes quite low, only about 2mV/°C at 4K. 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 20K, the non-letter-designated thermocouple, KP versus gold-0.07, 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 gauge wires are recommended because the oxidation rate is rapid at elevated temperatures. About 50 years ago, Dahl [11] studied the thermoelectric stability of EP and EN type alloys when heated in air at elevated temperatures. 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 percent (whichever is greater) between 0°C and 900°C, and ±1.7°C or ±1 percent (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 percent (whichever is greater) between 0°C and 900°C, and ±1°C or ±0.5 percent (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 (3.25 mm) wire. It decreases to 650°C for AWG 14 (1.63 mm), 540°C for AWG 20 (0.81 mm), 430°C for AWG 24 or 28 (0.51 mm or 0.33 mm), and 370°C for AWG 30 (0.25 mm). 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.

Type J Thermocouples

This section discusses Iron Versus Copper-Nickel Alloy (SAMA) thermocouples, called type J thermocouples. A type J thermocouple 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 percent 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 gauge 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 (3.3 mm) 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 40µV (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 percent (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 (3.25 mm) wire. For smaller diameter wires the suggested upper temperature limit decreases to 590°C for AWG 14 (1.63 mm), 480°C for AWG 20 (0.81 mm), 370°C for AWG 24 or 28 (0.51 mm or 0.33 mm), and 320°C for AWG 30 (0.25 mm). 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.

Type K Thermocouples

This section describes Nickel-Chromium Alloy Versus Nickel-Aluminum Alloy thermocouples, called type K 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 percent nickel, 9 to about 9.5 percent chromium, both silicon and iron in amounts up to about 0.5 percent, 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 percent nickel, 1 to 1.5 percent silicon, 1 to 2.3 percent aluminum, 1.6 to 3.2 percent manganese, up to about 0.5 percent 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 4K) but that its Seebeck coefficient becomes quite small below 20K. Its Seebeck coefficient at 20K is only about 4µV/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 20K. 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, avoid their use in atmospheres that promote “green-rot” corrosion [9] of the positive thermoelement. 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 percent (whichever is greater) between 0°C and 1250°C, and ±2.2°C or ±2 percent (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 (3.25 mm) wire. It decreases to 1090°C for AWG 14 (1.63 mm), 980°C for AWG 20 (0.81 mm), 870 for AWG 24 or 28 (0.51 mm or 0.33 mm), and 760°C for AWG 30 (0.25 mm). 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.

Type N Thermocouples

This section describes Nickel-Chromium-Silicon Alloy Versus Nickel-Silicon-Magnesium Alloy thermocouples, commonly referred to as type N 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 percent nickel, 14 to 14.4 percent chromium, 1.3 to 1.6 percent silicon, plus small amounts (usually not exceeding about 0.1 percent) of other elements such as magnesium, iron, carbon, and cobalt. The negative thermoelement, NN, is an alloy that typically contains about 95 percent nickel, 4.2 to 4.6 percent silicon, 0.5 to 1.5 percent magnesium, plus minor impurities of iron, cobalt, manganese and carbon totaling about 0.1 to 0.3 percent. 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 4K) but that its Seebeck coefficient becomes very small below 20K. Its Seebeck coefficient at 20K is about 2.5μV/K, roughly one-third that of type E thermocouples which are the most suitable of the letter-designated thermocouples types for measurements down to 20K. 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 3.25 mm 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 percent (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 (3.25 mm) wire. It decreases to 1090°C for AWG 14 (1.63 mm), 980°C for AWG 20 (0.81 mm), 870°C for AWG 24 or 28 (0.51 mm or 0.33 mm), and 760°C for AWG 30 (0.25 mm). 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.

Type R Thermocouples

This section describes Platinum-13 percent Rhodium Alloy Versus Platinum thermocouples, called type R thermocouples. This type is often referred to by the nominal chemical composition of its positive (RP) thermoelement: platinum-13 percent rhodium. The negative (RN) thermoelement is commercially-available platinum that has a nominal purity of 99.99 percent [21]. An industrial consensus standard (ASTM E1159-87) specifies that rhodium having a nominal purity of 99.98 percent shall be alloyed with platinum of 99.99 percent purity to produce the positive thermoelement, which typically contains 13.00 ± 0.05 percent 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 percent 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 percent (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 percent (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 (0.51 mm) 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.

Type S Thermocouples

This section describes Platinum-10 percent Rhodium Alloy Versus Platinum thermocouples, commonly known as type S thermocouples. This type is often referred to by the nominal chemical composition of its positive (SP) thermoelement: platinum-10 percent rhodium. The negative (SN) thermoelement is commercially available platinum that has a nominal purity of 99.99 percent [21]. An industrial consensus standard (ASTM E1159-87) specifies that rhodium having a nominal purity of 99.98 percent shall be alloyed with platinum of 99.99 percent purity to produce the positive thermoelement, which typically contains 10.00 ± 0.05 percent 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 percent 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 percent) per weight percent increase in rhodium content; the Seebeck coefficient increases by about 4 percent 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 percent (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 percent (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 (0.51 mm) 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.

Type T Thermocouples

This section describes Copper Versus Copper-Nickel Alloy thermocouples, called type T 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 percent pure copper with an oxygen content varying from 0.02 to 0.07 percent (depending upon sulfur content) and with other impurities totaling about 0.01 percent. 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 percent 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 percent copper, 45 percent nickel, and small but thermoelectrically significant amounts, about 0.1 percent 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, if 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 4K) but that its Seebeck coefficient becomes quite small below 20K. Its Seebeck coefficient at 20K is only about 5.6μV/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 70K 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 20K. 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 (1.63 mm) 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 percent (whichever is greater) between 0°C and 350°C, and ±1°C or ±1.5 percent (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 (1.63 mm) wire. It decreases to 260°C for AWG 20 (0.81 mm), 200°C for AWG 24 or 28 (0.51 mm or 0.33 mm), and 150°C for AWG 30 (0.25 mm). 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.

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Using Thermocouple Junctions

This appendix describes the types of thermocouple junctions available, and explains the trade-offs in using them with the 1762-IT4 thermocouple/mV analog input module.

ATTENTION

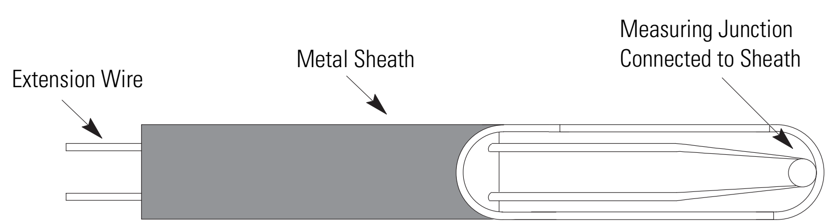
Take care when choosing a thermocouple junction, and connecting it from the environment to the module. If you do not take adequate precautions for a given thermocouple type, the electrical isolation of the module might be compromised.

Available thermocouple junctions are:

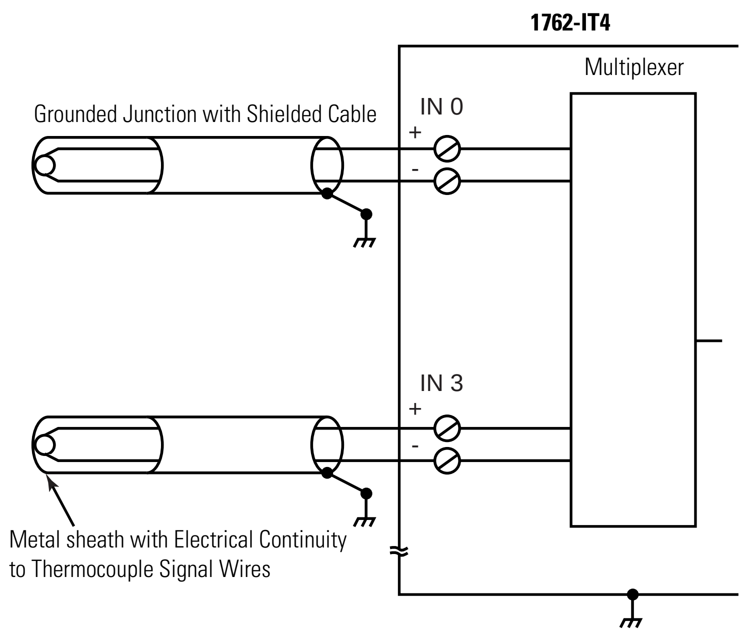
- grounded
- ungrounded (isolated)
- exposed

Using a Grounded Junction Thermocouple

With a grounded junction thermocouple, the measuring junction is physically connected to the protective sheath, forming a completely sealed integral junction. If the sheath is metal (or electrically conductive), 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 described in Using an Exposed Junction Thermocouple on page D-3.



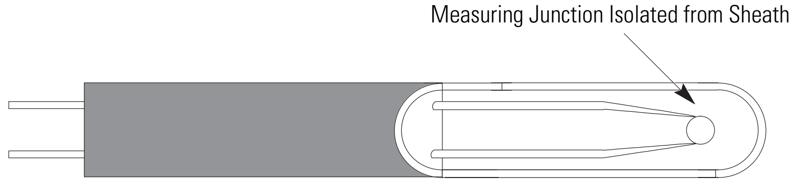
The shield input terminals for a grounded junction thermocouple are connected together and then connected to chassis ground. Use of this thermocouple with an electrically conductive sheath removes the thermocouple signal to chassis ground isolation of the module. In addition, if multiple grounded junction thermocouples are used, the module channel-to-channel isolation is removed, since there is no isolation between signal and sheath (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.



Rockwell Automation recommends that a grounded junction thermocouple have a protective sheath made of electrically insulated material (for example, ceramic). An alternative is to float the metal sheath with respect to any path to chassis ground or to another thermocouple metal sheath. Thus, the metal sheath must be insulated from electrically conductive process material, and have all connections to chassis ground broken. Note that a floated sheath can result in a less noise-immune thermocouple signal.

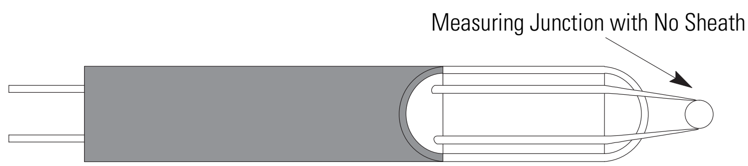
Using an Ungrounded (Isolated) Junction Thermocouple

An ungrounded (isolated) junction thermocouple uses a measuring junction that is electrically isolated from the protective metal sheath. This junction type is often used in situations when noise will affect readings, as well as situations using frequent or rapid temperature cycling. For this type of thermocouple junction, the response time is longer than for the grounded junction.

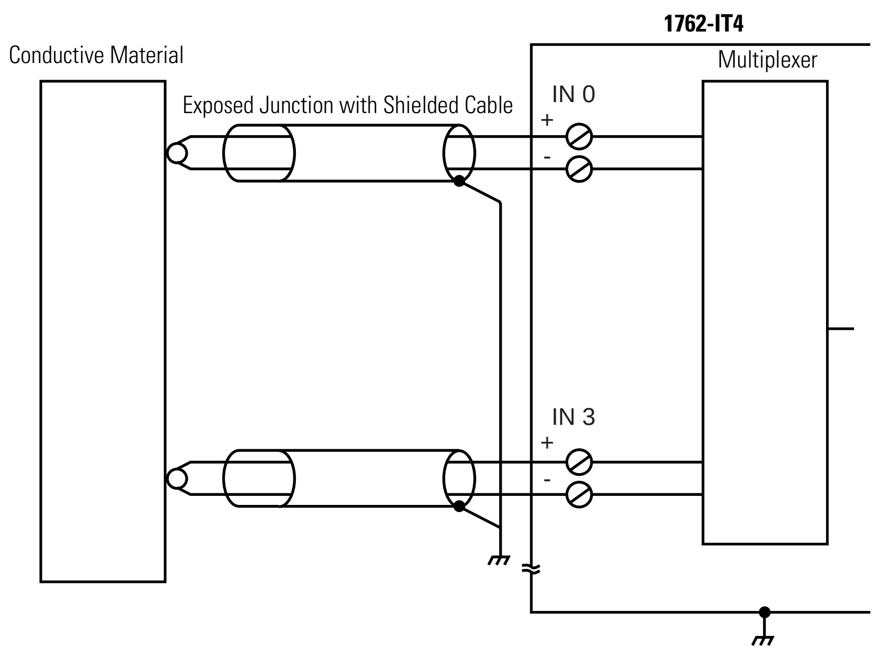


Using an Exposed Junction Thermocouple

An exposed junction thermocouple uses a measuring junction that does not have a protective metal sheath. A thermocouple with this junction type provides the fastest response time but leaves thermocouple wires unprotected against corrosive or mechanical damage.



As shown in the next illustration, using an exposed junction thermocouple can result in removal of channel-to-channel isolation. Isolation is removed if multiple exposed thermocouples are in direct contact with electrically conductive process material.



To prevent violation of channel-to-channel isolation:

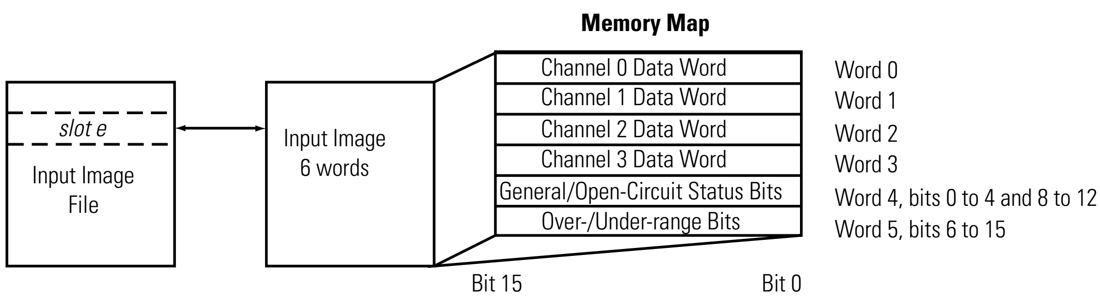
- For multiple exposed junction thermocouples, do not allow the measuring junctions to make direct contact with electrically conductive process material.
- Preferably use a single exposed junction thermocouple with multiple ungrounded junction thermocouples.
- Consider using all ungrounded junction thermocouples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

Module Configuration Using MicroLogix 1200 and RSLogix 500

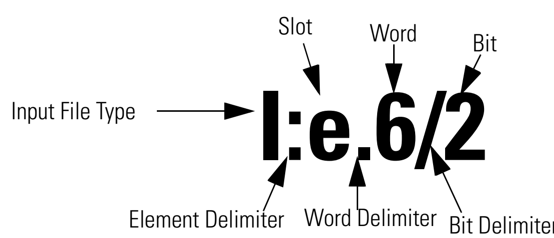
This appendix examines the 1762-IT4 module's addressing scheme and describes module configuration using RSLogix 500 and a MicroLogix 1200 controller.

Module Addressing

The following memory map shows the input image table for the module. Detailed information on the image table is located in Chapter 3.



For example, to obtain the general status of channel 2 of the module located in slot e, use address I:e.6/2.



1762-IT4 Configuration File

The configuration file contains information you use to define the way a specific channel functions. The configuration file is explained in more detail in Configuring Channels on page 3-4.

The configuration file is modified using the programming software configuration screen. For an example of module configuration using RSLogix 500, see Configuration Using RSLogix 500 Version 5.50 or Higher on page E-2.

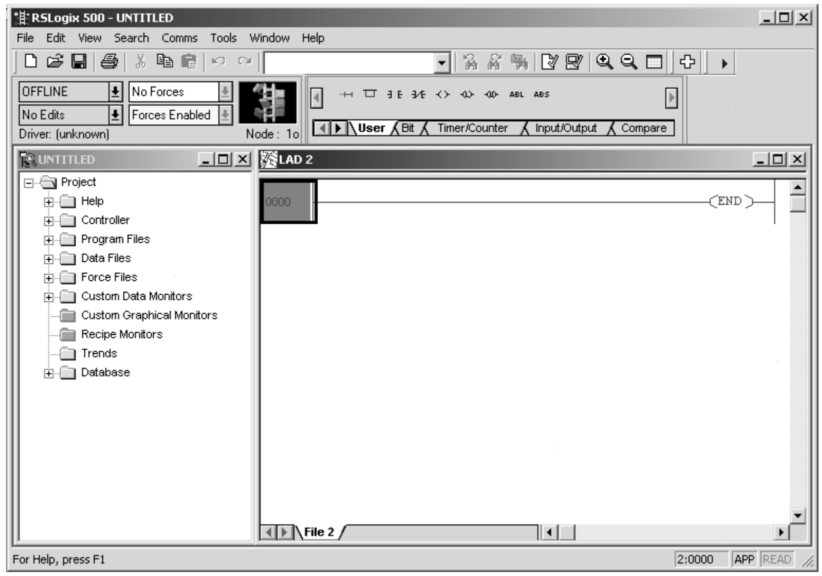
Table 5.1 Software Configuration Channel Defaults

Parameter	Default Setting
Disable/Enable Channel	Disable
Filter Frequency	60 Hz
Input Type	Thermocouple Type J
Data Format	Raw/Proportional
Temperature Units	°C
Open-Circuit Response	Upscale
Disable Cyclic Calibration	Enable

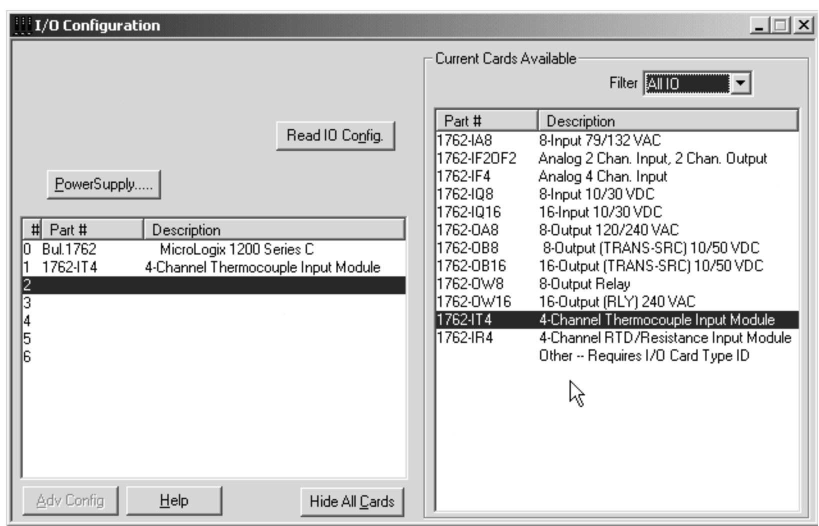
Configuration Using RSLogix 500 Version 5.50 or Higher

This example takes you through configuring your 1762-IT4 thermocouple/mV input module with RSLogix 500 programming software, assumes your module is installed as expansion I/O in a MicroLogix 1200 system, and that RSLinx™ is properly configured and a communications link has been established between the MicroLogix processor and RSLogix 500.

Start RSLogix and create a MicroLogix 1200 application. The following screen appears:

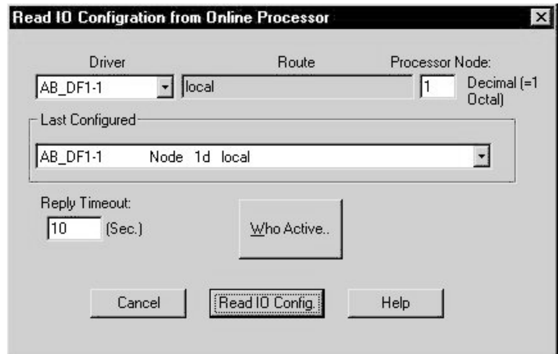


While offline, double-click on the IO Configuration icon under the controller folder and the following IO Configuration screen appears.

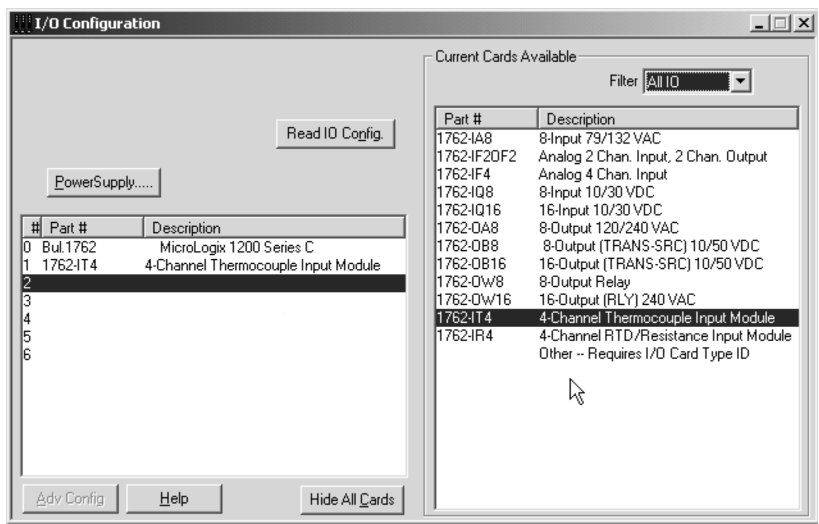


This screen allows you to manually enter expansion modules into expansion slots, or to automatically read the configuration of the controller. To read the existing controller configuration, click on the Read IO Config button.

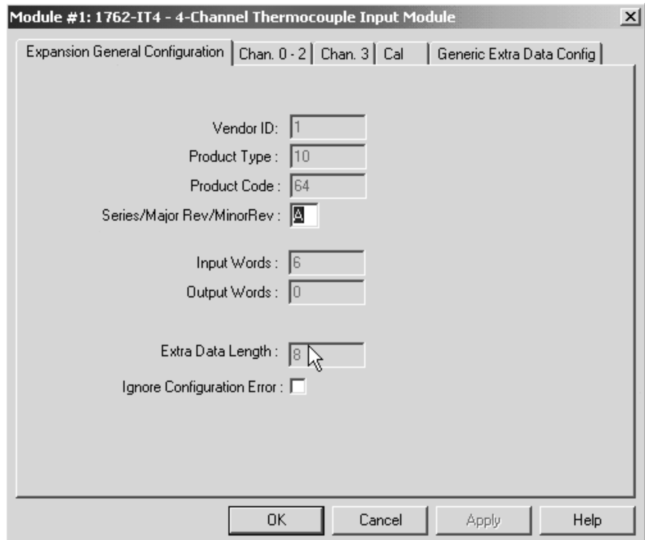
A communications dialog appears, identifying the current communications configuration so that you can verify the target controller. If the communication settings are correct, click on Read IO Config.



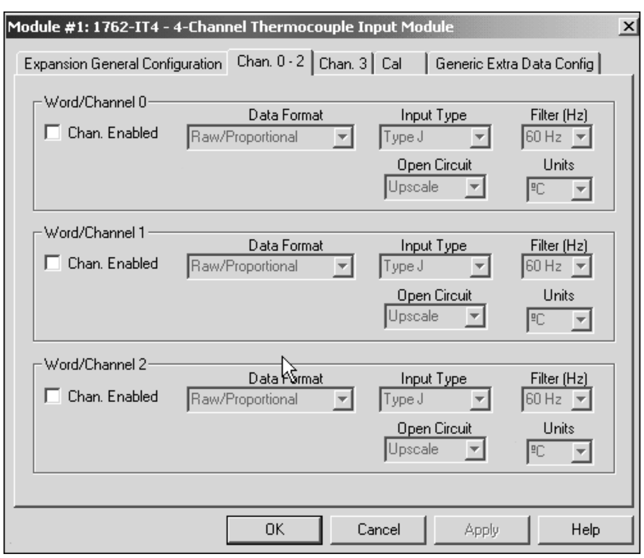
The actual I/O configuration is displayed. In this case, it matches our manual configuration.

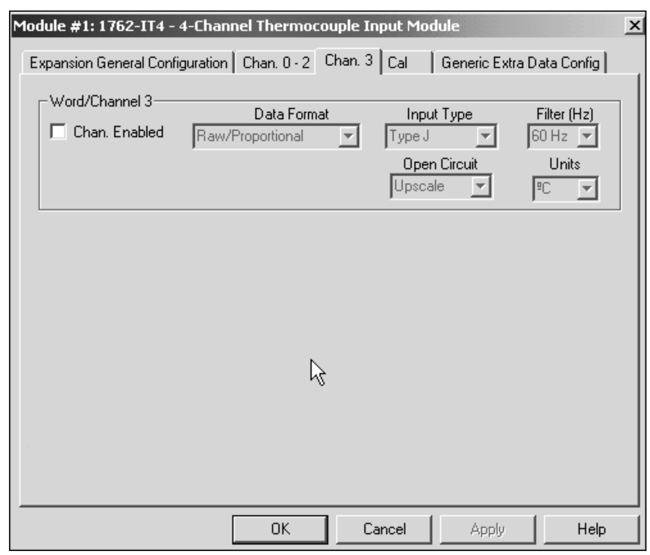


The 1762-IT4 module is installed in slot 1. To configure the module, double-click on the module/slot. The general configuration screen appears.



Configuration options for channels 0 to 2 are located on a separate tab from channel 3, as shown below. To enable a channel, click its Enable box so that a check mark appears in it. For optimum module performance, disable any channel that is not hardwired to a real input. Then, choose your Data Format, Input Type, Filter Frequency, Open Circuit response, and Units for each channel.

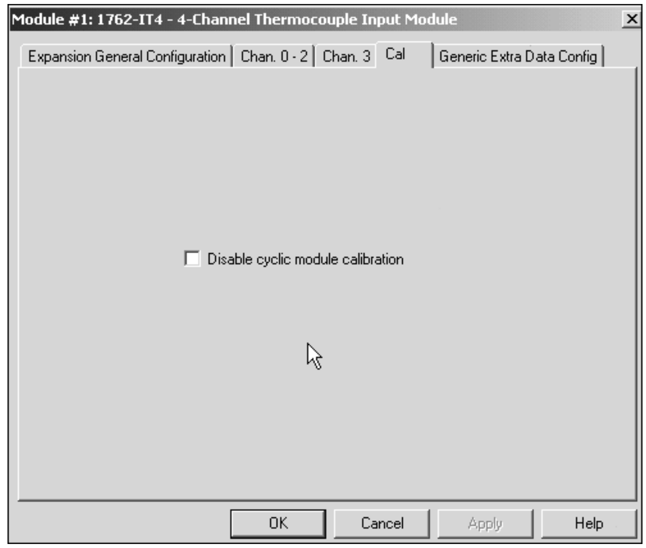




TIP

For a complete description of each of these parameters and the choices available for each of them, see Configuration Data File on page 3-4.

The Cal tab contains a check box for disabling cyclic calibration. See Selecting Enable/Disable Cyclic Calibration (Word 4, Bit 0) on page 3-14 for more information.



Generic Extra Data Configuration

This tab redisplays the configuration information entered on the 1762-IT4 configuration screen in raw data format. As explained on page E-7, you can enter the configuration information using this tab instead of using the Chan 0-2 and Chan 3 tabs. You do not have to enter data in both places.

Configuration Using RSLogix 500 Version 5.2 or Lower

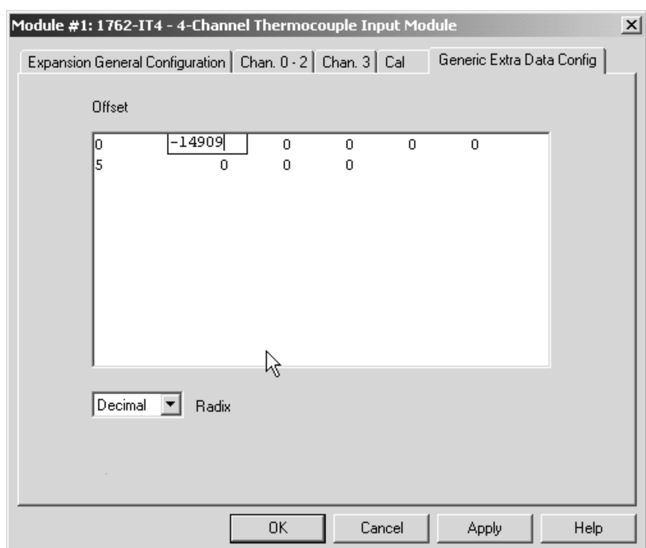
If you do not have version 5.5 or higher of RSLogix 500, you can still configure your module, using the Generic Extra Data Configuration dialog.

The 1762-IT4 uses six 16-bit binary numbers to configure each of its four channels. To properly configure and enable input channel 1 for the setting in the table below, add the decimal values given to each of the six parameters. These decimal values are listed in the configuration table on page 3-5.

Table 5.2 1762-IT4 Parameter Decimal Values

Parameter	Setting	Decimal Value
Filter Frequency	250 Hz	3
Open Circuit	Hold Last State	64
Temperature Units	Degrees F	128
Input Type	Thermocouple S	1280
Data Format	Engineering Units x 10	16384
Enable Channel	Enable	-32768
	Total	-14909

Enter this value into the Generic Extra Data Config tab.



The following terms and abbreviations are used throughout this manual. For definitions of terms not listed here refer to *Allen-Bradley's Industrial Automation Glossary*, Publication AG-7.1.

A/D Converter– Refers to the analog to digital converter inherent to the module. The converter produces a digital value whose magnitude is proportional to the magnitude of an analog input signal.

attenuation – The reduction in the magnitude of a signal as it passes through a system.

bus connector – A 16-pin male and female connector that provides electrical interconnection between the modules.

channel – Refers to input interfaces available on the module's terminal block. Each channel is configured for connection to a thermocouple or millivolt input device, and has its own data and diagnostic status words.

channel update time – The time required for the module to sample and convert the input signals of one enabled input channel and update the channel data word.

CJC – Cold junction compensation. CJC is the means by which the module compensates for the offset voltage error introduced by the temperature at the junction between a thermocouple lead wire and the module terminal block (the cold junction).

common mode rejection – For analog inputs, the maximum level to which a common mode input voltage appears in the numerical value read by the processor, expressed in dB.

common mode rejection ratio (CMMR) – 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 input terminals relative to ground. $CMRR=20 \, Log_{10} \, (V1/V2)$

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

common mode voltage range – The largest voltage difference allowed between either the positive or negative terminal and analog common during normal differential operation.

configuration word – Word containing the channel configuration information needed by the module to configure and operate each channel.

cut-off frequency – The frequency at which the input signal is attenuated 3 dB by a 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.

data word – A 16-bit integer that represents the value of the input channel. The channel data word is valid only when the channel is enabled and there are no channel errors. When the channel is disabled the channel data word is cleared (0).

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

digital filter – A low-pass filter incorporated into the A/D converter. The digital filter provides very steep roll-off above it's cut-off frequency, which provides high frequency noise rejection.

effective resolution – The number of bits in a channel configuration word that do not vary due to noise.

filter – A device that passes a signal or range of signals and eliminates all others.

filter frequency – The user-selectable frequency for a digital filter.

full-scale – The magnitude of input over which normal operation is permitted.

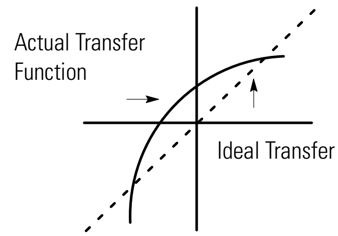
full-scale range – The difference between the maximum and minimum specified analog input values for a device.

gain drift – Change in full-scale transition voltage measured over the operating temperature range of the module.

input data scaling – Data scaling that depends on the data format selected for a channel configuration word. Scaling is selected to fit the temperature or voltage resolution for your application.

input image – The input from the module to the controller. The input image contains the module data words and status bits.

linearity error – Any deviation of the converted input or actual output from a straight line of values representing the ideal analog input. An analog input is composed of a series of input values corresponding to digital codes. For an ideal analog input, the values lie in a straight line spaced by inputs corresponding to 1 LSB. Linearity is expressed in percent full-scale input. See the variation from the straight line due to linearity error (exaggerated) in the example below.



LSB – Least significant bit. The LSB represents the smallest value within a string of bits. For analog modules, 16-bit, two's complement binary codes are used in the
I/O image. For analog inputs, the LSB is defined as the rightmost bit of the 16-bit field (bit 0). The weight of the LSB value is defined as the full-scale range divided by the resolution.

module scan time – same as *module update time*

module update time – 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 processor.

multiplexer – An switching system that allows several 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. The measurement does not apply to noise signals between the equipment grounding conductor or signal reference structure and the signal conductors.

number of significant bits – The power of two that represents the total number of completely different digital codes to which an analog signal can be converted or from which it can be generated.

overall accuracy – The worst-case deviation of the digital representation of the input signal from the ideal over the full input range is the overall accuracy. Overall accuracy is expressed in percent of full scale.

repeatability – The closeness of agreement among repeated measurements of the same variable under the same conditions.

resolution – The increment of change represented by one unit.
For example, the resolution of engineering units x1 is 0.1° and the resolution of raw/proportional data is equal to
(maximum_value - minimum_value)/65534.

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 channel data word signal to reach a specified percentage of its expected final value, given a full-scale step change in the input signal.

thermocouple – A temperature sensing device consisting of a pair of dissimilar conductors welded or fused together at one end to form a measuring junction. The free ends are available for connection to the reference (cold) junction. A temperature difference between the junctions must exist for the device to function.

update time – see "module update time"

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