**Allen-Bradley**

# SLC 500 Fast Analog I/O Module

Catalog Numbers 1746-FIO4I and 1746-FIO4V

User Manual

**Rockwell Automation**

## Important User Information

Solid state equipment has operational characteristics differing from those of electromechanical equipment. Safety Guidelines for the Application, Installation and Maintenance of Solid State Controls (publication SGI-1.1 available from your local Rockwell Automation sales office or online at http://literature.rockwellautomation.com) describes some important differences between solid state equipment and hard-wired electromechanical devices. Because of this difference, and also because of the wide variety of uses for solid state equipment, all persons responsible for applying this equipment must satisfy themselves that each intended application of this equipment is acceptable.

In no event will Rockwell Automation, Inc. be responsible or liable for indirect or consequential damages resulting from the use or application of this equipment.

The examples and diagrams in this manual are included solely for illustrative purposes. Because of the many variables and requirements associated with any particular installation, Rockwell Automation, Inc. cannot assume responsibility or liability for actual use based on the examples and diagrams.

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Throughout this manual, when necessary, we use notes to make you aware of safety considerations.

| 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. |
|---|---|
| IMPORTANT | Identifies information that is critical for successful application and understanding of the product. |
| ATTENTION | Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss. Attentions help you identify a hazard, avoid a hazard, and recognize the consequence |
| SHOCK HAZARD | Labels may be on or inside the equipment, for example, a drive or motor, to alert people that dangerous voltage may be present. |
| BURN HAZARD | Labels may be on or inside the equipment, for example, a drive or motor, to alert people that surfaces may reach dangerous temperatures. |

# *Table of Contents*

## About This Publication

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

- Who should use this manual
- The purpose of this manual
- Terms and abbreviations
- Conventions used in this manual
- Allen-Bradley support

This manual is a reference guide for the 1746-NR4 RTD/Resistance Input Module. The manual:

- gives you an overview of system operation.
- explains the procedures you need to install and wire the module at the customer site.
- provides ladder programming examples.
- provides an application example of how this input module can be used to control a process.

## Who Should Use This Manual

Use this manual if you are responsible for designing, installing, programming, or troubleshooting control systems that use Allen-Bradley small logic controllers.

You should have a basic understanding of SLC 500 products. You should understand programmable controllers and be able to interpret the ladder logic instructions required to control your application. If you do not, contact your local Allen-Bradley representative for information on available training courses before using this product.

## Additional Resources

The following documents contain information that may be helpful to you as you use Allen-Bradley SLC products.

| Resource | Description |
| --- | --- |
| SLC 500 Systems Selection Guide, publication <u>1747-SG001</u> | An overview of the SLC 500 family of products |
| SLC 500 Module Hardware Style User Manual, publication <u>1747-UM011</u> | A description on how to install and use your modular SLC 500 programmable controller |
| Installation & Operation Manual for Fixed Hardware Style Programmable Controllers, publication <u>1747-6.21</u> | A description on how to install and use your fixed SLC 500 programmable controller |
| SLC 500 Instruction Set Reference Manual, publication <u>1747-RM001</u> | A reference manual that contains status file data, instruction set, and troubleshooting information about the software |
| SLC 500 4-Channel Analog I/O Modules User's Manual, publication <u>1746-UM005</u> | A resource manual and user's guide containing information about the analog modules used in your SLC 500 system. |
| Industrial Automation Wiring and Grounding Guidelines, publication <u>1770-4.1</u> | In-depth information on grounding and wiring Allen-Bradley programmable controllers |
| Application Considerations for Solid-State Controls. publication <u>SGI-1.1</u> | A description of important differences between solid-state programmable controller products and hard-wired electromechanical devices |
| National Electrical Code, published by the <u>National Fire Protection Association</u> of Boston, MA | An article on wire sizes and types for grounding electrical equipment |

You can view or download publications at <u>http://literature.rockwellautomation.com</u>. To order paper copies of technical documentation, contact your local Rockwell Automation distributor or sales representative.

## Conventions

The following conventions are used throughout this manual:

- Bulleted lists such as this one provide information, not procedural steps.
- Numbered lists provide sequential steps or hierarchical information.

# Quick Start

This chapter presents an overview of installation and start-up procedures to help you get the module working quickly.

It refers to full procedures in corresponding chapters of this manual or in other SLC documentation that may be helpful if you are unfamiliar with programming techniques or system installation.

We recommend that you use this chapter in either of two ways.

- Use as a fast installation and start-up guide for the experienced users.
- Use as an overview for using the entire manual for the first-time user.

| | |
|---|---|
| **IMPORTANT** | If you have any questions about the abbreviated procedures presented in this chapter, always read the referenced chapters and other recommended documentation before trying to apply the information. |

## Required Tools and Equipment

Have the following tools and equipment ready.

- Medium flat-head screwdriver
- Medium Phillips-head screwdriver
- Wire strippers
- Utility knife
- Hot-air blower
- Shrink wrap
- Belden 8761 cable or equivalent
- Analog I/O devices for your application
- I/O modules (1746-FIO4I and/or 1746-FIO4V)
- Programming software

## Procedures

Follow these steps to get your module running in your SLC system.

**1.** Plan the inclusion of analog I/O modules in your SLC system.

If a new system, specify the type of processor, number of I/O racks, I/O modules, and power supply. If adding to an existing system:

- assign modules to slot locations in the I/O rack.
- verify that the power supply for the I/O rack can handle the increased load.

See SLC 500 Systems Selection Guide, publication 1747-SG001, for more information.

**2.** Configure module input channels for current or voltage operation.

Locate the 2-switch assembly on the module's circuit board, and set each channel as follows.

Current (ON)

Switch 1 = Channel 0
Switch 2 = Channel 1

Voltage (OFF)
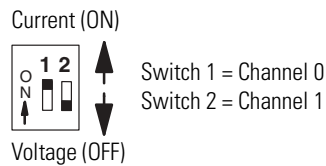
**3.** Connect I/O devices with cables.

> **IMPORTANT**
> - Connect only one end of the cable shield to earth ground.
> - Channels are not isolated from each other. All analog commons are connected together internally.
> - The module does not provide loop power for analog inputs.
> - Use a power supply that matches the transmitter (sensor) specifications.

Refer to Install and Wire the Modules on page 11.

For Differential Inputs
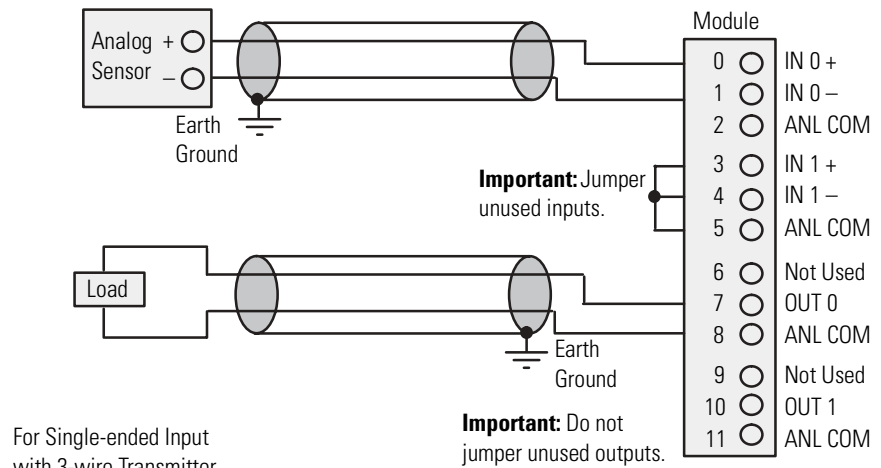


For Single-ended Input
with 3-wire Transmitter
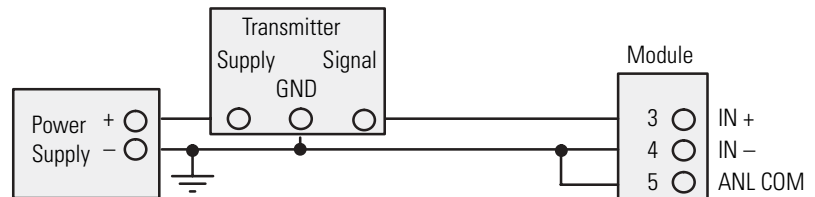


**4.** Configure the system I/O and module ID.

With the software, configure the processor, I/O racks, slots, and I/O modules.

When assigning an I/O module to a slot location, select the module from the displayed list. If not listed, select OTHER at the bottom of the list and enter the module's ID code at the prompt.

ID code for 1746-FIO4I is 3224
ID code for 1746-FIO4V is 3218

**5.** Understand A/D & D/A converter resolution on input and output words.

The module's I/O channel converters limit bit usage to less than a full 16-bit word.

The input channel converter resolution is 12 bits, where the highest four bits are always zero.

The output channel converter resolution is 14 bits, where the lowest two bits are never used.

The lowest two bits have no effect on the output value.

Refer to Processor and Module Considerations on page 29 for more information.

SLC 500 Processor
Data Files

| Input Image (2 words) | Output Image (2 words) |

**Address**
I:1.0  Channel 0 Input Word ← msb (variable input data) lsb
        0 0 0 0
        Bit 15  Bit 11         Bit 0
I:1.1  Channel 1 Input Word

**Address**
O:1.0  Channel 0 Output Word ← msb variable output data) lsb
        X X
        Bit 15         Bit 2  Bit 0
O:1.1  Channel 1 Output Word
                                X = not used
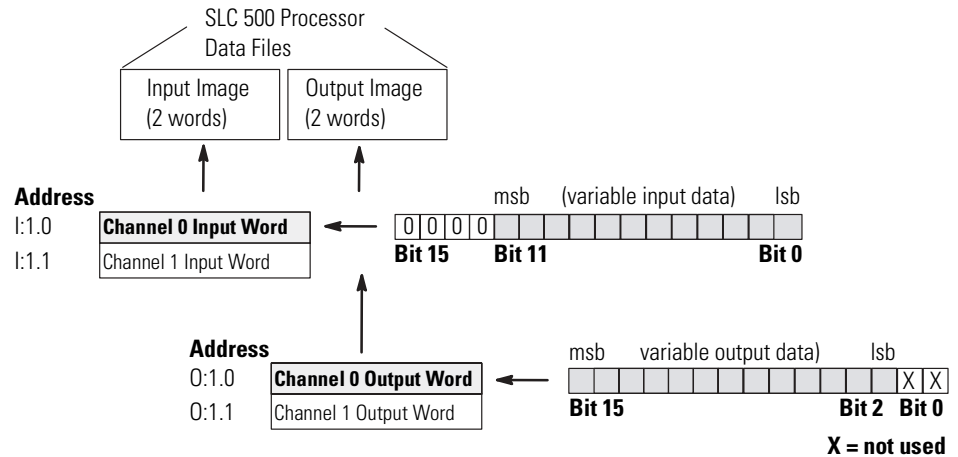
**6.** Write ladder logic to process the module's analog data.

We provide several programming examples that include the following:

- Clear the output when changing mode or cycling power
- Detect an out-of-range input
- Scale analog outputs
- Scale offsets
- Scale and range-check analog inputs and outputs
- PID control with analog I/O scaling

Study these examples to understand how to program the module.

Refer to Write Ladder Logic on page 39.

**7.** (Optional) Write ladder logic to maintain calibrated inputs.

We show you how to write ladder logic that provides a calibrated input reference during runtime, and lets you periodically calibrate module inputs. We suggest that you modify the logic examples to suit your application and add them to your application program.

Refer to Calibrate the Module on page 61 for more information.

# Install and Wire the Modules

This chapter describes procedures to install fast analog I/O modules in an SLC 500 system. The procedures include the following tasks.

- determine the module's power requirements
- determine compatibility with other I/O modules
- configure input channels
- select the I/O rack slot
- install the module
- consider when wiring
  - using system wiring guidelines
  - grounding the cable
  - determining cable length
- minimize electrical noise interference
- wire the module
- minimize ground loops
- label the terminal block

## Determine the Module's Power Requirements

Analog modules require power from the 5V dc and 24V dc backplane power supplies of the SLC 500 system. This table shows the backplane power requirements for fast analog I/O modules.

**Current Load**

| Catalog Number | Current at 5V dc | Current at 24V dc |
|----------------|------------------|-------------------|
| 1746-FIO4I | 55 mA | 150 mA |
| 1746-FIO4V | 55 mA | 120 mA |

Use this table to compute the module's portion of total load on the modular system power supply.

For more information, refer to SLC 500 Systems Selection Guide, publication 1747-SG001.

## Determine Compatibility with Other I/O Modules

Use the I/O Compatibility chart when using the expansion rack of a fixed controller (1747-L20, 1747-L30, and 1747-L40). The chart determines compatibility of other I/O modules with fast analog modules. Compatibility is solely based on current drawn from the backplane.

For more information, refer to the SLC 500 Fixed Hardware Style Installation and Operation Manual, publication 1747-6.21.

**I/O Compatibility**

| 1746-FIO4I | 1746-FIO4V | 1746 Module |
|:---:|:---:|:---:|
| | | FIO4I |
| | | FIO4V |
| ●[1] | ● | IA4, IA8, IA16 |
| ● | ● | IB8, IB16 |
| ● | ● | IB32 |
| ● | ● | IG16 |
| ● | ● | IM4, IM8, IM16 |
| ● | ● | IN16 |
| ● | ● | IO4 |
| | ● | IO8 |
| | | IO12 |
| ● | ● | ITB16, ITV16 |
| ● | ● | IV8, IV16, IV32 |
| | | NIO4I, NIO4V |
| ∇[2] | ∇ | NO4I, NO4V |
| | | NI4 |
| ● | ● | NR4 |
| ● | ● | NT4 |
| ● | ● | OA8 |
| | | OA16 |
| ● | ● | OB8 |
| | | OB16, OB32 |
| | ● | OBP16 |
| ● | ● | OG16 |
| ● | ● | OV8 |
| | ● | OV16 |
| | | OV32 |

**I/O Compatibility**

| 1746-FIO4I | 1746-FIO4V | 1746 Module |
|---|---|---|
| | • | OW4 |
| | | OW8, OW16 |
| | | OX8 |
| | • | BASIC |
| | | BASn |
| | | DCM |
| | | HS |
| | • | KE |
| | | KEn |

[1]    The • symbol indicates an allowable combination of 1746 I/O modules.

[2]    The ∇ symbol indicates an auxiliary 24V dc power supply may be needed.

# Configure Input Channels

Your fast analog I/O modules have a two-switch assembly to configure the input channels for either current or voltage operation. The switches are on the module's circuit board. Switch orientation is shown on the nameplate of the module.

**Switch Orientation**

ON – Configures channel for current input

OFF – Configures channel for voltage input

Switches labeled 1 and 2 control the input mode of channels 0 and 1 respectively.

**Channels 0 and 1 Input Mode**

Current (ON)
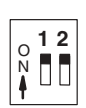
Switch 1 = Channel 0
Switch 2 = Channel 1

Voltage (OFF)

## Select the I/O Rack Slot

Two factors determine where you should locate the module in the I/O rack: ambient temperature and electrical noise. Consider the following conditions when selecting an I/O rack slot for the module. Position the module:

- in a slot away from ac or high voltage dc modules.
- away from the rack power supply if installed in a modular system.
- in the I/O rack lowest in the enclosure for a cooler ambient.

## Install the Module

When installing the module in an I/O rack, you do not need to remove the terminal block from the module. However, if the terminal block is removed, use the write-on label located on the side of the terminal block to identify the module location and type. To remove the terminal block, grasp it on the top and bottom and pull outward and down.

| **ATTENTION** ⚠ | Never install, remove, or wire modules with power applied to the I/O rack. Rid yourself of electrostatic charge before handling the module. Electrostatic discharge can degrade module performance or destroy analog circuitry. |
|---|---|

| **IMPORTANT** | Do not tamper with the module's factory-sealed potentiometer. It does not require any adjustments. |
|---|---|

Follow these steps when installing or removing the module.

**1.** Verify that input configuration switches 1 and 2 are set correctly.

| **ATTENTION** ⚠ | Take care to avoid connecting a voltage source to a channel configured for current input. This could result in improper module operation or damage to the module. |
|---|---|

**2.** Align the module's circuit board with the rack's card guide.

See Installing the Module on page 15.

**3.** Slide the module in until top and bottom retaining clips are secured.

**4.** To remove the module, press the retaining clips at the top and bottom of the module and slide the module out.

**Installing the Module**

Card Guide

Self-locking tabs secure the module in the I/O rack.
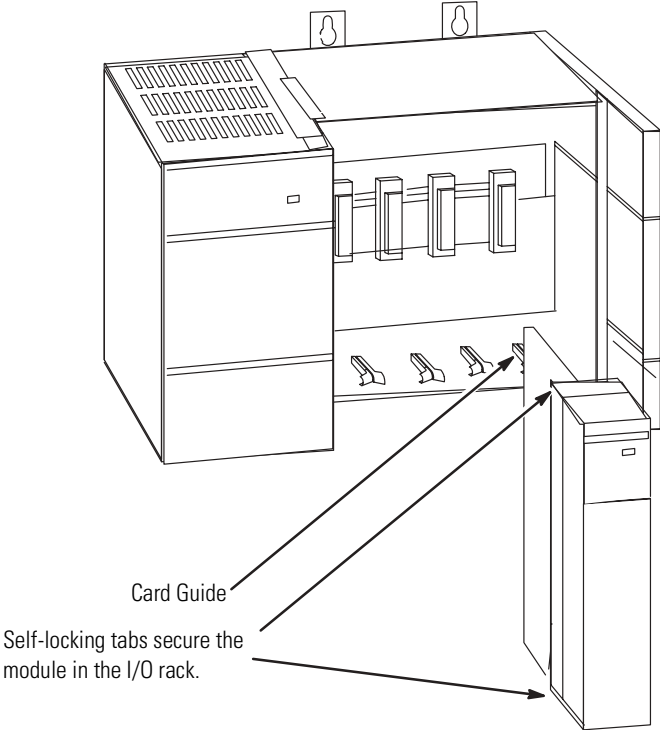
# Considerations When Wiring

This section provides guidelines on wiring the system, grounding the cables, determining cable length.

| ⚠ **ATTENTION** | Before wiring the module, disconnect SLC system power, I/O rack power, and module power. |
|---|---|

## System Wiring Guidelines

Use the following guidelines in planning the system wiring to the module.

- Analog common terminals (ANL COM) are electrically interconnected inside the module, but not internally connected to earth.
- Voltages on IN+ and IN– terminals must be within 0…20V with respect to ANL COM to ensure proper input channel operation. This is true for current and voltage input channel operation.
- Voltage outputs (OUT 0 and OUT 1) of the 1746-FIO4V module are referenced to ANL COM. Load resistance (R1) for a voltage output channel must be equal to or greater than 1 KΩ
- Current output channels (OUT 0 and OUT 1) of the 1746-FIO4I module source current that returns to ANL COM. Load resistance (R1) for a current output channel must be within 0…500 Ω
- Input connections for single-ended or differential input are the same.

## Ground the Cable

Signal cable such as Belden cable #8761 (or equivalent) has two signal wires (black and clear), one drain wire, and a foil shield. The drain wire and foil shield must be grounded at only one end of the cable, not at both ends.

**Typical Signal Cable**
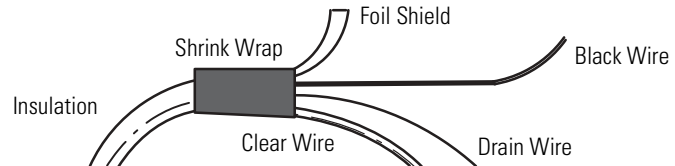


| | |
|---|---|
| **IMPORTANT** | Ground the cable shield at one end having a good earth-ground connection, such as at an I/O chassis mounting bolt or nearest ground bus in the I/O enclosure. Make this connection as short as possible. Do not ground the cable at the module's terminal block. |

## Determine Cable Length

When you determine the length of cable required to connect an I/O device, remember to include additional length to route the drain wire and foil shield to earth ground. Route your cable long enough to avoid areas of high radiated electrical noise, but short enough to avoid signal attenuation.

# Minimize Electrical Noise Interference

Because high-speed analog signals are particularly vulnerable to electrical noise, take precautions when routing your signal cables. To help reduce the effects of electrical noise on analog signals, we recommend that you do the following:

- Install the SLC 500 system in a NEMA rated enclosure.
- Make sure that the SLC 500 system is properly grounded.
- Use Belden cable #8761 (or equivalent) for signal wiring.
- Ground the cable properly.
- Route signal cables away from other wiring or in grounded conduit.
- Group these modules away from ac or high-voltage dc modules.

We recommend re-checking system operation after installing new machinery or other sources of electrical noise near the system.

For additional information on this subject, refer to Industrial Automation Wiring and Grounding Guidelines, publication 1770-4.1.

# Wire the Module

Follow this procedure when wiring your modules.

| **ATTENTION** | Before wiring a module, disconnect power from the SLC 500 system and from any other source to the module. |
|---|---|

1. Strip about 7.6 cm (3 in.) of casing to expose the wires at each end of the cable.

2. Twist the drain wire and foil shield together and bend them away from the cable at the grounded end of the cable.

**Grounded End**

Twisted Foil Shield and Drain Wire
Black Wire
Casing
Shrink Wrap     Clear Wire

**Ungrounded End**

Black Wire
Casing     Shrink Wrap     Clear Wire
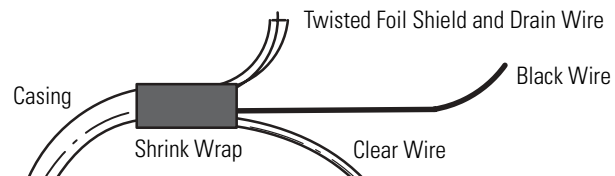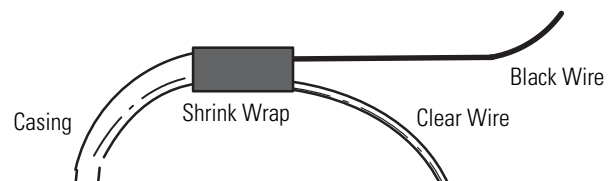
**3.** Apply shrink wrap where wires leave the casing with the hot-air blower.

**4.** Cut off the drain wire and foil shield at the other end of the cable.

**5.** Apply shrink wrap to the junction where wires leave the casing.

**6.** Trim the signal wires to 5 cm (2 in.) lengths. Strip about 4.76 mm (3/16 in.) of insulation away to expose the copper strands for your connections.

**7.** Decide where you will connect the cable to earth ground, and ground it.

Refer to Ground the Cable on page 17.

**8.** Connect signal wires (black and clear) to the terminal block and to the input or output device.

**Wiring Diagram for Module, Sensor, and Load (showing differential inputs)**

**Important:** Channels are not isolated from each other.
All analog commons are connected together internally.

+
Analog Sensor
−

Earth Ground

**Important:** Jumper unused inputs.

Load

Earth Ground

**Important:** Do not jumper unused outputs.
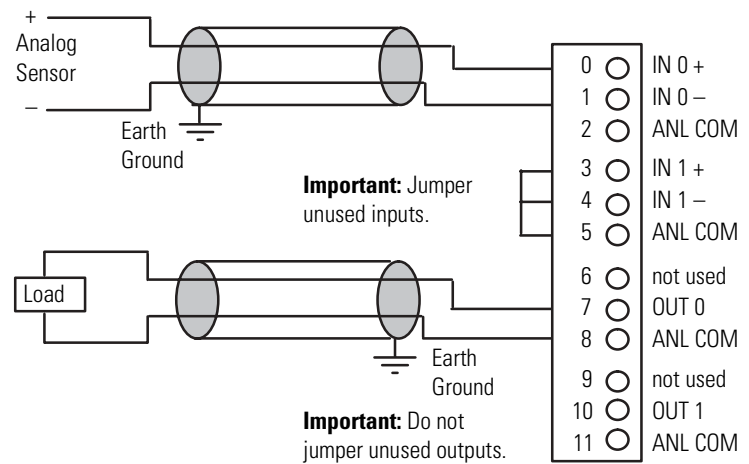
| | |
|---|---|
| 0 ○ | IN 0 + |
| 1 ○ | IN 0 − |
| 2 ○ | ANL COM |
| 3 ○ | IN 1 + |
| 4 ○ | IN 1 − |
| 5 ○ | ANL COM |
| 6 ○ | not used |
| 7 ○ | OUT 0 |
| 8 ○ | ANL COM |
| 9 ○ | not used |
| 10 ○ | OUT 1 |
| 11 ○ | ANL COM |

| **IMPORTANT** | Single-ended inputs are less immune to noise than are differential inputs. |
|---|---|

**Wiring Schematic for Single-ended Current-loop Analog Input Connections**

**Important:** The module does not provide loop power for analog inputs.
Use a power supply that matches the transmitter specifications.

2-wire Transmitter
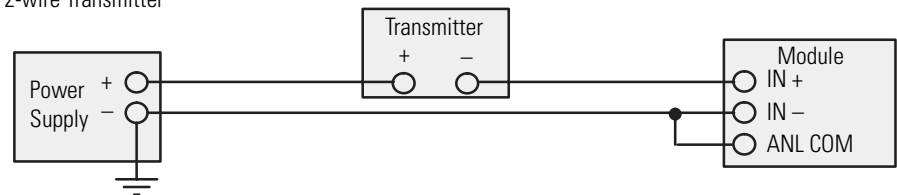
3-wire Transmitter
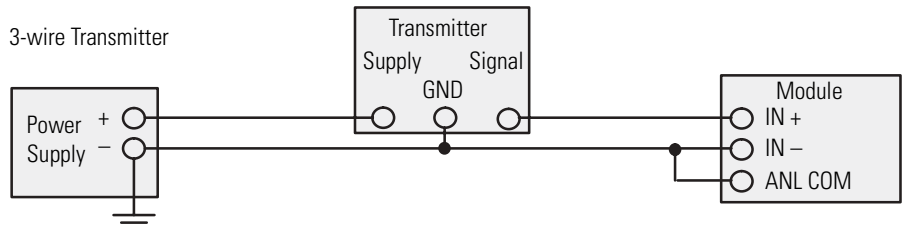
4-wire Transmitter
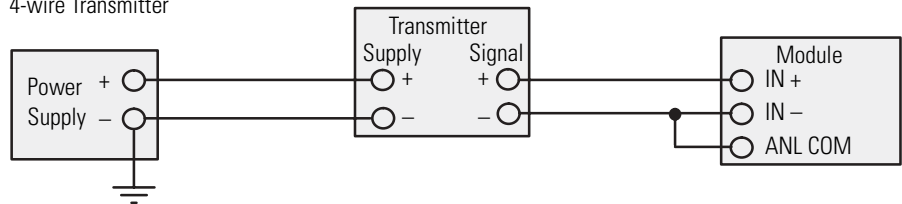
**9.** Repeat steps 1…6 for each channel. For each unused input channel, jumper together the plus (+), minus (–), and common (ANL COM) terminals. For each unused output channel, do not connect terminals.

# Minimize Ground Loops

To keep the ground-loop currents of input circuits to a minimum, we recommend that you:

- use the same power supply to power both input channels of a module.
- otherwise, tie together the grounds of separate power supplies.

See Wiring Schematic for Single-ended Current-loop Analog Input Connections for more information.

## Label the Terminal Block

The terminal block has a write-on label. Use it to ensure that you install the correct terminal block on the corresponding module.

**Terminal Block**

Note: The black dot on the label indicates the position of terminal 0.

SLOT _____ RACK _____
● MODULE _____
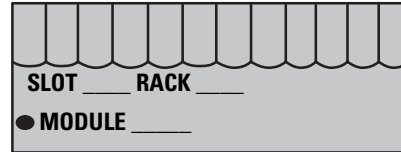
# Access Files to Configure I/O

There are two ways to configure the SLC Chassis for a 1746-FIO4I/V module. You can either click and drag items from the list or you can use the Read IO Config method.

## Click and Drag Configuration

Follow these steps to configure the SLC chassis by clicking and dragging modules.

1. Double-click the menu item to open the IO Configuration menu in RSLogix500 software.
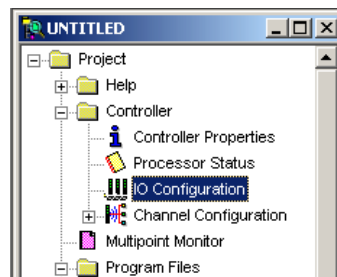


2. Place the 1746-FIO4I/V module into the correct slot by clicking and dragging from the list.
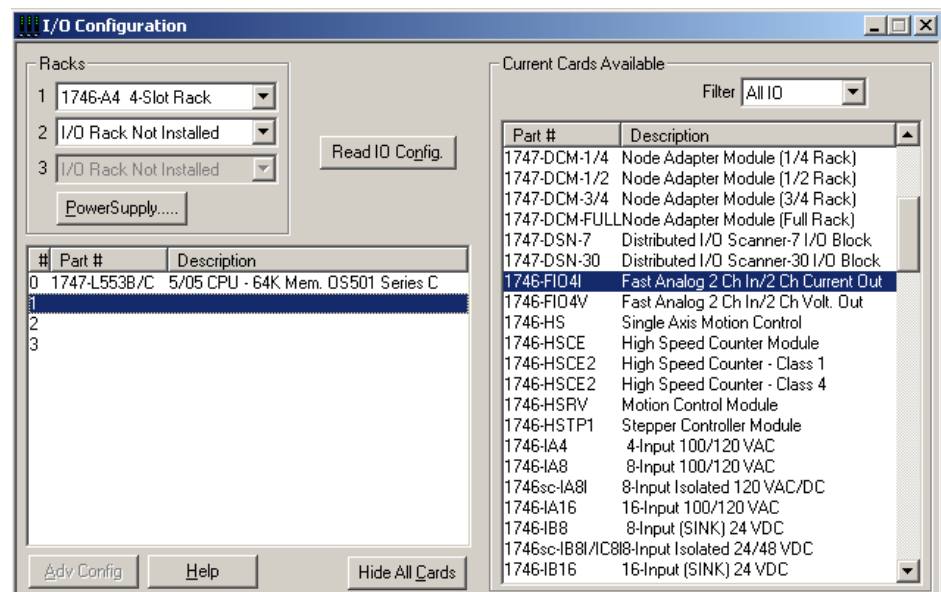
The I/O Configuration is now complete. Each slot shows the corresponding module that is located on the rack. In this example the 1746-FIO4V is in slot 1.
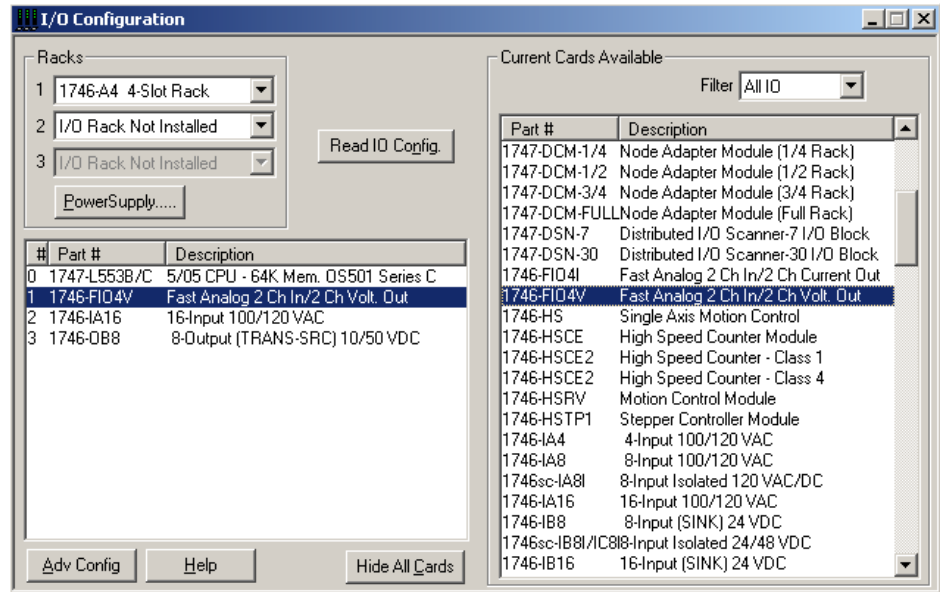


## Read IO Config Method

Follow these steps to configure the SLC chassis by using the Read IO configuration method.

1. Double-click the menu item to open the IO Configuration menu in RSLogix500 software.
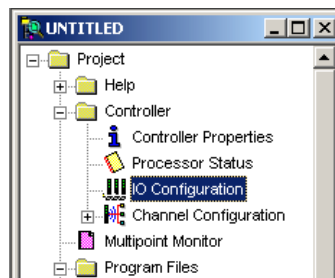
**2.** Place the 1746-FIO4I/V module into the correct slot by clicking Read IO Config.
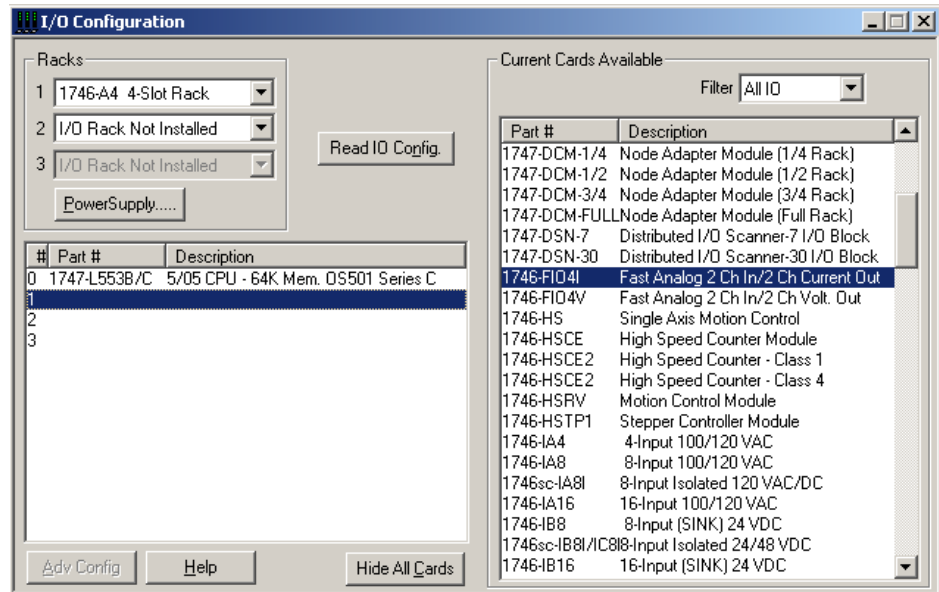


The following screen appears.
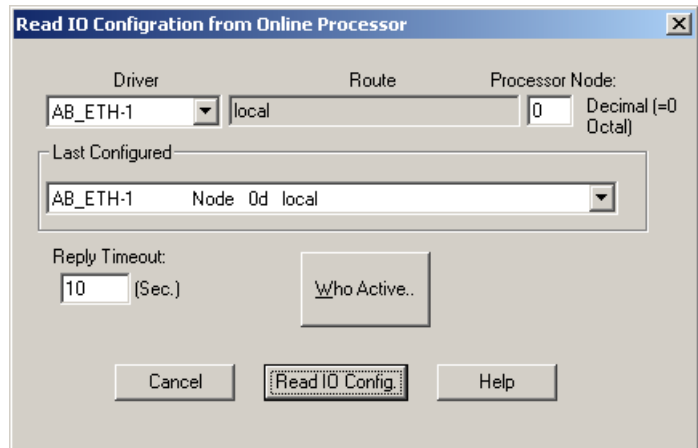


**3.** Select either the driver and processor node number or use the Who Active button to browse for the device.

- If you selected the driver and node number, proceed to step 5.
- If you clicked Who Active, the following screen appears.

The Who Active screen lets you browse for the SLC device.
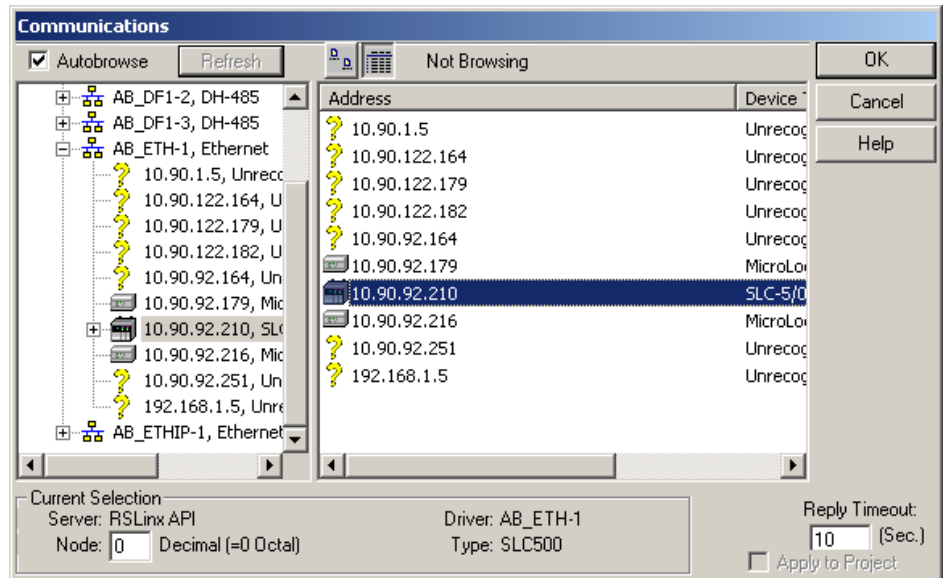


4. Locate the SLC Chassis under the appropriate driver and click OK.

   You are brought back to the Read IO Config screen.

5. Click Read IO Config and the rack is populated automatically.
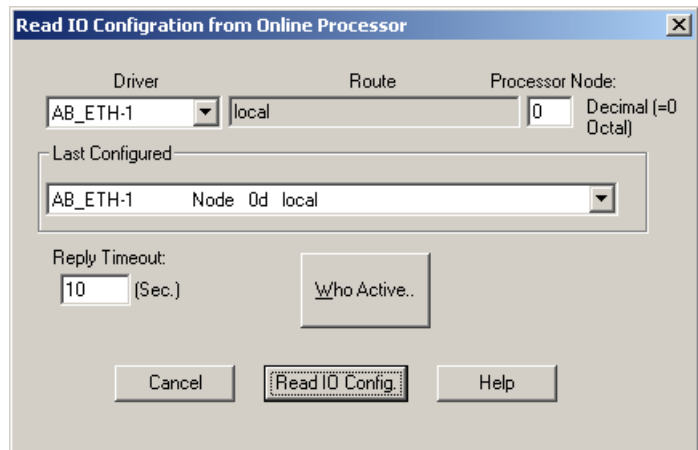
The I/O Configuration is now complete. Each slot shows the corresponding module on the rack. In this example the 1746-FIO4V is in slot 1.
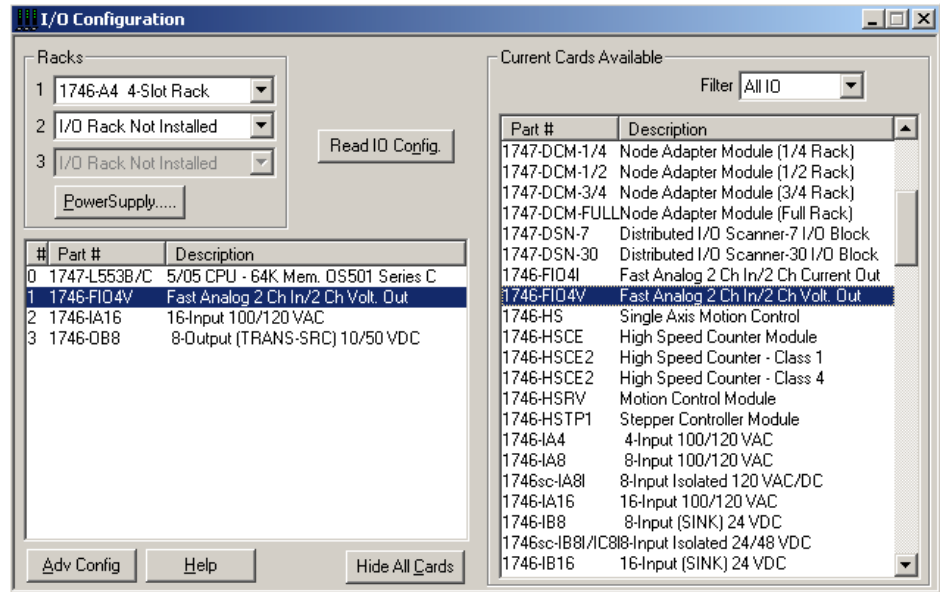
# Processor and Module Considerations

This chapter describes concepts that you need to understand to program the fast analog I/O module in an SLC 500 system.

The following are processor considerations.

- Update processor analog I/O data
- Monitor analog I/O data
- Address I/O image words

The following are module considerations.

- Resolve data of the module's I/O channel converters
- Convert analog input data
- Compute the analog input signal level
- Convert analog output data
- Compute the analog output
- Filter input channel
- Compute time delay for A/D conversion
- Determine response to slot disable
- Determine safe state for outputs
- Enter module ID code

# Processor Considerations

Knowing how the processor works helps you program it more effectively.

## Processor Update of Analog I/O Data

Analog input and output image words are updated by the processor once every processor scan when the processor scans data and program files in succession.

Processor scan time depends largely on the size of your program files: the greater the number of programming instructions, the longer the time to scan the file. Some instructions take longer to scan than others.

For information on processor scan time and instruction execution time, refer to the SLC 500 Instruction Set Reference Manual, publication 1747-RM001.

If an application requires processor updates of analog data more frequently than once per scan, use Immediate Input or Immediate Output instructions. These instructions typically update an analog channel in 1 ms, but also increase the overall scan time by the same amount.

Typical update times for SLC processors are:

- ≃10 ms for a typical 1K program.
- 1 ms per analog channel when using immediate I/O instructions.

## Monitor Analog I/O Data

You can monitor analog input and output data in binary or decimal format. You select the format by its radix. The default radix is binary. Binary data is presented in 2's-complement format. Changing the radix to decimal lets you view analog I/O data as decimal representations of integer words.

Refer to 2's-complement Binary Numbers on page 83 for more information.

## Address I/O Image Words

Each module input channel is addressed as a single word in the processor's input image table and each module output channel is addressed as a single word in the processor's output image table. The module uses a total of two input words and two output words.

**Processor I/O Image Words Used by the Module**
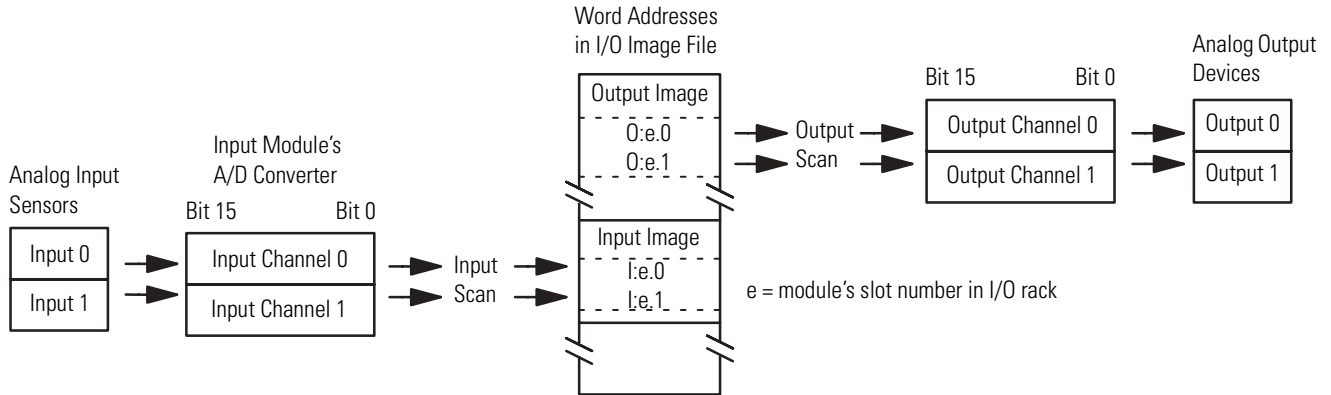


The converted input values from input channels 0 and 1 are addressed as words 0 and 1 of the slot where the module resides. The output values for the output channels 0 and 1 are addressed as output words 0 and 1 of the slot where the module resides.

| EXAMPLE | You would address the output image word for output 0, word 0, in slot 3 as: O:3.0 where delimiters : and . must be placed as shown. |
|---------|------|
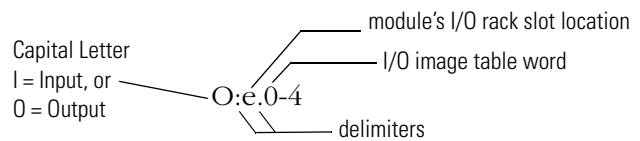
# Module Considerations

The module's I/O channel converters affect resolution of I/O data and bit usage in I/O image words. We show you how to compute I/O signal levels. Input filtering and input A/D conversion affect input response time.

## Data Resolution of the Module's I/O Channel Converters

The module's I/O channel converters limit bit usage to less than a full 16-bit word when converting analog to digital input data and digital to analog output data. Bit maps show resulting digital data storage in input and output image words.

**Bit Usage for I/O Channel Converters**

| | msb | | | | | | | | | | | | | | | lsb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I:e.0 | 0 | 0 | 0 | 0 | | | | CH 0 INPUT | | | | | | | | |
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| I:e.1 | 0 | 0 | 0 | 0 | | | | CH 1 INPUT | | | | | | | | |
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

| | msb | | | | | | | | | | | | | | lsb | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O:e.0 | | | | | | | | CH 0 OUTPUT | | | | | | | Bits not used | |
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| O:e.1 | | | | | | | | CH 1 OUTPUT | | | | | | | Bits not used | |
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
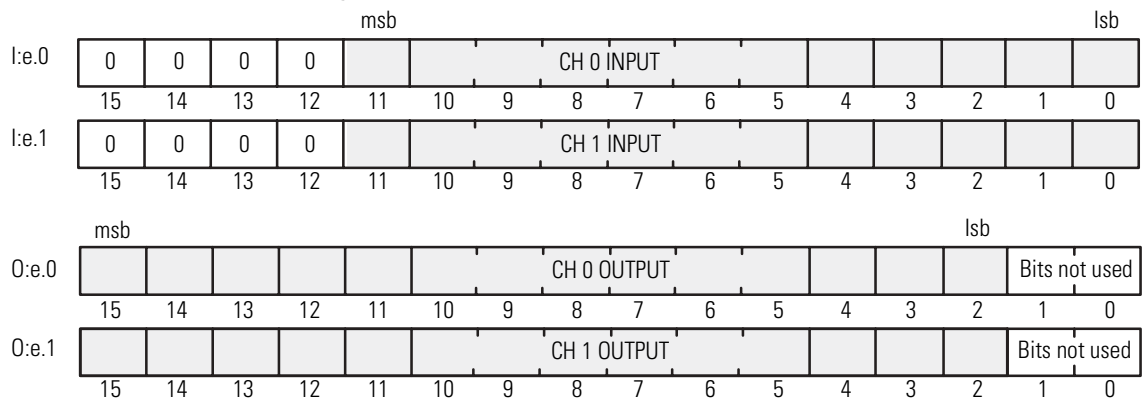
e = module's slot number

The input channel converter resolution is 12 bits, where the highest four bits are always zero. The usable range of the channel word is 0…4095.

The output channel converter resolution is 14 bits, where the lowest two bits are not used. They have no effect on the output value.

**IMPORTANT**   The module left-justifies the 14-bit data (lsb at bit 2) in the output channel word. This reduces the output resolution to:

- 2.56348 µA/LSB for current outputs

- 1.22070 mV/SLB for voltage outputs

## Convert Analog Input Data

The module converts analog input signals to 12-bit binary values for storage in the input image table.

The decimal range, number of significant bits, and converter resolution depend on the input range that you use for the channel.

| Input Range | Decimal Range (input image table) | Significant Bits | Nominal Resolution |
|---|---|---|---|
| 0…10V – 1LSB | 0…4095 | 12 | |
| 0…5V | 0…2047 | 11 | 2.4414 mV/LSB |
| 1…5V | 409…2047 | 10 | |
| 0…20 mA | 0…2047 | 11 | 9.7656 µA/LSB |
| 4…20 mA | 409…2047 | 10 | |

## Compute the Analog Input Signal Level

Use the following formula to determine what the analog input signal level (sensor signal) should be for a given decimal value in the input image table.

$$\text{Sensor Signal} = \frac{\text{Full Scale Input}}{\text{Full Scale Count}} \times \text{Input Image Value}$$

For voltage inputs, a full scale input of 10V dc has a full scale count of 4095 and a full scale input of 5V dc has a full scale count of 2047.

$$\text{Sensor Signal} = 2.44 \text{ mV/count} \times \text{Input Image Value}$$

For current inputs, a full scale input of 20 mA has a full scale count of 2047.

$$\text{Sensor Signal} = 0.00977 \text{ mA/count} \times \text{Input Image Value}$$

| **EXAMPLE** | For example, if the input image table value is 409 from a 4…20 mA sensor. |

$$\text{Sensor Signal} = \frac{\text{Full Scale Input}}{\text{Full Scale Count}} \text{ x Input Image Value} = 0.00977 \text{ x } 409 = 4 \text{ mA}$$

## Convert Analog Output Data

The module converts 16-bit binary values from the output image table to 14-bit analog output signals and left-justifies the bit code in the channel word. The output range, decimal representation for the output range, number of significant bits, and converter resolution are as shown in the following table.

**Analog Output Data**

| Module | Output Range | Decimal Representation (output image table) | Significant Bits | Resolution |
|--------|--------------|---------------------------------------------|------------------|------------|
| FIO4I  | 0…21 mA – 1LSB | 0…+32,764 | 13 bits | 2.56348 µA/LSB |
|        | 0…20 mA | 0…+31,208 | 12.92 bits | |
|        | 4…20 mA | 6242…31,208 | 12.6 bits | |
| FIO4V  | −10…+10V dc − 1LSB | −32,768…+32,764 | 14 bits | 1,22070 mV/LSB |
|        | 0…10V dc – 1LSB | 0…32,764 | 13 bits | |
|        | 0…5V dc | 0…16,384 | 12 bits | |
|        | 1…5V dc | 3277…16,384 | 11.67 bits | |

## Compute the Analog Output

Use the following formula to compute the output image-table value (decimal representation) required for a desired analog-output signal level (to the output device).

$$\text{Output Image Value} = \frac{\text{Full-scale Decimal Representation}}{\text{Full-scale Output}} \text{ x Desired Signal Level}$$

**EXAMPLE**    If the module's output range is 4…20 mA and you want to set the output to 4 mA, compute the output image value as follows.

$$\text{Output Image Value} = \frac{31{,}208}{20 \text{ mA}} \times 4 \text{ mA} \simeq 6242$$

**IMPORTANT**    The actual resolution for analog current outputs is 2.56348 µA/LSB, where the 14-bit decimal representation is left justified as follows.

| msb | | | | | | | | | | | | | | | lsb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHANNEL OUTPUT WORD | | | | | | | | | Bits not |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
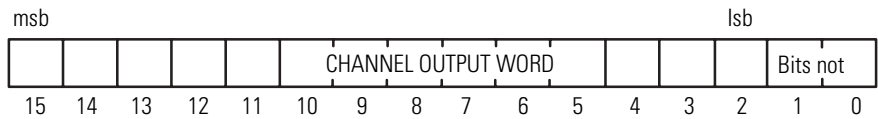
**EXAMPLE**    Use the following formula to compute the output image value if the module's output range is 1…5V dc and you want to set the output to 1V dc.

$$\text{Output Image Value} = \frac{16{,}384}{5 \text{V dc}} \times 1 \text{V dc} \simeq 3277$$

**IMPORTANT**    The actual resolution for analog voltage outputs is 1.22070 mV/LSB, where the 14-bit decimal representation is left justified as follows.

| msb | | | | | | | | | | | | | | | lsb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Channel Output Word | | | | | | | | | Bits not used |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
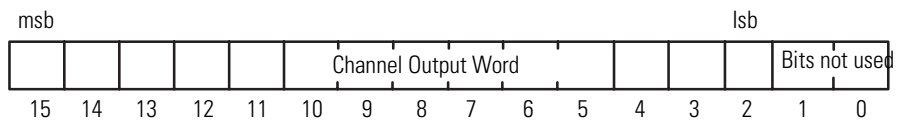
## Input Channel Filtering

The module's input filters are designed to attenuate less than 1% of the input signal in the 0…1000 Hz range.

**Percent of Signal Passed**
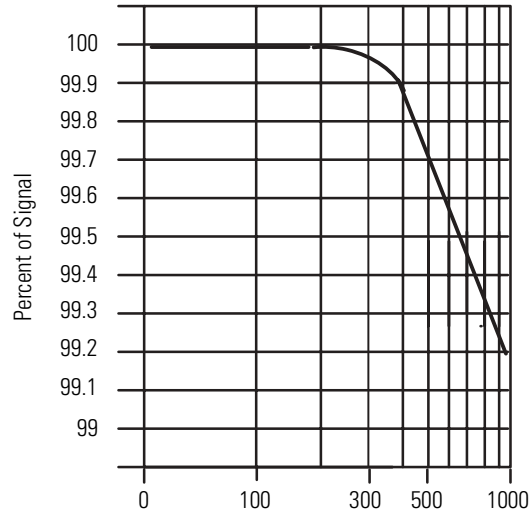


The −3dB point is approximately 7000 Hz. The input filter causes a signal delay of approximately 100 µs. The module's A/D converter sees a 95% step change of an input signal in that time.

**Input Channel Frequency Response**
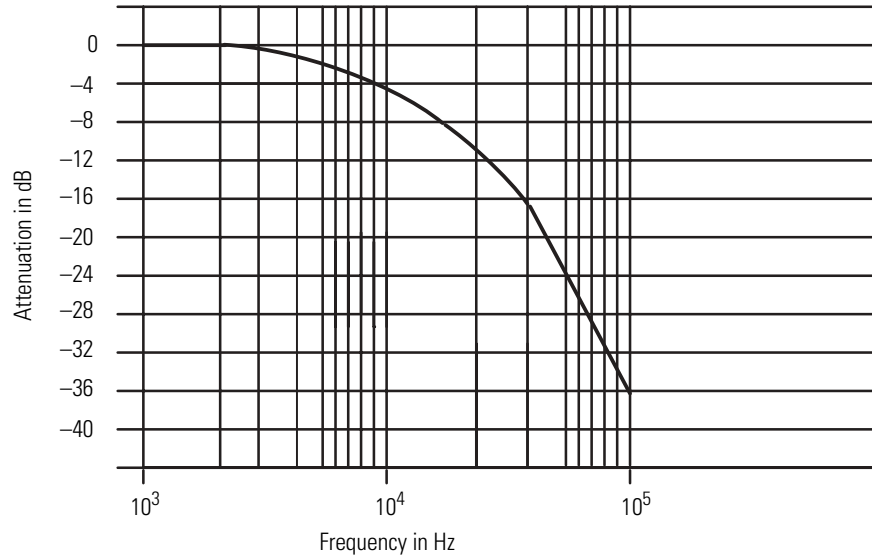
## Time Delay for A/D Conversion

The A/D converter uses 7.5 µs for data conversion, 248.5 µs for data settling, and 256 µs for data transfer to the backplane. New data is available in 512 µs cycles.

**Response Time of A/D Converter**

| Start | Data conversion | Data settling | Data transfer to the backplane | Data ready for processor read |
|---|---|---|---|---|
| | 7.5 µs | 248.5 µs | 256 µs | |

512 µs

Worst case point for a change of input to occur.
This results in a 1.1ms delay for the processor to read a step change.
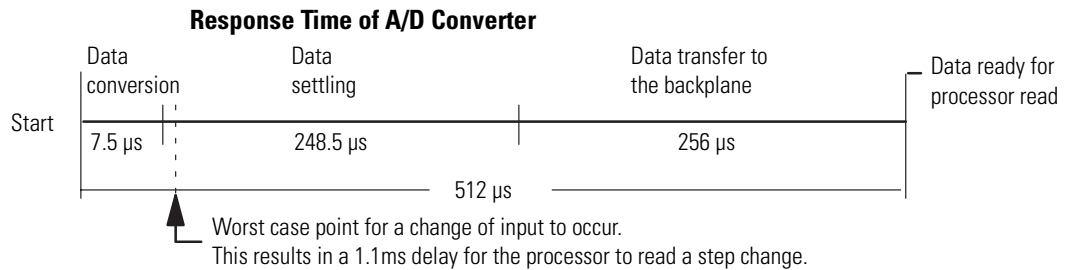
The worst-case specification for the SLC processor to read a step change is 1.1ms between readings. This is true for a step change occurring just after data conversion (first 7.5 µs of the 512 µs cycle). In this case, the read cycle cannot begin until the next data conversion.

**IMPORTANT**  Do not attempt to read data from the module more often than once every 512 µs. If you do, the module may not be able to update new data.

## Response to Slot Disable

You can disable any I/O rack slot by means of a processor function. Before disabling a slot containing an analog I/O module, be aware of the implications.

**ATTENTION**  Clearly understand the safety implications of disabling an analog module slot before doing it.

*Input Response to Slot Disable*

The module continues to update its inputs for transfer to the processor, but the processor:

- does not read inputs from the module in a disabled slot.
- retains the last-state input image table values.
- upon re-enabling the slot, reads current inputs in the subsequent scan.

*Output Response to Slot Disable*

While the module holds its outputs in their last state, the processor:

- may update its output image table.
- does NOT transfer output image table values to the module.
- upon re-enabling, transfers the current output image in the subsequent scan.

## Safe State for Outputs

Whenever an SLC 500 system is **not** in RUN mode, the analog module's outputs are automatically forced to 0V or 0 mA by the SLC 500 system. This occurs when the processor is in one of the following modes:

- Fault
- Program
- Test

| ATTENTION | When designing and installing the SLC 500 system, place devices connected to analog output channels in a safe state whenever the analog output is zero (± the offset error). Determine which output conditions must be held ON for a safe state. |
|---|---|

## Module ID Code

You must enter the ID code if your programming software does not include the subject I/O module in its list of modules.

ID code for FIO4I is 3224
ID code for FIO4V is 3218

# Write Ladder Logic

This chapter presents these programming examples.

- Retentive and non-retentive programming
- Detect an out-of-range input
- Scale analog inputs and detect an out-of-range condition
- Scale analog outputs
- Scale offsets when > 32,767 or < –32,768
- Scale and range-check analog inputs and outputs
- PID xontrol with analog I/O scaling

| | |
|---|---|
| **IMPORTANT** | We present programming examples for instructional purposes only. Because of the many variables and requirements associated with any application, Rockwell Automation cannot assume responsibility or liability for actual use based on these examples. |

## Retentive and Non-retentive Programming

The processor's automatic response for scanning the I/O image table is described below.

**Processor Automatic Response**

| Conditions | Processor Response |
|---|---|
| • Mode is switched to Program<br>• Power is turned OFF | Retains the last values in the I/O image table |
| • Mode is switched to Run<br>• Power is turned ON | Transfers output image data to the module and input image data from the module |
| • Processor detects a **minor** fault | Resets analog outputs to zero, but retains output image values |
| • Fault condition is corrected | Transfers output image data to the module |

We give you the following examples for programming a different response.

- Retentive analog output
- Non-retentive analog output
- Clear the output for changing mode or cycling power

## Retentive Analog Output

This example loads a program constant into an analog output channel. Consider a digital I/O module in slot 1, and an analog I/O module in slot 2. When bit 0 of the digital I/O module is set, the rung is true, and the full-scale value of 32,764 is moved into the output image table location corresponding to slot 2, analog output channel 0. At the end of the scan, the value is transferred to the module and converted to a corresponding full-scale voltage or current output.

**Retentive Example**
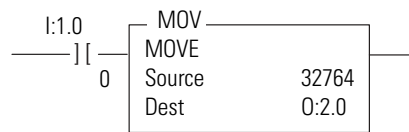
```
   I:1.0        ┌─ MOV ──────────────┐
───┤ ├─────────┤  MOVE               │
    0           │  Source      32764 │
                │  Dest        0:2.0  │
                └─────────────────────┘
```

## Non-retentive Analog Output

This example loads a program constant into an analog output channel and clears it, based on logical conditions. Consider a digital I/O module in slot 1, and an analog I/O module in slot 2. When bit 0 is set in word 0 of the digital I/O module, the first rung is true and the full-scale value of 32,764 is transferred to channel 0. When the bit is reset to zero, the second rung is true, and the value of zero is transferred to the channel.

**Non-retentive Example**

```
   I:1.0        ┌─ MOV ──────────────┐
┬──┤ ├─────────┤  MOVE               │
│   0           │  Source      32764 │
│               │  Dest        0:2.0  │
│               └─────────────────────┘
│
│   I:1.0        ┌─ MOVE ─────────────┐
┴──┤/├─────────┤  Source          0  │
    0           │  Dest        0:2.0  │
                └─────────────────────┘
```
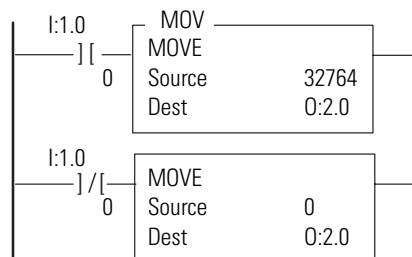
### Clear the Output for Changing Mode or Cycling Power

This example clears analog output channel 0 during the initialization scan (first processor scan). The first pass bit, S2:1/15, in the Status File is used to initialize the analog output when you apply power in the RUN mode or upon setting the processor to the RUN or TEST mode. This bit goes ON automatically only for the first-pass scan. To clear another analog output channel, use another rung with a different MOV destination address. The analog module is in slot 2.

```
 S2:1/15 ┌─ MOV ──────────────┐
─────][──┤ MOVE               │
         │ Source        0    │
         │ Dest       O:2.0   │
         └────────────────────┘
```
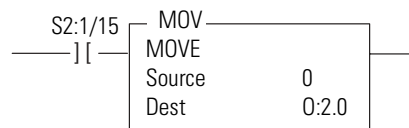
## Detect an Out-of-range Input

Analog modules do not provide an input out-of-range signal to the processor. However, if this feature is critical to a specific application, you can program the processor to provide this function.

The following program applies to all SLC 500 processors. It uses comparison instructions (LES and GRT) to check for analog input values which exceed low and high limits respectively. Whenever this happens, the program latches a bit that could serve to trigger an alarm elsewhere in your ladder program. In this example, the input range is 1…5V dc (decimal range of 409…2047).

```
              MAIN
─────────────────────────────┬── B3/0 ──┐
                              │   (U)    │
                              ├── B3/1 ──┤   Turn OFF Alarms
                              │   (U)    │
       ┌─ LES ──────────┐     │   B3/0   │
       │ LESS THAN      │     │   (L)    │   Turn ON Alarm,
       │ Source A  I:1.0│     │          │   Low Limit Exceeded
       │ Source B    409│     │          │
       └────────────────┘     │          │
       ┌─ GRT ──────────┐     │   B3/1   │
       │ GREATER THAN   │     │   (L)    │   Turn ON Alarm,
       │ Source A  I:1.0│     │          │   High Limit Exceeded
       │ Source B   2047│     │          │
       └────────────────┘     │          │
              Remainder of Program
                  END
```
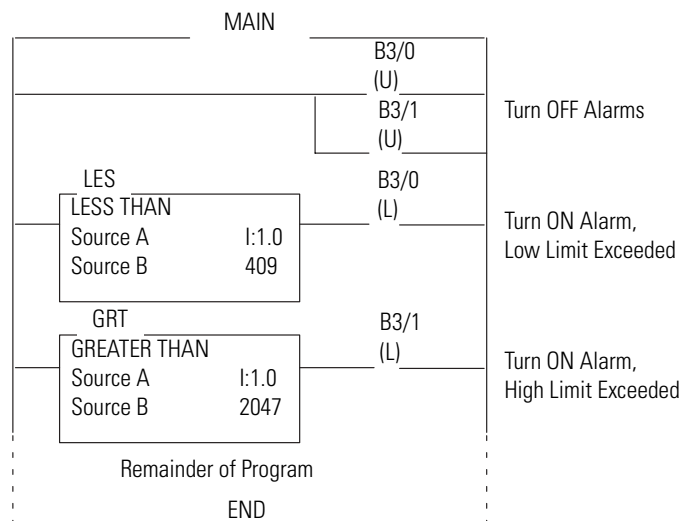
We present an alternative program for SLC 5/02 (and later) processors. It uses a single Limit Test instruction that checks low and high limits. Whenever the input value exceeds a limit, this program latches a bit that could trigger an alarm elsewhere in your ladder program. In this example, the input range is 0…10V dc (decimal range of 0…4095). If the input range were 4…20 mA, the low and high limits would be 2047 and 408, respectively.

```
─────────── MAIN ───────────
                              B3/0        Turn OFF Alarm
                             ─(U)─
       LIM                    B3/0        Turn ON Alarm,
  LIMIT TEST (CIRC)          ─(L)─        Limit Exceeded
  Low Lim         4095
  Test            I:1.0
  High Lim        408

       Remainder of Program
─────────── END ───────────
```
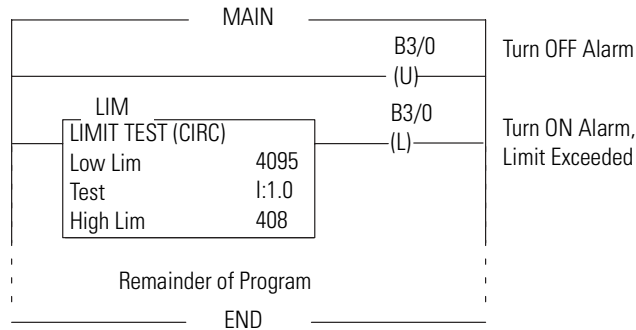
In both examples, the analog input value is in word 0 of slot 1 (I:1.0).

# Overview of Scaling Inputs and Outputs

Scaling is the application of a ratio on the variable to be scaled, where the ratio is the scaled range ($\Delta y$) to the input range ($\Delta x$).

The purpose for scaling values when programming analog I/O modules is to change data format.

**Scaling Inputs and Outputs**

| When you scale | You start with this data format | And typically change the format to |
|---|---|---|
| Inputs | Decimal input range in raw counts (from the module's A/D converter) | Engineering units such as PSI (stored in the data table) |
| Outputs | Integer values from the data table (or from the input image table) | Decimal output range in raw counts to match the module's output range |
| On a linear graph | $\Delta x$ | $\Delta y$ |

We illustrate input and output scaling, the source and type of data to be scaled, and the type and destination of the scaled data.

**Data Scaling**

**Input Scaling**

**Output Scaling**

Scaled Values in Engineering Units for Data Table (Δy)

Module's Input in Raw Counts (Δx)

Scaled Values to Match Module's Raw Counts

Integer Values (from Data Table or Input Image)

Sensor

Module A/D

Input Image Table

Data Table

Output Image Table

Module D/A

Output Device

| Input Signal Range | Input Raw Counts from A/D |
|---|---|
| 0…5V dc | 0…2047 |
| 1…5V dc | 409…2047 |
| 0…10V dc | 0…4095 |
| 0…20 mA | 0…2047 |
| 4…20 mA | 409…2047 |

| Input Raw Counts to D/A | Output Signal Range |
|---|---|
| 0…16,384 | 0…5V dc |
| 3277…16,384 | 1…5V dc |
| 0…32,764 | 0…10V dc |
| -32,768…32,764 | -10 …10V |
| 0…31,208 | 0…20 mA |
| 6242…31,208 | 4…20 mA |
| 0…32,764 | 0…21 mA |

You scale data with ladder logic using arithmetic instructions such as add, multiply, and double divide; or by using the scaling instruction available with SLC 5/02 (or later) processors. The scaling computation is as follows:

**Scaled value** = (input value x slope) + offset

Slope = $\Delta y / \Delta x$ = scaled range / input range

= (scaled max. – scaled min.) / (input max. – input min.)

Offset = scaled min. – (input min. x slope)

In this context, the input value and input range are inputs to the scaling function, not necessarily inputs associated with the sensor input.

# Scale an Analog Input and Detect an Out-of-range Condition

The following example shows input range checking and scaling the analog input to engineering units for a 1746-FIO4V analog input module.

We are making the following assumptions:

- The 1746-FIO4V module is located in slot 3 of a modular system.
- A pressure sensor with a 0…10V dc output is wired to input channel 1.
- The sensor signal voltage is proportional to a range of 100…500 PSI.
- The process pressure must stay between 275…300 PSI. (If the pressure deviates from this range, your logic sets an alarm bit.)
- Data is presented in PSI for monitoring and display purposes.

## Input Scaling

The scaling operation is displayed in the following graph. It displays the linear relationship between the input and the resulting scaled values.

**Input Scaling**
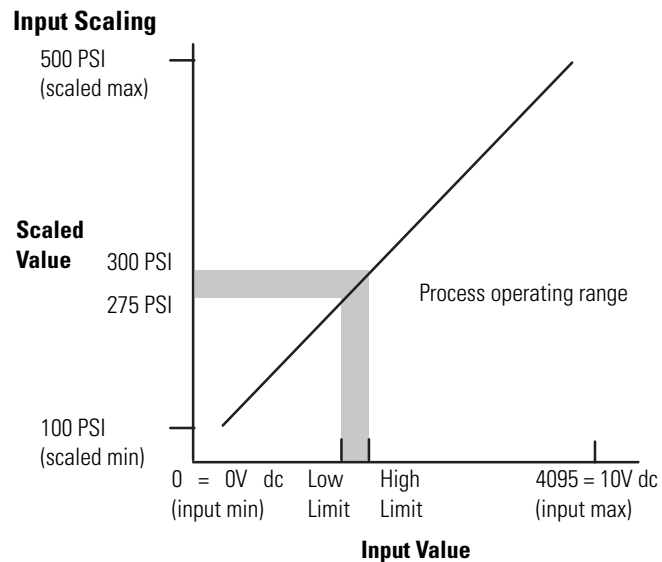
## Calculate the Linear Relationship

Use the following equations to express the linear relationship between the input value and the resulting scaled value.

**Scaled value** = (input value x slope) + offset

Slope = (scaled max − scaled min) / (input max − input min)
(500 − 100) / (4095 − 0) = 400/4095 = 0.0977

Offset = scaled min − (input min x slope)
(100 − (0 x [400/4095]) = 100

**Scaled value** = (input value x [0.0977]) + 100

## Calculate the Out-of-range Limits

Use the following equation to compute low and high out-of-range limits.

**Input value** = (scaled value − offset) / slope

low limit: (275 − 100) / (0.0977) $\simeq$ 1750 counts

high limit: (300 − 100) / (0.0977) $\simeq$ 2750 counts

## Ladder Logic

We present two examples for programming the processor.

The first example uses standard math instructions available in any SLC 500 processor. This ladder logic prevents a processor fault by unlatching the mathematical overflow bit S2:5/0 before the end of the scan.

The second example uses the scaling instruction (SCL) available in SLC 5/02 (and later) processors. The rate parameter is calculated by multiplying the slope by 10,000. If the slope exceeds 3.2767, you cannot use the SCL instruction.

**rate** = (400/4095) x 10,000 = 977     (The slope is 0.0977 so you can use the SCL instruction.)

Standard Math Example

Rung 2:0
Check for below range

LES
LESS THAN
Source A    I:3.1
Source B    1750

Below-range flag
B3/0
(L)

Rung 2:1
Check for above range

GRT
GREATER THAN
Source A    I:3.1
Source B    2750

Above-range flag
B3/1
(L)

Rung 2:2
Scale the analog input

Multiply by the scaled range

MUL
MULTIPLY
Source A    I:3.1
Source      400
Dest        N7:0

Clear fault bit from overflow

S2:5/0
(U)

Divide result by input range

DDV
DOUBLE DIVIDE
Source A    4095
Dest        N7:0

Add offset

N7:0 contains process pressure

ADD
ADD
Source A    N7:0
Source B    100
Dest        N7:0

Rung 2:3
END

Example Program Using the Scaling Instruction (SCL)

Rung 2:0
Check for below range

LES
LESS THAN
Source A    I:3.1
Source B    1750

Below-range flag
B3/0
(L)

Rung 2:1
Check for above range

GRT
GREATER THAN
Source A    I:3.1
Source B    2750

Above-range flag
B3/1
(L)

Rung 2:2
Scale the analog input

N7:0 contains process temperature

SCL
SCALE
Source          I:3.1
Rate (/10000)   977
Offset          100
Dest            N7:0

Rung 2:3
END
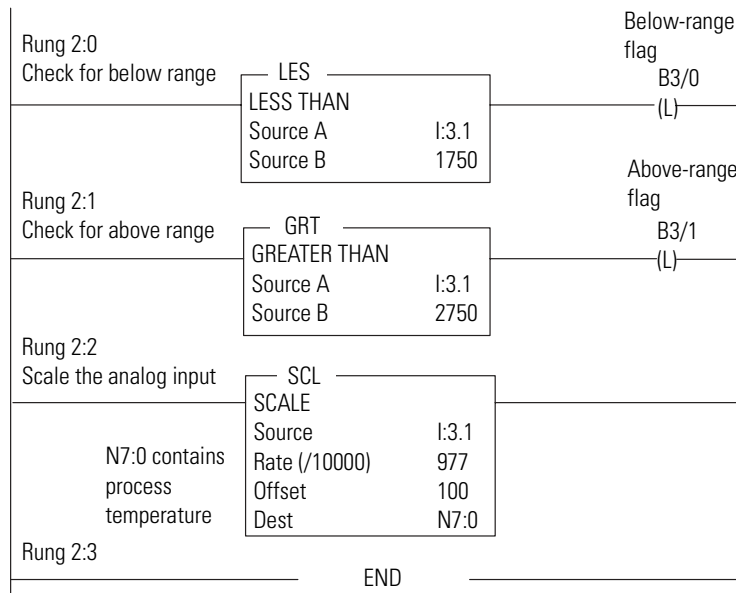
## Scale an Analog Output

This example shows the scaling of analog output values to engineering units for monitoring or controlling purposes.

We are making these assumptions.

- The FIO4I module is located in slot 2 of an SLC 500 system.
- An actuator of a flow control valve is wired to output channel 0.
- The actuator accepts a 4…20 mA signal for a 0…100% of valve opening.
- The actuator can not receive a signal out of the 4…20 mA range.
- The percentage of valve opening is manually input to the SLC processor.

This graph displays the linear relationship.
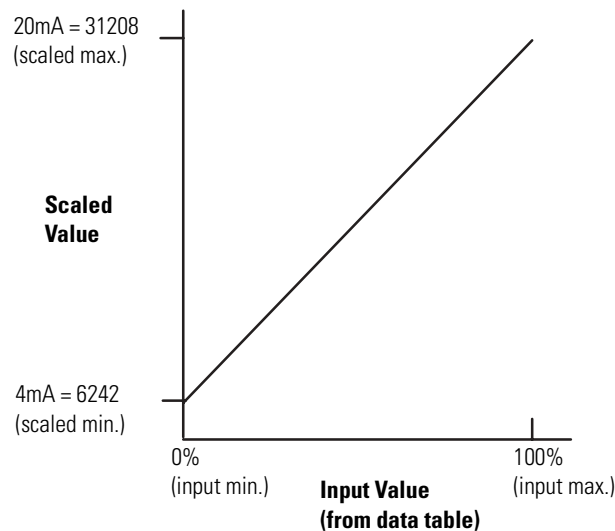


### Calculate the Linear Relationship

Use these equations to compute the scaled output value:

**Scaled value** = (input value x slope) + offset

    Slope = (scaled range) / (input range)
          = (scaled max – scaled min) / (input max – input min)
          = (31208 – 6242) / (100 – 0) = 24966/100
             The slope is greater than 3.2767 so you cannot use SCL instruction.

    Offset = scaled min – (input min x slope)
          = 6242 – [0 x (24966 / 100)] = 6242

**Scaled value** = [input value x 24966 / 100] + 6242

## Ladder Logic

The out-of-range limits are predetermined because any value less than 0% is 6242 and any value greater than 100% is 31,208. The ladder logic checks for out-of-range limits to verify that not less than 4 mA and not more than 20 mA is delivered to the analog output channel.

The following ladder logic uses standard math. It unlatches the mathematical overflow bit S2:5/0 before the end of the scan to prevent a processor fault.

**Example Program for Any SLC Processor**

```
Rung 2:0
Set in-range bit                                          B3/0
                                                          (L)

Rung 2:1
Check for below range
      ┌─ LES ──────────────┐              ┌─ MOV ──────────────┐
      │ LESS THAN          │              │ MOVE               │
      │ Source A     N7:0  │              │                    │
      │ Source B        0  │              │ Source A     6242  │
      └────────────────────┘              │ Dest        0:2.0  │
                                          └────────────────────┘
                    N7:0 contains                       B3/0
Rung 2:2            % valve open                         (U)
Check for above range
      ┌─ GRT ──────────────┐              ┌─ MOV ──────────────┐
      │ GREATER THAN       │              │ MOVE               │
      │ Source A     N7:0  │              │                    │
      │ Source B      100  │              │ Source A    31208  │
      └────────────────────┘              │ Dest        0:2.0  │
                                          └────────────────────┘
                                                        B3/0
Rung 2:3                                                 (U)
Scale the analog input
           B3/0                           ┌─ MUL ──────────────┐
          ─┘ ┌─                           │ MULTIPLY           │
                     Multiply by the      │ Source A     N7:0  │
                     scaled range         │ Source B    24966  │
                                          │ Dest         N7:1  │
                                          └────────────────────┘
                     Clear fault bit                    S2:5/0
                     from overflow                       (U)

                     Divide result       ┌─ DDV ──────────────┐
                     by input range      │ DOUBLE DIVIDE      │
                                         │ Source A      100  │
                                         │ Dest         N7:1  │
                                         └────────────────────┘
                                         ┌─ ADD ──────────────┐
                     Add offset          │ ADD                │
                                         │ Source A     N7:1  │
                                         │ Source B     6242  │
                                         │ Dest        0:2.0  │
Rung 2:4                                 └────────────────────┘
                          END
```

## Scale Offsets When >32,767 or <32,768

Some applications may produce an offset greater than 32,767 or less than –32,768, the largest value that can be stored in a 16-bit integer or processed by an SLC processor. If so, you may reduce the magnitude of the offset by shifting the linear relationship along the input value axis. When you compute linear relationships, you will see how the offset is reduced in this manner. The following example applies to a 0.5…9.5V dc output scaled from a narrow input range of 90…100%.

**1.** First we compute linear relationships and observe that the offset is beyond –32,768.
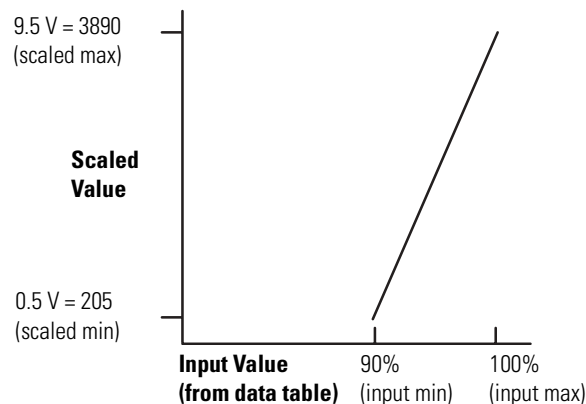


Use the following equations to compute linear relationships:

Scaled value = (input value x slope) + offset

 Slope = (scaled max – scaled min) / (input max – input min)
  (3890 – 205) / (100 – 90) = 3685/10 ≃ 369 (> 3.2767 so you cannot use SCL)

 **Offset** = scaled min – (input min x slope)
  205 – [90 x (368.5)] = 205 – 33165 = **–32,960**

Scaled value = (input value) x (368.5) – 32,960

Notice the offset is beyond –32,768.

**2.** Then we shift the linear relationship along the input value axis.

9.5 V = 3890
(scaled max)

**Scaled
Value**

0.5 V = 205
(scaled min)

90%              100%              **Input Value**
(input min)     (input max)
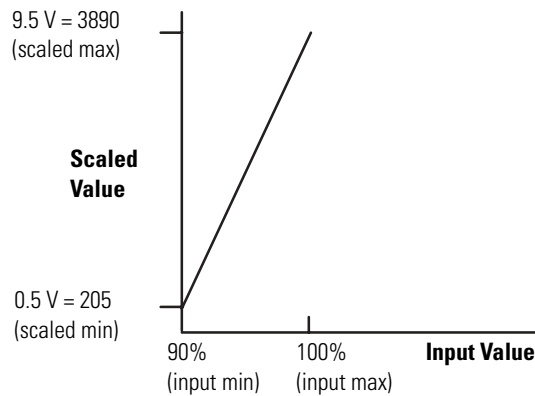
**3.** Now we compute the offset for the shifted linear relationship.

**Offset** = scaled min – (input min x slope)
        = 205 – [0 x (368.5)] = **205**

The offset is 205, well below 32,767. The slope remains 3685/10 (> 3.2767), so you cannot use the SCL instruction for scaling.

Slope = (scaled range) / (input range) = (3890 – 205) / 10 = 3685/10
Scaled value = (input value x slope) + offset = [input value x 3685 /10] + 205

## Ladder Logic

The following ladder logic uses standard math. It unlatches the mathematical overflow bit S2:5/0 before the end of the scan to prevent a processor fault. The module is located in slot 2, and the output device is wired to channel 0.

**Scale Offset**

Rung 2:0
Set in-range bit
```
                                                      B3/0
                                                      (L)
```

Rung 2:1
Check for below range
```
  ┌─ LES ──────────────┐        ┌─ MOV ──────────────┐
  │ LESS THAN           │        │ MOVE                │
  │ Source A      N7:0  │        │                     │
  │ Source B         0  │        │ Source A       205  │
  └─────────────────────┘        │ Dest         0:2.0  │
                                 └─────────────────────┘

                                                      B3/0
                                                      (U)
```

Rung 2:2
Check for above range
```
  ┌─ GRT ──────────────┐        ┌─ MOV ──────────────┐
  │ GREATER THAN        │        │ MOVE                │
  │ Source A      N7:0  │        │                     │
  │ Source B       100  │        │ Source A      3890  │
  └─────────────────────┘        │ Dest         0:2.0  │
                                 └─────────────────────┘
```

Rung 2:3
Scale the analog input
```
                                                      B3/0
                                                      (U)
          B3/0
        ──] [──
                       Subtract the    ┌─ SUB ──────────────┐
                       input minimum.  │ SUBTRACT            │
                                       │ Source A      N7:0  │
                                       │ Source B        90  │
                                       │ Dest          N7:1  │
                                       └─────────────────────┘

                       Multiply by the ┌─ MUL ──────────────┐
                       scaled range    │ MULTIPLY            │
                                       │ Source A      N7:1  │
                                       │ Source B      3685  │
                                       │ Dest          N7:1  │
                                       └─────────────────────┘

                       Clear fault bit                S2:5/0
                       from overflow                  (U)

                       Divide result   ┌─ DDV ──────────────┐
                       by input range  │ DOUBLE DIVIDE       │
                                       │ Source A        10  │
                                       │ Dest          N7:1  │
                                       └─────────────────────┘

                       Add offset      ┌─ ADD ──────────────┐
                                       │ ADD                 │
                                       │ Source A      N7:1  │
                                       │ Source B       205  │
                                       │ Dest         0:2.0  │
                                       └─────────────────────┘
```

# Range-check an Analog Input and Scale It for an Output

This example checks the range of an analog input and scales it for use as an output. An 1746-FIO4V module is placed in slot 1 of an SLC 500 system. A 4…20 mA signal representing 0…200 PSI from a pressure sensor is delivered to input channel 0. The input value is checked to ensure it remains within range. If the ladder logic detects an out-of-range condition, it sets a flag bit.

The input signal is then scaled and delivered as a 0…1.0V output signal to a panel pressure meter connected to output channel 0.

The graph displays the linear relationship between the analog input signal and the 0…1.0 output signal delivered to the panel pressure meter.
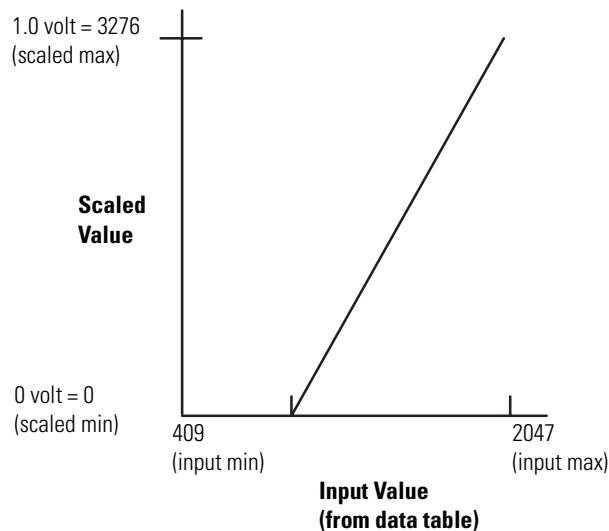


## Calculate the Linear Relationship

Use the following equations to compute the linear relationship between the input values (from the input image table) and resulting scaled values for the 0…1V output:

**Scaled value** = (input value x slope) + offset

> Slope = (scaled max − scaled min) / (input max − input min)
> (3276 − 0) / (2047 − 409) = 3276 / 1638 = 2.0
> Since the slope is less than 3.2767, you can use the SCL instruction.

> Offset = scaled min − (input min x slope)
> 0 − (409 x 2) = −818

**Scaled value** = (input value x 2) − 818

## Ladder Logic

We present two examples. The first runs on any SLC 500 processor. The second uses the scaling instruction available on SLC 5/02 (and later) processors.

In the first example, the analog input value is checked against the minimum and maximum input limits. B3:0/0 is the in-range flag bit.

If the input is out of range, the in-range flag bit is reset and the output is set to its minimum or maximum limit. If the input is in range, the output value is determined by scaling the input.

Follow these steps to scale an analog input for this example.

1. Multiply the input by the scaled range
   Scale range = (scaled max − scaled min) = 3276 − 0 = 3276

2. Divide the 32 bit result by the input range
   Input range = (input max − input min) = 2047 − 409 = 1638

3. Add the offset value (in this case negative) = −818
   Move the final value to the analog output channel 0.

In this example, the multiply operation generates an overflow bit and minor error flag whenever the result exceeds 16 bits. Since the divide operation uses a 32-bit result in the math register, the overflow is no problem. The minor error flag has to be cleared before the end of the program scan to avoid a system error.

Refer to the ladder program on the next page.

**Example Program for Any SLC Processor**

Rung 2:0
Set in-range bit
B3/0
—(L)—

Rung 2:1
Check for below range

```
LES
LESS THAN
Source A        I:1.0
Source B         409
```

```
MOV
MOVE

Source            0
Dest            N7:0
```

Rung 2:2
Check for above range

B3/0
—(U)—

```
GRT
GREATER THAN
Source A        I:1.0
Source B        2047
```

```
MOV
MOVE

Source A        3276
Dest            N7:0
```

B3/0
—(U)—

Rung 2:3
Scale the analog input

B3/0
—] [—

Multiply by the
scaled range

```
MUL
MULTIPLY
Source A        I:1.0
Source B        3276
Dest            N7:0
```

Clear fault bit
from overflow

S2:5/0
—(U)—

Divide result
by input range

```
DDV
DOUBLE DIVIDE
Source A        1638
Dest            N7:0
```

Add offset

```
ADD
ADD
Source A        N7:0
Source B        −818
Dest            N7:0
```

Rung 2:4
Move value to output channel 0

```
MOV
MOVE

Source A        N7:0
Dest            0:1.0
```

Rung 2:5
END

Using the scaling instruction (SCL) requires less ladder logic. The SCL instruction uses the same multiply, divide, and add algorithm but it does so with a single rate instead of using scaled range and input range values. The rate is determined by this formula.

$$
\begin{aligned}
\text{Rate} &= \text{slope x 10,000} \\
&= \text{(scale range / input range) x 10,000} \\
&= \text{3276 / 1638 x 10,000} \\
&= \text{2 x 10,000} \\
&= \text{20,000}
\end{aligned}
$$

If the slope was greater than 3.2767, you could not use the SCL instruction because the rate would exceed 32,767, a value too large to handle.

**Example Program for SLC 5/02 (or later) Processors**

```
Rung 2:0
Set in-range bit                                                    B3/0
                                                                   ─(L)─


Rung 2:1
Check for below range
          ┌─ LES ──────────┐              ┌─ M0 ──────────┐
          │ LESS THAN       │              │ MOVE          │
          │ Source A   I:1.0│              │               │
          │ Source B    409 │              │ Source      0 │
          └─────────────────┘              │ Dest     N7:0 │
                                           └───────────────┘
Rung 2:2                                                            B3/0
Check for above range                                              ─(U)─
        ┌─ GRT ──────────────┐             ┌─ MOV ──────────┐
        │ GREATER THAN        │            │ MOVE           │
        │ Source A      I:1.0 │            │                │
        │ Source B      2047  │            │ Source A  3276 │
        └─────────────────────┘            │ Dest      N7:0 │
                                           └────────────────┘
                                                                   B3/0
Rung 2:3                                                          ─(U)─
Scale the analog input
           B3/0                         ┌─ SCL ─────────────┐
          ─┤ ├─                         │ SCALE             │
                                        │ Source      I:1.0 │
                                        │ Rate (/10,000) 20,000│
                                        │ Offset       −818 │
                                        │ Dest        N7:0  │
                                        └───────────────────┘
Rung 2:4                                ┌─ MOV ─────────────┐
Move value to output channel 0          │ MOVE              │
                                        │                   │
                                        │ Source A    N7:0  │
                                        │ Dest        0:1.0 │
Rung 2:5                                └───────────────────┘
                          END
```
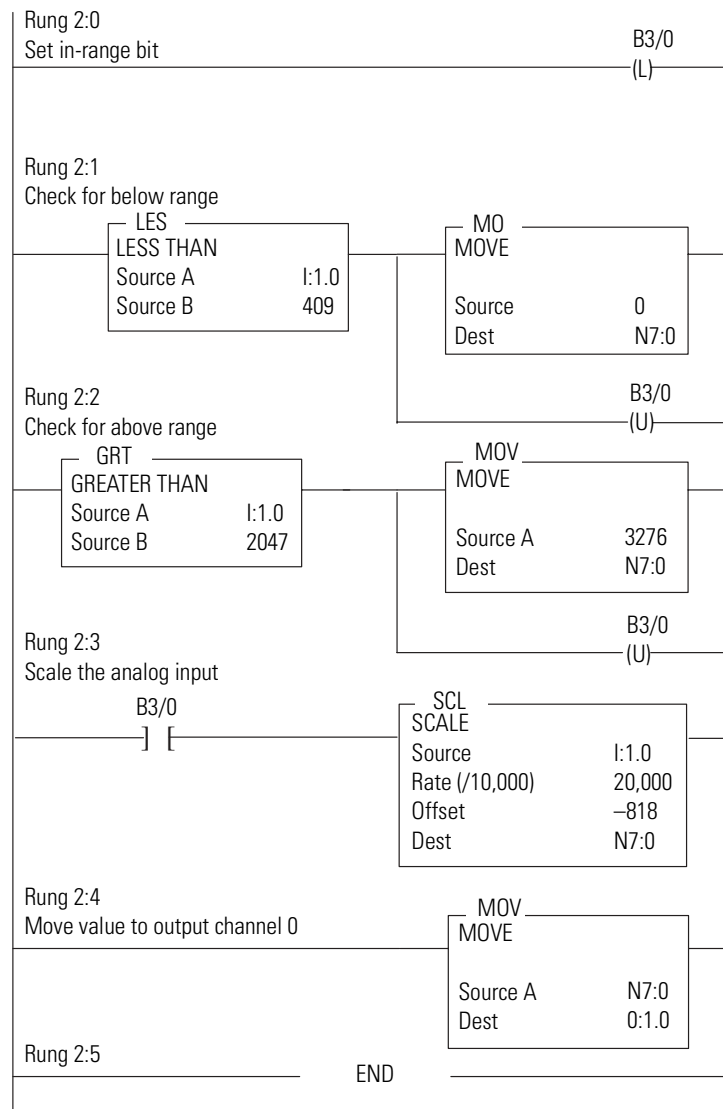
## PID Control with Analog I/O Scaling

With the combination of PID and SCL (scale) instructions or PID and standard math instructions, you can write and display ladder logic in engineering units such as PSI or °C.

Follow these steps to display ladder logic in engineering units.

1. Scale the analog input PV by calculating the slope (or rate) of the analog input range.

   For example, an input range such as 1…5V dc has a corresponding scaled range of 409…2047. You would scale the 409…2047 against 0…16383 for a slope of 10 (SCL rate of 100,000).

   | | |
   |---|---|
   | **IMPORTANT** | You cannot use the SCL instruction for scaling inputs if input rates (slope x 10,000) are too large (exceed 32,767). You must use standard math instructions instead. |

2. Scale the analog output CV by calculating the slope (or rate) of the analog output range.

   For example, an output range such as 4…20 mA has a corresponding decimal (scaled) range of 6242…31,208. You would scale the 6242…31,208 against 0…16,383.

| For this output range | Compute the slope as follows | Compute offset as follows |
|---|---|---|
| 4…20 mA | $\dfrac{\text{scaled max} - \text{scaled min}}{\text{input max} - \text{input min}}$ | scaled min − [input min x slope] |
| | $\dfrac{31208 - 6242}{16383 - 0} = \dfrac{24966}{16383} = 1.5238$ | = 6242 − [0 x 1.5238] <br> = 6242 |

Here are some useful rate and offset parameters for the SCL instruction when scaling analog output ranges.

| SCL Parameter | 0…20 mA | 4…20 mA | 0…5V dc | 1…5V dc | 0…10V dc |
|---|---|---|---|---|---|
| Rate (slope x 10,000) | 19,049 | 15,239 | 10,000 | 8,000 | 19,999 |
| Offset | 0 | 6242 | 0 | 3277 | 0 |

**3.** Enter PID parameters in engineering units into the PID instruction.

For example, if the 4…20 mA analog input range represents 0…300 PSI, enter 0 as the minimum (Smin) and 300 as the maximum (Smax). You can also enter setpoints and deadband in engineering units. The data monitor screen for PID displays its parameters in the same engineering units.

## Ladder Logic

We present two examples of PID control logic with analog I/O scaling for use on an SLC 5/02 (or later) processor.

- Scaled voltage input and output, 0…10V dc
- Scaled current input and output, 4…20 mA

**Example Program for SLC 5/02 (or later) Processors (scaled voltage input and output)**

Rung 2:0
```
                                                                IIM
                                                                IMMEDIATE INPUT w MASK
                                                                Slot              I:1.0
                                                                Mask              FFFF
                                                                Length            1
```

Rung 2:1
```
                                                                MUL
                                                                MULTIPLY
                                                                Source A     I:1.0
                                                                Source B     4
                                                                Dest         N7:0
                                                                             0
```

Rung 2:2
```
                                                                PID
                                                                PID
                                                                Control Block        N10:0
                                                                Process Variable     N7:0
                                                                Control Variable     N10:29
                                                                Control Block Length 23
```

Rung 2:3
```
                                                                SCL
                                                                SCALE
                                                                Source        N10:29
                                                                              0
                                                                Rate (/10000) 19999
                                                                Offset        0
                                                                Dest          O:1.0
```

Rung 2:4
```
                                                                IOM
                                                                IMMEDIATE OUT w MASK
                                                                Slot          O:1.0
                                                                Mask          FFFF
                                                                Length        1
```

Rung 2:5                                    +END+
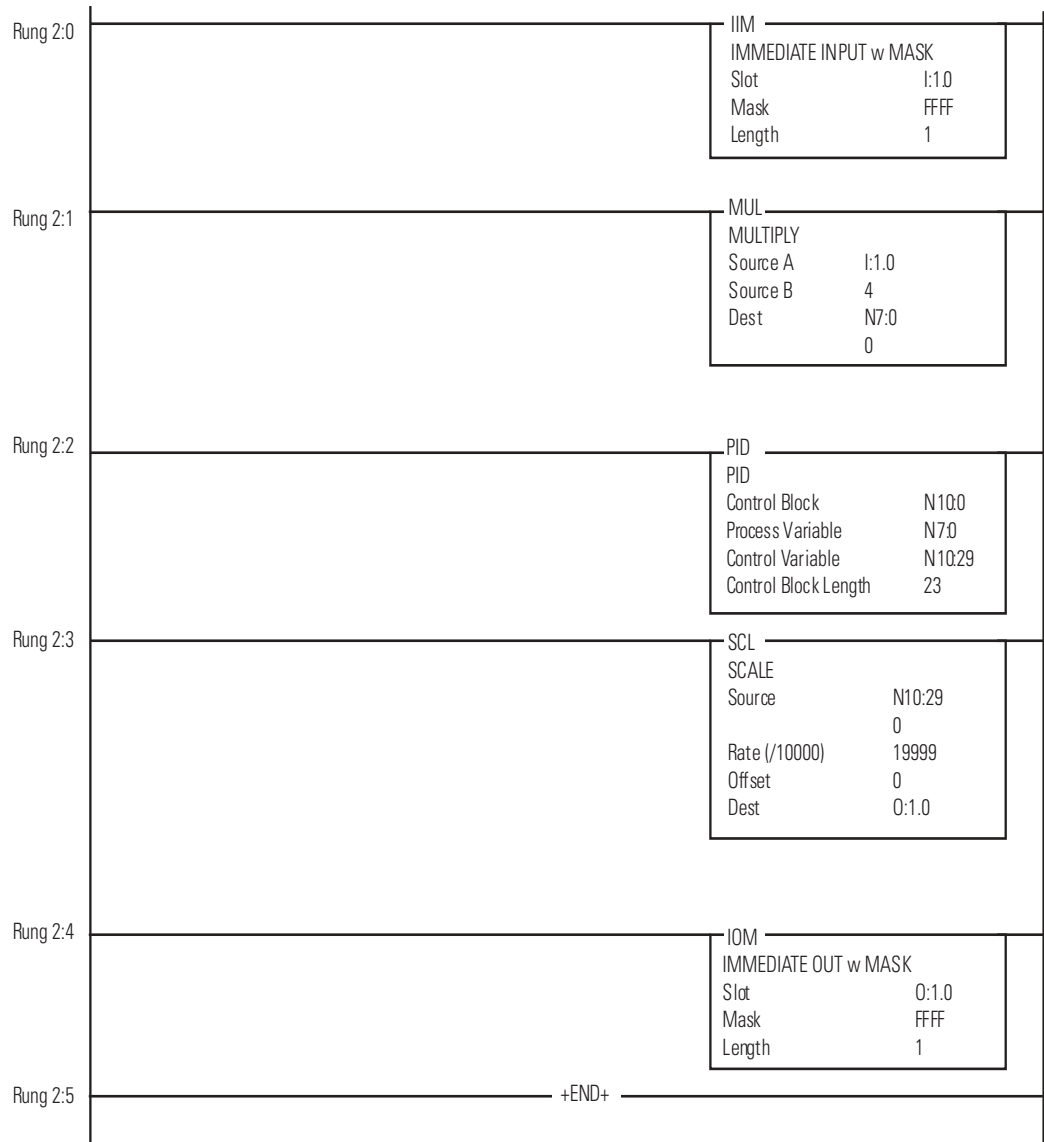
**Example Program for SLC 5/02 (or later) Processors (scaled current input and output)**

Rung 2:0

```
                                                    ┌─ IIM ──────────────────┐
                                                    │  IMMEDIATE INPUT w MASK  │
                                                    │  Slot              I:1.0 │
                                                    │  Mask               FFFF │
                                                    │  Length                1 │
                                                    └──────────────────────────┘
```

Rung 2:1
Scale the analog input with math instructions.

```
                                          ┌─ MUL ──────────────┐
                                          │  MULTIPLY           │
        Multiply by scaled range          │  Source A     I:1.0 │
                                          │  Source B     16383 │
                                          │  Dest         N7:0  │
                                          └─────────────────────┘

                                                    S2:5
        Clear overflow fault bit                    (U)
                                                     0

                                          ┌─ DDV ──────────────┐
        Divide by input range             │  DBL DIVIDE         │
                                          │  Source A      1638 │
                                          │  Dest         N7:0  │
                                          └─────────────────────┘

                                          ┌─ ADD ──────────────┐
        Add offset                        │  ADD                │
                                          │  Source A     N7:0  │
                                          │                     │
                                          │  Source B     −4091 │
                                          └─────────────────────┘
```
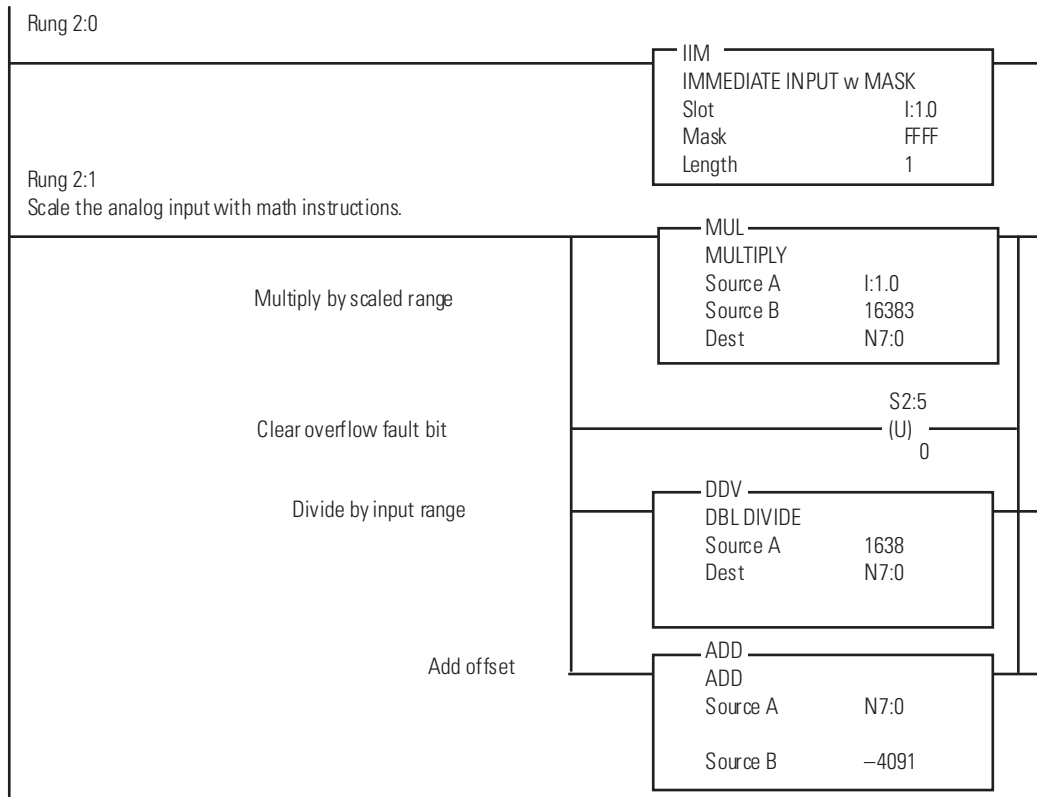
**Brake Monitor Example Program for SLC 5/02 (or later) Processors**

Rung 2:2
The next 2 rungs ensure that the analog input value to be scaled remains within the limits of 409 and 2047. This prevents out-of-range conversion errors in the SCL and PID instructions. The latch bits can be used elsewhere in the program to identify the particular out-of-range error which occurred.

```
                                                              Under
                                                              Range B3
    ┌─ LES ─────────────────────┐                              ─(L)─
    │  LESS THAN                 │                                0
    │  Source A        N7:0      │                    ┌─ MOV ──────────────────┐
    │                  0         │                    │  MOVE                   │
    │  Source B        409       │                    │  Source A       409     │
    └────────────────────────────┘                    │                         │
                                                       │  Dest           N7:0    │
                                                       │                 0       │
                                                       └─────────────────────────┘
```

Rung 2:3

```
                                                              Over
                                                              Range B3
    ┌─ GRT ─────────────────────┐                              ─(L)─
    │  GREATER THAN              │                                1
    │  Source A        N7:0      │
    │                  0         │                    ┌─ MOV ──────────────────┐
    │  Source B        2047      │                    │  MOVE                   │
    └────────────────────────────┘                    │  Source         2047    │
                                                       │                         │
                                                       │  Dest           N7:0    │
                                                       │                 0       │
                                                       └─────────────────────────┘
```

Rung 2:4

```
                                                    ┌─ PID ──────────────────────────────┐
                                                    │  PID                                 │
                                                    │  Control Block          N10:0        │
                                                    │  Process Variable       N7:0         │
                                                    │  Control Variable       N10:29       │
                                                    │  Control Block Length                │
                                                    └──────────────────────────────────────┘
```

Rung 2:5
The PID control variable is the input for the scale instruction. The PID instruction guarantees that the CV remains within the range of 16383. The CV is scaled to 6242–31208, the numeric range required for a 4–20 mA output signal.

```
                                                    ┌─ SCL ──────────────────────────────┐
                                                    │  SCALE                               │
                                                    │  Source               N10:29         │
                                                    │                       0              │
                                                    │  Rate (1/10000)       15239          │
                                                    │                                      │
                                                    │  Offset               6242           │
                                                    │                                      │
                                                    │  Dest                 O:1.0          │
                                                    └──────────────────────────────────────┘
```

Rung 2:6
This rung immediately updates the analog output card driven by the PID's CV.

```
                                                    ┌─ IOM ──────────────────────────────┐
                                                    │  IMMEDIATE OUT w MASK                │
                                                    │  Slot                 O:1.0          │
                                                    │  Mask                 FFFF           │
                                                    │  Length                              │
                                                    └──────────────────────────────────────┘
```

Rung 2:7

+END+

# Calibrate the Module

This chapter helps you calibrate the module's analog input channels to increase the expected accuracy from ± 21 LSB of error to ± 6 LSB. The combination of calibration program and procedure is designed to reduce offset and gain errors by:

- scaling the values read during calibration.
- applying them during runtime.

We provide example computations and ladder logic for your reference.

## Calibration Tradeoffs

Operating a calibrated module requires the addition of the calibration program for each calibrated input channel. Scanning the calibration program increases the program scan time during runtime, slowing the module's response. If the overall channel error of ± 0.510% of full scale at 25 °C (77 °F) is acceptable to your application, you need not calibrate. If you require a calibrated input channel, consider recalibrating every time you change the input sensor and/or the analog module.

# Calibrate an Analog Input Channel

We provide an example calibration program and a calibration procedure to show you how to calibrate an analog input channel.

This example assumes an analog output of 4…20 mA from a transducer. The corresponding decimal code that the module would write into the processor's input image table would be 409 at 4 mA and 2047 at 20 mA if the overall error of an input channel were zero. However, the overall error of ± 0.510% at 20 mA equates to ± 21 LSB of error, or a code range of 2026…2068. In other words, the value that the module transfers to the data table for a full scale sensor signal of 20 mA could be any value within the range of 2026…2068. Calibration should reduce the overall error to less than ± 6 LSB, or a code range of 2041…2053 for the error of the 20 mA signal.

**Code Ranges**

| With this full-scale sensor output | For an uncalibrated channel, the corresponding output would have this range of error | For a calibrated channel, the corresponding output would have this range of error |
|---|---|---|
| | 2068 | |
| | | 2053 |
| 20 mA > > | > > > 2047 > > > > | > > > 2047 |
| | | 2041 |
| | 2026 | |

## Example Calibration Program

Complete these tasks to maintain calibrated inputs for each channel.

- Add a calibration program for each channel to your application logic.
- Calibrate each channel.
- Enable the Convert Enable rung (rung 2:4) during runtime.

The calibration program requires three external inputs to calibrate each channel.

- Lo captures the low calibration value (calibration procedure, step 3).
- Hi captures the high calibration value (calibration procedure, step 4).
- Cal scales the Hi and Lo values to provide the slope and offset (step 5).

These addresses are used in the example program.
(Each channel requires its own program and separate addresses.)

**Example Program Addresses**

| Bit or Value | Address |
|---|---|
| Cal_Lo | I:1.0/0 and N10:0/0 (You set these bits in step 3.) |
| Cal_Hi | I:1.0/1 and N10:0/1 (You set these bits in step 4.) |
| Calibrate | I:1.0/2 and N10:0/2 (You set these bits in step 5.) |
| Convert Enable | N10:10/4 (Runtime enable) |
| Analog_In | I:2.0 |
| Lo_Value | N10:1 |
| Hi_Value | N10:2 |
| Scale_Hi | N10:3 |
| Scale_Lo | N10:4 |
| Scale_Span | N10:7 |
| Span | N10:9 |
| Slope_x10K | N10:18 |
| Offset | N10:21 |
| Analog Scale | N10:22 |

Compute values required for the calibration program as follows:

**Scaled value** = (input value x slope) + offset

Slope = (scaled max. − scaled min.) / (input max. − input min.)
= (2047 − 409) / (2055 − 400)[1] = 1638 / 1655 = **.9897**

[1] The values of 2055 and 400 are from the calibration procedure steps 3 and 4, respectively.

Offset = scaled min. − (input min. x slope)
= 409 − (400 x .9897) = 409 − 395.88 = 13.12

Rung 2:0
Cal_Lo

```
  I:1.0              N10:0          ┌─ MOV ──────────────────┐
──┤ ├──────────────┤[OSR]├─────────│   MOVE                 │
    0                  0            │   Source    Analog_In  │
                                    │                  1000  │
                                    │   Dest       Lo_Value  │
                                    │                   400  │
                                    └────────────────────────┘
```

Rung 2:1
Cal_Hi

```
  I:1.0              N10:0          ┌─ MOV ──────────────────┐
──┤ ├──────────────┤[OSR]├─────────│   MOVE                 │
    1                  1            │   Source    Analog_In  │
                                    │                  1000  │
                                    │   Dest       Hi_Value  │
                                    │                  2055  │
                                    └────────────────────────┘
```

Rung 2:2
Calibrate

```
  I:1.0              N10:0          ┌─ SUB ──────────────────┐
──┤ ├──────────────┤[OSR]├─────────│   SUBTRACT             │
    2                  2            │   Source A   Hi_Value  │
                                    │                  2055  │
                                    │   Source B   Lo_Value  │
                                    │                   400  │
                                    │   Dest           Span  │
                                    │                  1655  │
                                    └────────────────────────┘

                                    ┌─ SUB ──────────────────┐
                                    │   SUBTRACT             │
                                    │   Source A   Scale_Hi  │
                                    │                  2047  │
                                    │   Source B   Scale_Lo  │
                                    │                   409  │
                                    │   Dest     Scale_Span  │
                                    │                  1638  │
                                    └────────────────────────┘

                                    ┌─ MUL ──────────────────┐
                                    │   MULTIPLY             │
                                    │   Source A  Scale_Span │
                                    │                  1638  │
                                    │   Source B       10000 │
                                    │   Dest          N10:16 │
                                    │                 32767  │
                                    └────────────────────────┘

                                    ┌─ DDV ──────────────────┐
                                    │   DOUBLE DIVIDE        │
                                    │   Source         Span  │
                                    │                  1655  │
                                    │   Dest    Slope_x 10K  │
                                    │                  9897  │
                                    └────────────────────────┘
```

```
                                          ┌─ MUL ──────────────────┐
                                          │ MULTIPLY               │
                                          │ Source A      Lo_Value  │
                                          │                    400  │
                                          │ Source B     Slope_x10K │
                                          │                   9897  │
                                          │ Dest            N10:5   │
                                          │                  32767  │
                                          └────────────────────────┘

                                          ┌─ DDV ──────────────────┐
                                          │ DOUBLE DIVIDE          │
                                          │ Source          10000   │
                                          │ Dest            N10:6   │
                                          │                   396   │
                                          └────────────────────────┘

                                          ┌─ SUB ──────────────────┐
                                          │ SUBTRACT               │
                                          │ Source A      Scale_Lo  │
                                          │                    409  │
                                          │ Source B        N10:6   │
                                          │                   396   │
                                          │ Dest           Offset   │
                                          │                     13  │
                                          └────────────────────────┘

                                                     S:5
                                                    ─(U)─
                                                      0
Rung 2:4
Convert Enable During Runtime
       N10:10                             ┌─ MUL ──────────────────┐
      ──] [──                             │ MULTIPLY               │
         4                                │ Source A     Analog_In  │
                                          │                   1000  │
                                          │ Source B     Slope_x10K │
                                          │                   9897  │
                                          │ Dest            N10:8   │
                                          │                  32767  │
                                          └────────────────────────┘

                                                     S:5
                                                    ─(U)─
                                                      0
                                          ┌─ DDV ──────────────────┐
                                          │ DOUBLE DIVIDE          │
                                          │ Source          10000   │
                                          │ Dest            N10:12  │
                                          │                   990   │
                                          └────────────────────────┘

                                          ┌─ ADD ──────────────────┐
                                          │ ADD                    │
                                          │ Source A        N10:12  │
                                          │                   990   │
                                          │ Source B        Offset  │
                                          │                     13  │
                                          │ Dest         Analog_Scl │
                                          │                   1003  │
                                          └────────────────────────┘
Rung 2:5
─────────────────────────────  END  ─────────────────────────
```

## Calibration Procedure

Recalibrate every six months, or as necessary.

1. Let the module warm up under power for at least 20 minutes at ambient operating temperature.

2. Determine the scaled high and low values you wish to use in your application.

   In this example, scaled high is 2047 (20 mA) and scaled low is 409 (4 mA).

3. Capture the Lo calibration value.
   a. Place the input sensor (or input source) at the low (4 mA) position.
   b. Set the Cal Lo bit (I:1.0/0) and OSR bit (N10:0/0).

      Your low value must be within the analog input's conversion range. For this example, it is 400.

4. Capture the Hi calibration value.
   a. Place the input sensor (or input source) at the high (20 mA) position.
   b. Set the Cal Hi bit (I:1.0/1) and OSR bit (N10:0/1).

      Your high value must be within the analog input's conversion range. For this example, it is 2055.

5.  Set the Calibrate bit (I:1.0/2) and OSR bit (N10:0/2) to energize the calibration input.

   This causes the SCL instruction to compute and store the slope and offset values used to perform the error correction to the analog input.

| **IMPORTANT** | To apply calibration values to the input channel during normal operation, enable rung 2.4 during runtime. |
|---|---|

# Test Module Operation

This chapter helps you test the operation of the module's I/O channels.

## Test the SLC 500 System

Testing the SLC 500 system is beyond the scope of this manual. We mention it here only because you should test and debug at the system level before testing and debugging the module in the system.

If your module is installed in the expansion rack of a fixed system, test your SLC 500 system using procedures described in the Fixed Hardware Installation & Operation Manual, publication 1747-6.21, before testing the analog module.

If your analog module is installed in a modular system, test your SLC 500 system using procedures described in the SLC 500 Modular Hardware Style User Manual, publication 1747-UM011, before testing the analog module.

## Test the Module

Once you have tested your SLC 500 system, follow this procedure to test the module at start up. We describe each of the steps in detail.

1. Inspect module switches and wiring.

2. Disconnect analog process control devices.

3. Apply power to the I/O rack.

4. Test analog inputs.

5. Test analog outputs.

## Inspect Module Switches and Wiring

Inspect the module as follows before installing it.

1. Set the input configuration switches 1 and 2 correctly.

2. Check that wiring connections are OK and no wires are missing or broken.

3. Tighten terminal connections to secure the wires.

| **ATTENTION** ⚠ | Care should be taken to avoid connecting a voltage source to a channel configured for a current input. Improper module operation or damage to the module can occur. |
|---|---|

4. Ground the cable shields properly.

| **ATTENTION** ⚠ | Do not attempt to ground the cable at the module's terminal block. It does not connect to earth ground. Ground the cable at one end only, as described in chapter 2. |
|---|---|

5. Securely connect the module's terminal block.

6. Install the module in its addressed I/O rack slot.

## Disconnect Analog Process Control Devices

During the following test procedures, you need to operate the processor in Run mode. Make sure that analog process control devices are inoperative as a safety precaution. These devices include the following:

- proportional valves.
- proportional drives.
- servo amplifiers.
- other analog signal amplifiers that drive analog output devices.

Leave the module connected to the output device to serve as the output load where possible, but inhibit its affect on controlling the process. Substitute a passive load for the active device as an alternative.

---

**ATTENTION**

⚠️

Process operation during system checkout can be hazardous to personnel. During checkout procedures, disconnect, inhibit, or substitute a passive load for all devices which, when energized, might cause the process to operate.

---

## Apply Power to the I/O Rack

Apply power to the fixed or modular system. The module's LED indicator should be illuminated (red), indicating that the module is receiving power. If not, troubleshoot the non-illuminated LED indicator. Check the following:

- The SLC 500 system is not receiving power from its power supply. For an SLC processor in the fixed system, check the processor's POWER LED indicator. For the modular system, check the power supply LED indicator.

  If the LED indicator is not illuminated, refer to the Installation & Operation Manual of the system.

- System power is not being received by the remainder of the SLC 500 system. Test this by attempting to go online with the programming device.

- The module's slot in the I/O rack is not operational. Remove power from the SLC 500 system, move the module to another slot, and restore power. Replace the I/O rack if power distribution is faulty.

- The module is defective.

## Test Analog Inputs

Before testing the module's input channels, the SLC 500 system must be installed and tested according to the SLC 500 Modular Hardware Style User Manual, publication 1747-UM011.

The processor must be connected to a programming device, properly configured, and must have no rungs in its ladder program. The module's LED indicator must also be illuminated.

| | |
|---|---|
| **ATTENTION** ⚠ | Do not attempt to test the module's input channels unless its process control output devices have been disconnected, inhibited, or replaced by a passive load. |

If your input sensors can be manually varied over their normal operating range, use them to test the input channels. If not, use a replacement voltage or current source after disconnecting the sensor.

| | |
|---|---|
| **IMPORTANT** | If a current source is not available to test a current input channel, carefully apply a substitute input voltage instead. Determine the substitute input voltage using this formula. |

Voltage Input (V) = Current Input (mA) x 0.25

For example, substitute input voltages for 1 mA, 5 mA, and 20 mA inputs would be 0.25, 1.25, and 5.0V, respectively. Do not exceed 5V.

In normal operation, a voltage source should not be connected to an analog input channel in the current mode.

1. Determine the limits of the sensor's signal range for the channel.

   For example, if the sensor has an output range of 1…5 mA, the lower limit is 1 mA and the upper limit is 5 mA.

2. Compute the decimal value that should appear in the processor's input image table for the sensor's lower and upper signal limits at the input channel.

   For example, limits of 1 mA and 5 mA would have typical decimal values of 407 and 2047, respectively. If necessary, refer to the section, Converting Analog Input Data, in chapter 4.

**3.** With the programming device on-line, select the processor's Test- Continuous scan mode.

This provides a safer testing mode because outputs are not energized.

**4.** Display the data in File 2 (Input Image table).

**5.** Select the Data Monitor mode of your programming device when viewing I/O point I:1.0.

**6.** Change the radix of the display to decimal.

**7.** If the sensor is connected, set it to its lower limit.

If the sensor was disconnected from the module's input channel, attach the replacement voltage or current source and set the source to the lower limit.

**8.** Locate the channel's signal in the input image table.

The signal should be approximately equal to the lower limit computed in step B.

The value of the input image word is affected by the accuracy of the module and sensor.

Any error should be within the sum of their tolerances.

**9.** If the sensor is connected, set it to the upper limit.

If the sensor was disconnected from the module's input channel, set the replacement voltage or current source to the upper limit.

**10.** Repeat step 7, this time for the upper limit.

**11.** Repeat steps 1…10 for the other analog input channel.

If either of the analog input channels does not pass this start-up procedure, check for the following potential causes.

- The analog sensor (voltage or current source) is not operating properly.
- The processor is not in the Test/Continuous scan mode.
- The terminal block is not secured on the module.
- The terminal block is not wired properly or wires are broken.

## Test Analog Outputs

Before testing the module's output channels, the SLC 500 system must be installed and tested according to the SLC 500 Modular Hardware Style User Manual, publication 1747-UM011. The processor must be connected to a programming device, properly configured, and must have no rungs in its ladder program. The module's LED indicator must also be illuminated.

> ⚠️ **ATTENTION**
>
> Do not attempt to test the module's output channels unless its process control output devices have been disconnected, inhibited, or replaced by a passive load.

If the output device controls a potentially dangerous operation or a prime mover, use a voltmeter to test voltage outputs or an ammeter to test current outputs. Note that these meters have some inherent error of their own.

If using a meter, disconnect the output device and/or use a substitute load.

1. Determine the lower and upper limits of the module's output channel.

   For example, if connected to a signal amplifier with an input range of 1…5 volts, the signal limits are 1 volt (lower) and 5 volts (upper).

2. Compute the decimal value that should appear in the processor's output image table for the channel's lower and upper signal limits.

   For example, limits of 1 and 5 volts would have decimal values of 3277 and 16384, respectively. If you need help, refer to the section, Converting Analog Output Data, in chapter 4.

3. With the programming device on-line, select Program mode.

4. Create and save the test rung shown below.

```
          ┌─ MOV ─────────────┐
──────────┤ MOVE              ├──────
          │ Source      N7:0  │
          │ Dest      O:e.0-1 │
          └───────────────────┘
```
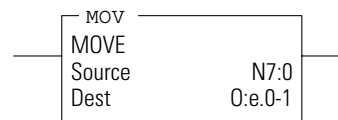
e is the module's I/O rack slot number
0-1 is the number of the module's output channel being tested

**5.** Download the test rung to the processor and select RUN mode.

**6.** Display the data in address N7:0.

**7.** Enter the lower limit in N7:0.

For example, if the lower limit is 1 volt, enter 3277 into N7:0.

**8.** Check that the output device is connected to the output channel and that the device assumes its lower limit condition.

If the output device is disconnected, read the replacement meter. Do not overlook module and meter errors.

**9.** Enter the upper limit in N7:0.

For example, if the upper limit is 5 volts, enter 16384 into N7:0.

**10.** Repeat step 7, this time for the upper limit.

**11.** Repeat steps 1…10 for the other output channel.

If either output channel does not pass this startup procedure, check that the:

- actuator or test meter is operating properly.
- processor is in RUN mode.
- terminal block is secured to the module.
- terminal block is wired properly or wires are not broken.

# Maintenance and Safety

This chapter provides preventive maintenance information and safety considerations when troubleshooting your SLC 500 system.

## Preventive Maintenance

The printed circuit boards of the analog modules must be protected from dirt, oil, moisture, and other airborne contaminants. To protect these boards, the SLC 500 system must be installed in an enclosure suitable for the environment. The interior of the enclosure should be kept clean and the enclosure door should be kept closed whenever possible.

Regularly inspect your terminal connections for tightness. Loose connections may cause improper functioning of the SLC 500 system or damage the components of the system.

| **ATTENTION** ⚠ | To ensure personal safety and to guard against damaging equipment, inspect connections with incoming power turned OFF. |
|---|---|

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

## Safety Considerations When Troubleshooting

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.

Refer to the Installation and Operation Manual for Fixed Hardware Style Programmable Controllers, publication 1747-6.21, or SLC 500 Module Hardware Style User Manual, publication 1747-UM011, for additional information on troubleshooting.

Follow these suggestions when troubleshooting your SLC 500 system.

**Indicator Lights** – When the red LED indicator on the analog module is illuminated it indicates that 24V dc power is applied to the module.

**Activating Devices When Troubleshooting** – When troubleshooting, never reach into the machine to actuate a device. Unexpected machine motion could occur. Use a wooden stick.

**Stand Clear of Machine** – When troubleshooting any SLC 500 system problem, have all personnel remain clear of the machine. 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 to the machine.

When troubleshooting, pay careful attention to this general warning.

> **WARNING**
>
> Never reach into a machine to actuate a switch since unexpected machine motion can occur and cause injury.
>
> Remove all electrical power at the main power disconnect switch before checking electrical connections or inputs/outputs that cause process actuation or machine motion.

**Program Alteration** – There are several causes of alteration to the user program, including extreme environmental conditions, Electromagnetic Interference (EMI), improper grounding, improper wiring, and unauthorized tampering. If you suspect the program has been altered, check it against a previously saved program on an EEPROM or UVPROM memory module.

**Safety Circuits** – Circuits installed on the machine for safety reasons, like over-travel limit switches, stop pushbuttons, 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 Specifications

## General Description

The 1746-FIO4I and 1746-FIO4V fast analog I/O modules provide two input and two output channels. Input channels are the same for both types of modules: you select either current or voltage operation for each channel. The 1746-FIO4I module contains two current-output channels, while the 1746-FIO4V module contains two voltage-output channels.

## Specifications

Specifications for the fast analog I/O modules include the following:

- general specifications.
- general input specifications.
- voltage input specifications.
- current-loop input specifications.
- current output specifications for the 1746-FIO4I.
- voltage output specifications for the 1746-FIO4V.

**General Specifications**

| Catalog 1746- | Input Channels per Module | Output Channels per Module | Backplane Current | | ID Code |
|---|---|---|---|---|---|
| | | | 5 V | 24 V | |
| FIO4I | Two differential, voltage or current, selectable per channel | Two current outputs, not individually isolated | 55 mA | 150 mA | 3224 |
| FIO4V | Same as FIO4I | Two voltage outputs, not individually isolated | 55 mA | 120 mA | 3218 |

**Electrical Specifications - 1746-FIO4I, 1746-FIO4V**

| Attribute | Value |
|---|---|
| Cable | Shielded, Belden #8761 (recommended) |
| Wire Size | 2.5 mm$^2$ (14 AWG) max |
| Terminal Block | Removable |
| Installation | Single slot in the 1746 I/O Rack |
| Calibration | Every six months or as necessary |

**Electrical Specifications - 1746-FIO4I, 1746-FIO4V**

| Attribute | Value |
|---|---|
| Noise Immunity | NEMA standard ICS 2-230 |
| Temperature, Operating | 0… 60 °C (32…140 °F) |
| Temperature, Storage | −40…85 °C (−40…185 °F) |
| Relative Humidity | 5 … 95% (noncondensing) |

**General Input Specifications - 1746-FIO4I, 1746-FIO4V**

| Attribute | Value |
|---|---|
| Converter Resolution | 12 bits |
| Converter Type | Successive approximation |
| Track and Hold Time to Acquire the Analog Signal Before Conversion | 1.5 µs (nom) |
| Signal Convert from Hold | 6.0 µs (nom) |
| Conversion Time (sum of above two specs) | 7.5 µs every 512 µs (nom) |
| Non-linearity | ±0.073% of full scale (max) |
| Location of LSB in I/O image word | 0000 0000 0000 0001 |
| Image Format (HEX) | 0FFF |
| Common Mode Voltage Range | 0 …20V (max) |
| Common Mode Rejection at 60 Hz | 50 dB (min with 1 k$\Omega$ imbalance) |
| Channel Bandwidth | 7.0 kHz (min @ 3 dB point) |
| Module Throughput | 1.10 ms (max[1])<br>512 µs (typical) |
| Step Response (5…95%) | 100 µs |
| Impedance to ANL COM | 500 k$\Omega$ |
| Impedance Channel-to-channel | 1 M$\Omega$ |
| Field Wiring to Backplane Isolation | 500V dc |

[1] Worst case throughput occurs when the module just misses seeing an event occur.

**Voltage Input Specifications - 1746-FIO4I, 1746-FIO4V**

| Attribute | Value |
|---|---|
| Input Operating Range | 0…10V dc (max) |
| Input Impedance | 1 M$\Omega$ (nom) |
| Resolution | 2.4414 mV per LSB (nom) |
| Voltage Input Coding (0…10V dc − 1 LSB) | 0…4095 counts |

**Voltage Input Specifications - 1746-FIO4I, 1746-FIO4V**

| Attribute | Value |
|---|---|
| Overall Accuracy at 25 °C (77 °F) | ±0.440% of full scale |
| Overall Accuracy at 60 °C (140 °F) | ±0.750% of full scale |
| Overall Accuracy Drift | ±88 ppm/°C (max) |
| Gain Error at 25 °C (77 °F) | ±0.323% of full scale |
| Gain Error at 0…60 °C (32…140 °F) | ±0.530% of full scale |
| Gain Error Drift | ±79 ppm/°C (max) |
| Offset Error at 0…60 °C (32…140 °F) | ±4 LSB (max) |
| Offset Error at 25 ° C (77 °F) | ±2 LSB (typical) |
| Offset Error Drift | ±0.14 LSB/°C (max[1]) |
| Overvoltage Protection (IN+ to IN–) | 220V dc or ac RMS, continuously |

[1]   Computed by box method: 2 [max offset error] / 60 °C

**Current-loop Input Specifications - 1746-FIO4I, 1746-FIO4V**

| Description | Specification |
|---|---|
| Input Operating Range | 0…20 mA (nom)<br>0…30 mA (max) |
| Input Voltage | ±7.5V dc or ac RMS (max) |
| Current Input Coding Range (0…20 mA) | 0…2047 counts |
| Input Impedance | 250 $\Omega$ (nom) |
| Resolution | 9.7656 µA per bit |
| Overall Accuracy at 25 °C (77 °F) | ±0.510% of full scale |
| Overall Accuracy at 60 °C (140 °F) | ±0.850% of full scale |
| Overall Accuracy Drift | ±98 ppm/°C of full scale (max) |
| Gain Error at 25 °C (77 °F) | ±0.400% of full scale |
| Gain Error at 0…60 °C (32…140 °F) | ±0.707% of full scale |
| Gain Error Drift | ±89 ppm/°C (max) |
| Offset Error at 0…60 °C (32…140 °F) | ±4 LSB |
| Offset Error at 25 °C (77 °F) | ±2 LSB (typical) |
| Offset Error Drift | ±0.14 LSB/°C (max[1]) |
| Overvoltage Protection | 7.5V ac RMS (max) |

[1]   Computed by box method: 2 [max offset error] / 60 °C

**Current Output Specifications for 1746-FIO4I**

| Attribute | Value |
| --- | --- |
| Converter Resolution | 14 bit |
| Location of LSB in I/O Image Word | 0000 0000 0000 01XX |
| Non-linearity | 0.05% of full scale (max) |
| Conversion Method | R–2R ladder |
| Step Response | 2.5 ms (at 95%) |
| Load Range | 0 … 500 $\Omega$ |
| Load Reactance | 100 µH (max) |
| Current Output Coding (0…+21 mA – 1 LSB) | 0 …32,764 |
| Output Range | 0…20 mA –1 LSB (normal) |
| Overrange Capability | 5% (0…21 mA – 1 LSB) |
| Resolution | 2.56348 mA per LSB |
| Full Scale | 21 mA |
| Overall Accuracy at +25 °C (77 °F) | ±0.298% of full scale |
| Overall Accuracy at 0…60 °C (32…140 °F) | ±0.541% of full scale |
| Overall Accuracy Drift | ±70 ppm/°C of full scale (max) |
| Gain Error at 25 °C (77 °F) | ±0.298% of full scale |
| Gain Error at 0…60 °C (32…140 °F) | ±0.516% of full scale |
| Gain Error Drift | ±62 ppm/°C (max) |
| Offset Error at 25 °C (77 °F) | ±10 LSB (typical) |
| Offset Error at 0…60 °C (32…140 °F) | ±12 LSB |
| Offset Error Drift | ±0.06 LSB/°C (max) |

**Voltage Output Specifications for 1746-FIO4V**

| Attribute | Value |
|---|---|
| Converter Resolution | 14 bit |
| Location of LSB in I/O Image Word | 0000 0000 0000 01XX |
| Non-linearity | 0.05% of full scale |
| Conversion Method | R–2R ladder |
| Step Response (to 95%) | 2.5 ms (normal) |
| Load Range | 1 k…∞$\Omega$ |
| Load Current | 10 mA (max) |
| Load Reactance | 1 µF (max) |
| Voltage Output Coding (−10…10V dc − 1 LSB) | −32,768 … +32,764 |
| Output Range | −10 … 10V − 1 LSB (normal) |
| Resolution | 1.22070 mV per LSB |
| Full Scale | 10V dc |
| Overall Accuracy at 25 °C (77 °F) | ±0.208% of full scale |
| Overall Accuracy at 0…60 °C (32…140 °F) | ±0.384% of full scale |
| Overall Accuracy Drift | ±54 ppm/°C of full scale (max) |
| Gain Error at 25 °C (77 °F) | ±0.208% of full scale |
| Gain Error at 0…60 °C (32…140 °F) | ±0.374% of full scale |
| Gain Error Drift | ±47 ppm/°C (max) |
| Offset Error at 25 °C (77 °F) | ±9 LSB (typical) |
| Offset Error at 0…60 °C (32…140 °F) | ±11 LSB |
| Offset Error Drift | ±0.05 LSB/°C (max) |

# 2's-complement Binary Numbers

## Use 2's-complement Binary Numbers

The SLC 500 processor stores data as 16-bit binary numbers. The processor uses 2's-complement binary format when making mathematical computations and when storing analog values in the I/O image table.

As indicated in the figure on next page, the equivalent decimal value of the 2's-complement binary number is the sum of corresponding position values. The corresponding position value is equal to 2 raised to the power designated by the position, beginning at the right with $2^0$ and ending at the left with $2^{15}$. The bit value in each position can be 0 or 1, where 0 excludes the corresponding position value from the sum and 1 includes it.

## Positive Decimal Values

The far left position is always 0 for positive values. Binary notation and 2's-complement binary notation are identical for positive values. This format limits the maximum positive value to 32767 when all positions are 1 except for the far left position (see figure below). Study these examples.

$$0000\ 1001\ 0000\ 1110 = 2^{11} + 2^8 + 2^3 + 2^2 + 2^1$$
$$= 2048 + 256 + 8 + 4 + 2 = 2318$$
$$0000\ 0011\ 0010\ 1000 = 2^9 + 2^8 + 2^5 + 2^3$$
$$= 512 + 256 + 32 + 8 = 808$$

| | |
|---|---|
| $1 \times 2^{14} = 16{,}384$ | 0 |
| $1 \times 2^{13} = 8192$ | 0 |
| $1 \times 2^{12} = 4096$ | 0 |
| $1 \times 2^{11} = 2048$ | 2048 |
| $1 \times 2^{10} = 1024$ | 1024 |
| $1 \times 2^{9} = 512$ | 512 |
| $1 \times 2^{8} = 256$ | 256 |
| $1 \times 2^{7} = 128$ | 128 |
| $1 \times 2^{6} = 64$ | 64 |
| $1 \times 2^{5} = 32$ | 32 |
| $1 \times 2^{4} = 16$ | 16 |
| $1 \times 2^{3} = 8$ | 8 |
| $1 \times 2^{2} = 4$ | 4 |
| $1 \times 2^{1} = 2$ | 2 |
| $1 \times 2^{0} = 1$ | 1 |

0 1 1 1 1 1 1 1 1 1 1 1 1 1 1S        4095

$0 \times 2^{15} = 0$  This position is always zero for positive numbers
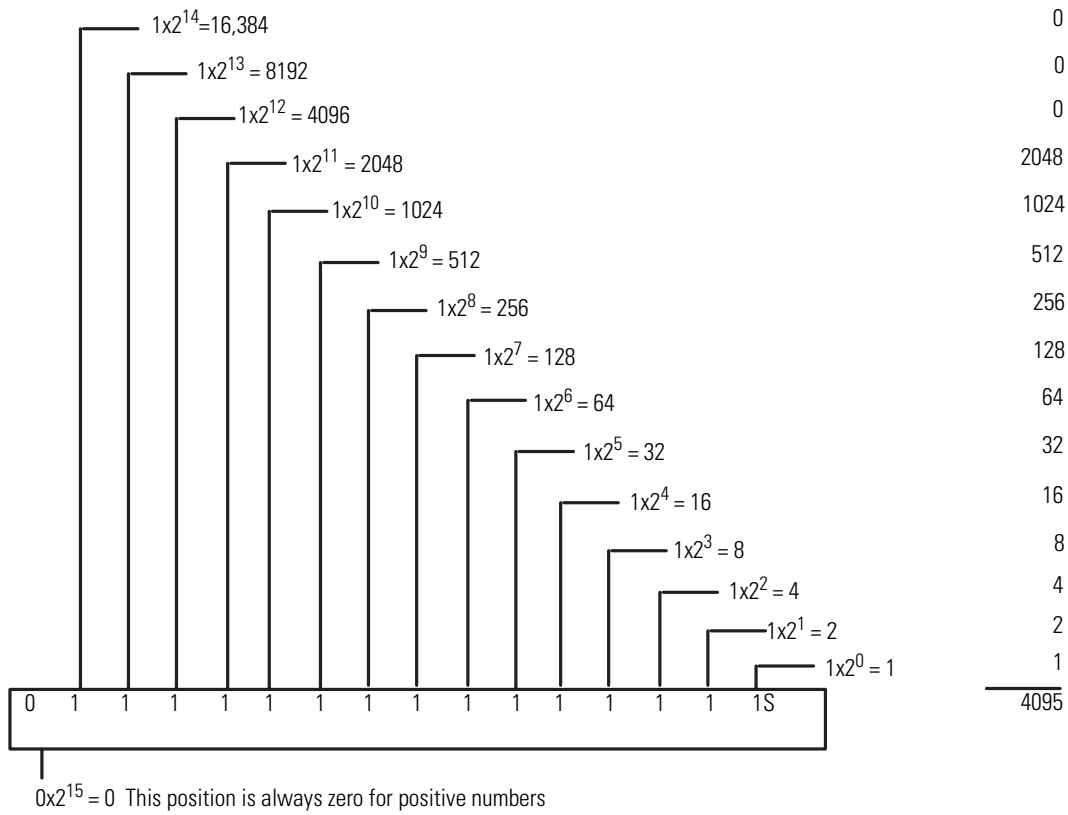
## Negative Decimal Values

The far left position is always 1 for negative values. The equivalent decimal value of a negative 2's-complement binary number is obtained by subtracting 32768 from the sum of the other position values. In the figure below, all positions are 1 and the value is 32767 − 32768 = −1. Study this example:

1111 1000 0010 0011 =

$(2^{14} + 2^{13} + 2^{12} + 2^{11} + 2^5 + 2^1 + 2^0) - 2^{15} =$

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

$30755 - 32768 = -2013$



| | |
|---|---|
| $1 \times 2^{14} = 16{,}384$ | 16,384 |
| $1 \times 2^{13} = 8192$ | 8192 |
| $1 \times 2^{12} = 4096$ | 4096 |
| $1 \times 2^{11} = 2048$ | 2048 |
| $1 \times 2^{10} = 1024$ | 1024 |
| $1 \times 2^9 = 512$ | 512 |
| $1 \times 2^8 = 256$ | 256 |
| $1 \times 2^7 = 128$ | 128 |
| $1 \times 2^6 = 64$ | 64 |
| $1 \times 2^5 = 32$ | 32 |
| $1 \times 2^4 = 16$ | 16 |
| $1 \times 2^3 = 8$ | 8 |
| $1 \times 2^2 = 4$ | 4 |
| $1 \times 2^1 = 2$ | 2 |
| $1 \times 2^0 = 1$ | 1 |
| 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1S | 32,767 |
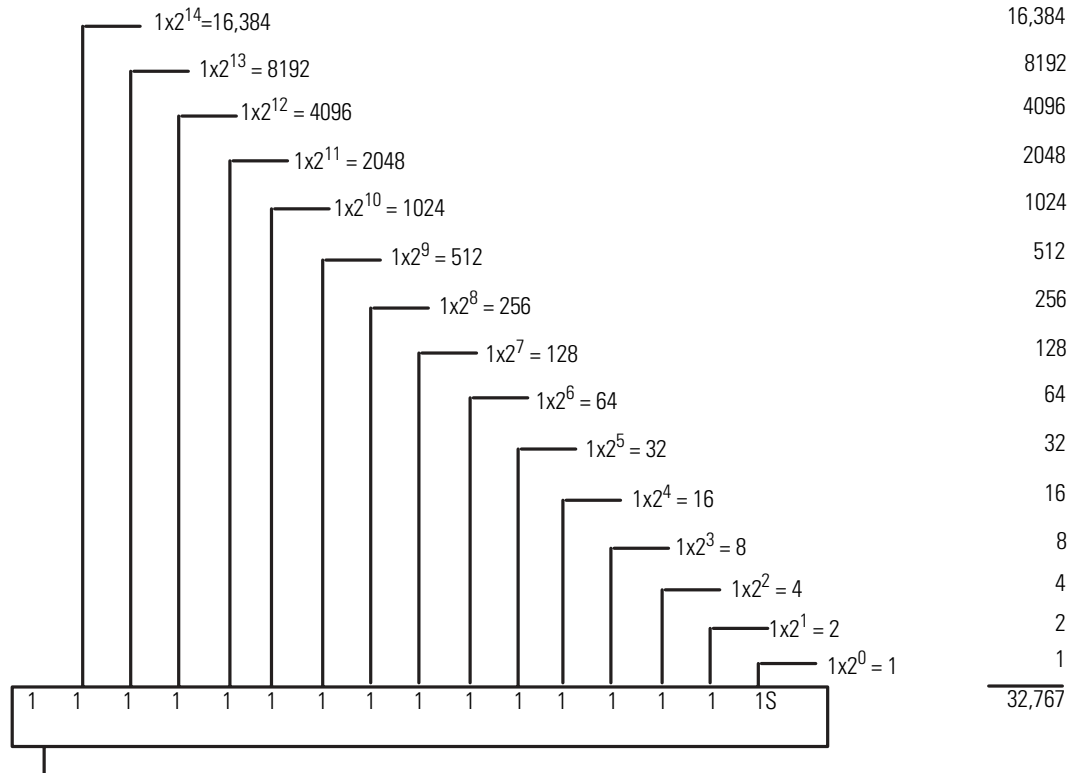
This position is always 1 for negative numbers    $(1 \times 2^{15} = 32{,}768)$

# Module Input and Output Circuits

These wiring diagrams show the input circuit, voltage output, and current output for the fast analog modules.

**Input Circuit for 1746-FIO4V and 1746-FIO4I Modules**
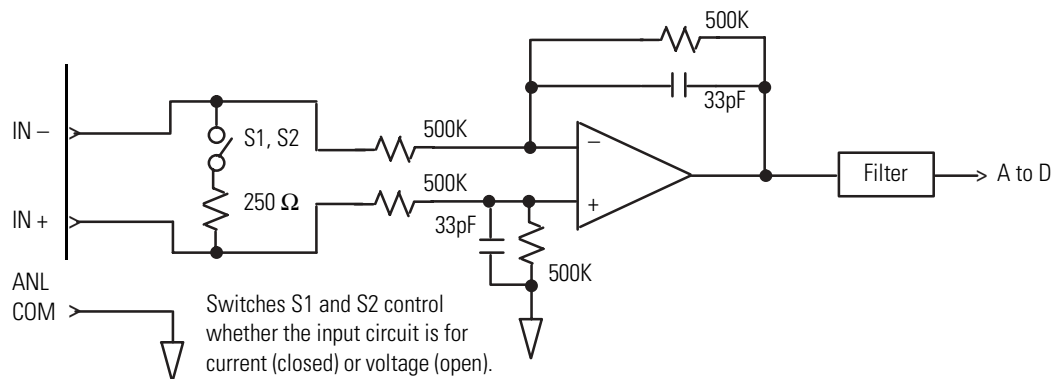


**Voltage Output Circuit for 1746-FIO4V Modules**
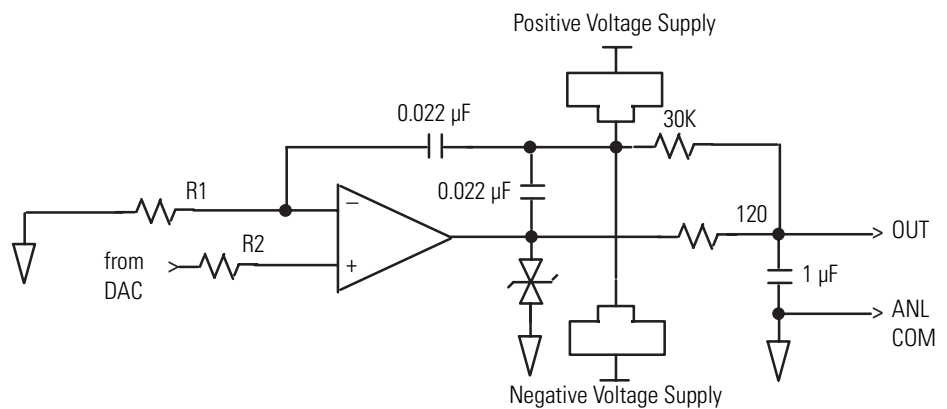
**Current Output Circuit for 1746-FIO4I Modules**

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Pub. Title/Type  SLC 500 Fast Analog I/O Module

Cat. No.    1746-FIO4I and        Pub. No.  1746-UM009B-EN-P    Pub. Date  September 2007    Part No.  XXXXXX-XX
            1746-FIO4V

Please complete the sections below. Where applicable, rank the feature (1=needs improvement, 2=satisfactory, and 3=outstanding).

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procedure/step    illustration    feature

example    guideline    other

explanation    definition

| | | | | |
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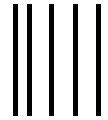
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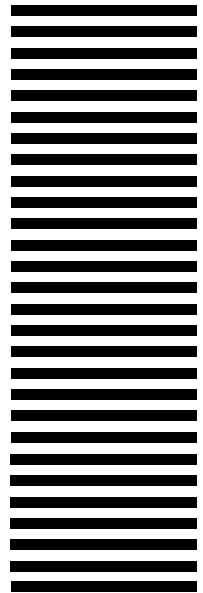
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