AIM3
Low-Level Analog Input Module

The AIM3 Low-level Analog Input Module accepts signals ranging from ±100mV to ±10V full scale, and offers either 32 channels of single-ended input, or 16 channels of differential input. The selection of high-level or low-level input is made by setting on-card switches.

The AIM3 module provides high-speed multiplexing, gain amplification from x1 to x100 volts/volt, and cold junction reference circuitry for the direct connection of thermocouples and other low-level transducers.

Signals from the AIM3 are routed along the private AN OUT signal line to the global selection and conditioning circuitry of the AIM1 module, where programmable gain can be applied prior to A/D conversion.

With optional resistor locations, the AIM3 module can be modified to accept current inputs, or to measure thermocouples in the differential mode. In addition, a guard terminal has been provided for the connection of signal shields to lower noise along input lines.

All signals are connected directly to on-card screw terminals.

The AIM3 module may be placed in slots 3-10 of the baseboard (slots 2-10 when an AMM1 is used). To install the module, remove the baseboard cover and place the module in the desired slot with the component side facing the power supply. To minimize power supply thermal and noise effects, place the AIM3 as close to AIM1 as possible.

CAUTION: Always turn off the system power before installing or removing modules. To minimize the possibility of EMI radiation, never operate the system with the top cover removed.

User-Configured Components

Switches, optional resistors, and screw terminals are user-configured components on the AIM3 module (See Table 1 and Figure 1).

Switches S103 and S104 select either the single-ended or differential mode for measuring signals. Both switches must be set to the same mode for the module to function. Single-ended and differential modes are discussed in greater detail in the reference section for the AIM1 module.

Switches S101 and S102 control the gain factor of the on-card instrumentation amplifier, and can be set for gains of x1, x10, and x100 volts/volt. A setting for external mode is used in conjunction with an optional resistor or a potentiometer to providean alternative to the gain factors offered by the switch setting. Once selected, the resistor-programmed gain factor applies to all input channels on the AIM3 module.

Resistor locations on J157 and J158 are provided for the installation of optional resistors between the positive and negative input terminals when signals are measured in the differential mode. With these resistors in place, the AIM3 module can be modified to allow for current to voltage conversion or noise filtering.

Resistor locations on J155, J156, J159, and J160 permit the installation of a resistor to ground for each channel when signals are measured in the single-ended mode. With the appropriate resistors, the AIM3 can be modified to accept current inputs, or provide a return path for bias currents from "floating source" signals in the differential mode.

Screw terminals banks J153 and J154 provide on-card signal connection for all analog inputs. Six terminals are available for common ground connection. Two terminals are actively driven at common mode voltage as a guard connection for cable shields.

Terminals on the AIM3 accept 16-24 gauge wire stripped 3/16 of an inch.

Table 1. User-Configured Components on the AIM3 Module

Name	Designation	Function
Switch 103	S103	Single-ended/Differential mode selection
Switch 104	S104	Single-ended/Differential mode selection
Switch 101	S101	Local channel gain selection
Switch 102	S102	Local channel gain selection
Resistor	User Installed	Optional external gain resistor or potentiometer
DIP Headers	J157, J158	Optional connection between positive and negative input terminals (differential mode)
DIP Headers	J155, J156 J159, J160	Optional per channel connection to ground (single-ended mode)
Screw Terminals	J153	Input connection for channels 0-15
Screw Terminals	J154	Input connection for channels 16-31 or minus in differential mode

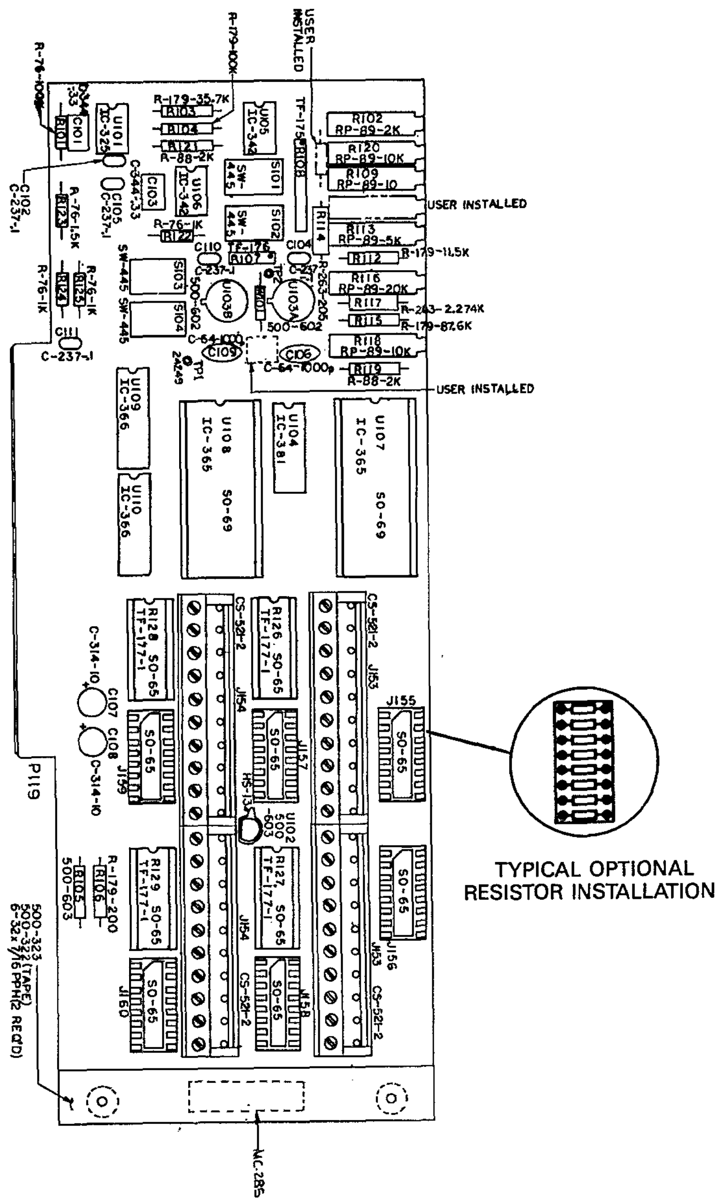


Figure 1. AIM3 Module Configuration

Connections

The AIM3 module has provisions for a maximum of 32 single-ended input channels or up to 16 differential input channels. For many applications, single-ended measurements floated from ground are required; these measurements must be made using the differential mode. Note that when the differential mode is used, noise common to both input lines is reduced due to increased CMRR (Common-Mode Rejection Ratio). To select either the differential or single-ended mode, you must set switches on the AIM3 module. Table 2 summarizes the input mode settings.

Terminal connections are marked on the board. Typical connections for the single-ended mode are shown in Figure 2. Differential connections are shown in Figure 3.

CAUTION: To minimize the possibility of EMI radiation, it is recommended that shielded cable be used for input signals. Connect the shield to module ground, but do not connect the opposite end. Maximum input voltage is ±30V (power on), or ±10V (power off). If any input exceeds ±10V, all inputs will be inoperative.

Table 2. Input Mode Switch Settings

Mode	Switch S103	Switch S104
Single-ended*	32	32
Differential	16	16

*Factory default value

Note: Both switches must be in the same position.

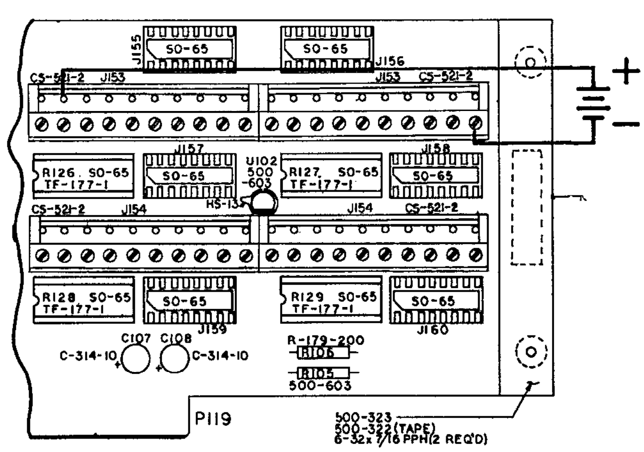


Figure 2. Typical AIM3 Single-ended Connections (Channel 0 shown)

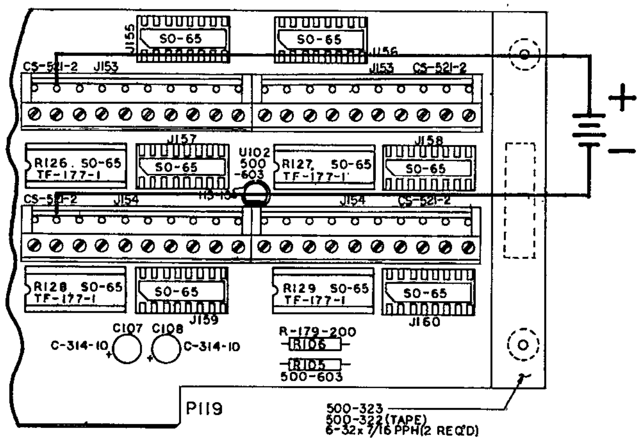


Figure 3. Typical AIM3 Differential Connections (Channel 0 shown)

The Guard Feature

On long signal runs, shielded cable will reduce noise pickup. When using shielded cable with the AIM3, the shield should not be connected to ground, but to the guard terminal. This terminal is actively driven by an on-card buffer amplifier so that the terminal is maintained at the common mode voltage developed by the signal source. Note that grounding is useful only in the differential mode.

The shield, if connected in this manner, should not be connected at the transducer, and never connected to ground at any point. Connecting the shield to ground will short-circuit the output of the guard amplifier.

For the guard to be effective, the same shielded cable must carry both the positive and negative leads of the signal source, and no other signal lines.

Grounding

Each input channel has an optional resistor location which permits the installation of a resistor to ground. In the single-ended mode, locations J155 and J156 connect input terminals 0-15 to ground, and locations J159 and J160 connect input terminals 16-31 to ground. In the differential mode, J155 and J156 resistors connect the positive input terminals of channels 0-15 to ground, and J156 and J160 resistors connect the negative terminals of these same channels to ground. This provision is useful when modifying the Series 500 to accept one or more channels of current input, or when measuring "floating source" signals (such as thermocouples) in the differential mode.

Floating Source Signals

When signals from thermocouples, batteries, transformers, and other "floating sources" are measured in the differential mode, the signals must have a path to ground. This path is provided by installing a resistor of less than 10kΩ between negative input terminals and ground, using resistor locations J159 and J160, for channels 0-15 and channels 16-31. These resistors are not required in the single-ended mode.

For more information about floating source signals, consult the reference section for the AIM1 module (Single-ended and Differential Modes) and the discussion of the thermocouple connection in this section.

Gain Adjustment

Switches S101 and S102 control the gain factor of the on-card instrument amplifier, and can be set for x1, x10 and x100 volts/volt. Table 3 summarizes the gain settings. An optional resistor or potentiometer can be installed by the user to provide a local gain, as an alternative to the three gain factors available via Switches S101 and S102. When the resistor is installed, S101 and S102 must be set to the x1 mode. The chosen gain factor is then applied to all of the 32 input channels on the AIM3 module.

The installed resistor provides a gain determined by the following formula:

$$G = 1 + 20{,}000/R$$

Where G equals the gain, and R equals the value of the resistor in ohms.

Once the resistor has been installed, S101 and S102 should not be set to another gain factor. Although it will not damage the system, this configuration will result in unpredictable amplification.

Holes on the AIM3 module are provided for the insertion of a resistor or potentiometer.

Table 3. Gain Switch Settings

Gain	Switch S102	Switch S101
x1	x1*	x1*
x10	X10	x1
x100	x1	x100
External	x1	x1

*Factory Default value

Current to Voltage Conversion

When connecting transducers and instrumentation with current outputs rather than voltage outputs, resistors can be installed between positive and negative terminals to convert the current range to an equivalent voltage range. For this purpose, locations J157 and J158 are provided for channels 0-31. These resistors should be installed on DIP headers. When instrumentation provides current output in the single-ended mode, resistors should be installed between the input terminals and ground, using locations J155, J156, J159 and J160. Determine the value of the resistor by applying Ohm's law, which describes the relationship of current and resistance to voltage:

E=I*R

Voltage (volts) = Current (amps) * Resistance (ohms)

Set E equal to the upper limit of the voltage range for the A/D converter, and I to the upper limit of the current range for the signal being measured. R will equal the resistor to be installed on that channel.

Consider the following example: The A/D range is 0 to +10V, and the anticipated current input range is 4 to 20mA. E should be set to 10, and I to .02 (20/1000A). R equals 10/.02, or 500Ω. Thus, a 500Ω resistor should be installed in the appropriate location.

Input Filtering

In some cases, it may be advantageous to filter the input to minimize noise. A single-pole filter may be placed at the input, as described in the AIM1 reference section.

Connecting Thermocouples

A thermocouple is a sensor made by joining two dissimilar metals for the purpose of temperature measurement. When dissimilar metals are joined in a closed circuit and the two junctions held at different temperatures, a small electric current will flow around the circuit. The electromotive force (emf) produced under such conditions is a function of the temperature difference between the two junctions.

When thermocouples are used in temperature measurement, one junction is kept at a known reference temperature (often the melting point of ice--0°C. Under these conditions, the emf is a function of the temperature at the second junction (the measuring junction). Tables and curves that describe the relationship of the voltage produced by the thermocouple to the measured temperature assume that the temperature of the reference junction is 0°C.

If the temperature of the reference junction is known, however, it is not necessary that it be maintained at 0°C. The same tables and curves will be accurate if compensation is made for the temperature of the reference junction. This is often referred to as "cold junction compensation", and is achieved by adding to the voltage output of the thermocouple the voltage which would be produced by measuring the temperature of the reference junction.

For example, if the reference junction is at 25°C and the measuring junction is at 75°C, the thermocouple will measure a difference of 50°C, rather than the expected 75°C; the output of the thermocouple will be too small. Adding the voltage equivalent of a 25°C difference to the voltage output of the thermocouple will compensate for the temperature of the reference junction.

Cold junction reference circuitry on the AIM3 measures the temperature of the reference junction at the screw terminals. When the SELECT CHANNEL command is loaded with the value 32, the output of the compensation circuitry can be read by the analog-to-digital converter. Channel 32 (cold junction reference) will read 100mV per degree Celcius so that 0°C, this channel will read 0V, and at 50°C, 5V.

Because this temperature/voltage relationship is linear, the voltage produced by the compensation circuitry converts easily to temperature in software. To find the appropriate voltage, consult the tables for the particular type of thermocouple being used. Find the voltage produced by that type of thermocouple at the temperature of the reference junction, and then add the correct voltage to the reading from the thermocouple itself.

In the previous example, consult a table to determine the compensation voltage produced at 25°C. If the thermocouple is type T (Copper/Constantan), the voltage at 25°C would be 0.992mV. Add this voltage (in software) to the voltage output of the thermocouple.

The voltage output of thermocouples does not vary linearly with respect to temperature. When using the AIM3 module, linearization and the conversion of the voltage into a temperature is carried out in software. This can be done by using a polynomial describing the specific voltage/temperature relationship for the type of thermocouple in question, or by looking up the values in an appropriate table.

The coefficients for these polynomials, and the tables themselves, are readily available from manufacturers of thermocouples and from books on the use of thermocouples. Consult the appropriate NBS monograph for details.

Thermocouples produce very small voltages. Typically the voltage varies only 7 - 75μV per degree celsius. Such small voltages can easily be obscured by ground loop noise and high common-mode voltages. For this reason, the AIM3 should be configured in the differential mode when measuring thermocouples.

Because thermocouples are "floating sources" of voltage, they have no connection to ground when measured differentially. Also, small bias currents flow at the input terminals of all instrumentation amplifiers. When there is no return path to ground for these currents, stray capacitances in the input wiring of the system will be charged. The output of the amplifier (hence, the system) will tend to drift, and in some cases the amplifier will become completely saturated, causing a full scale reading.

To provide an appropriate return path to ground for these bias currents, install a 10kΩ or smaller resistor in the optional resistor locations provided at J155 and J156 for channels 0-15, and J159 and J160 for channels 16-31. Only one resistor per channel is required in the differential mode.

Because voltage signals from thermocouples are small, they require amplification. When measuring thermocouples, select a gain factor of x100 by setting S101 and S102 on the AIM3 module. Further amplification can be applied from software via the SELECT GAIN command on the AIM1 module.

Commands

AIM3 module commands are listed in Table 4. Table 5 summarizes the locations for slot-dependent commands.

Table 4. Commands Used with the AIM3 Module

Command	Location
SELECT CHANNEL	CMDA (slot-dependent)

Table 5. Locations for Slot-dependent CMDA

Slot	Location
Slot 3	CFF84
Slot 4	CFF86
Slot 5	CFF88
Slot 6	CFF8A
Slot 7	CFF8C
Slot 8	CFF8E
Slot 9	CFF90
Slot 10	CFF92

SELECT CHANNEL

Location: Slot-dependent CMDA

The SELECT CHANNEL command is used to select one of 32 channels on the AIM3 module to be directed to the AIM1 module, and from there to the analog-to-digital converter. In the single-ended mode, 32 channels, numbered 0-31, are accessible with this command. In the differential mode, 16 channels, numbered 0-15, are accessible (See Table 6).

In all cases, the number of the channel being measured is the value to write to the SELECT CHANNEL location. If channel 0 is selected, the SELECT CHANNEL location should be loaded with the number 0; if channel 25 is selected, SELECT CHANNEL is loaded with 25, and so on.

On the AIM3 module, writing the value 32 to this location selects the voltage output of the cold junction compensation circuitry located on the module. The use of this reading is described in the section on thermocouples.

SELECT CHANNEL is always followed by the SELECT SLOT command, loaded with the number of the slot in which the module is installed (see AIM1 reference section). If successive readings are taken from various channels located on the same module, the SELECT SLOT command need not be reissued for each reading. Similarly, for successive readings of a single channel, SELECT CHANNEL need only be issued once.

SELECT CHANNEL and SELECT SLOT must be issued at least once before starting an A/D conversion.

Table 6. Values Written to SELECT CHANNEL

Function	Binary	Hex	Decimal
Channel 0	00000	H0	0
Channel 1	00001	H1	1
Channel 2	00010	H2	2
Channel 3	00011	H3	3
Channel 4	00100	H4	4
Channel 5	00101	H5	5
Channel 6	00110	H6	6
Channel 7	00111	H7	7
Channel 8	01000	H8	8
Channel 9	01001	H9	9
Channel 10	01010	HA	10
Channel 11	01011	HB	11
Channel 12	01100	HC	12
Channel 13	01101	HD	13
Channel 14	01110	HE	14
Channel 15	01111	HF	15
Channel 16	10000	H10	16
Channel 17	10001	H11	17
Channel 18	10010	H12	18
Channel 19	10011	H13	19
Channel 20	10100	H14	20
Channel 21	10101	H15	21
Channel 22	10110	H16	22
Channel 23	10111	H17	23
Channel 24	11000	H18	24
Channel 25	11001	H19	25
Channel 26	11010	H1A	26
Channel 27	11011	H1B	27
Channel 28	11100	H1C	28
Channel 29	11101	H1D	29
Channel 30	11110	H1E	30
Channel 31	11111	H1F	31
Cold junction Circuitry Output	100000	H20	32

Note: channels 16-31 can only be selected when the module is configured in the single-ended mode. In the differential mode, the values 0-15 are used to select channels 0-15.

AIM3 Module Calibration

To calibrate the AIM3 module voltage measuring functions, use the procedure below along with the information in Table 7 and Figure 4.

1. Place the AIM3 module in slot 4.
2. Place the AIM3 module in the differential mode (S101 and S104).
3. Connect the calibrator high lead to the + terminal of channel 0. Connect the low lead to − terminal. Use shielded cable and connect the shield to module ground only.
4. Connect the DMM high input to the TP2 and connect the DMM low terminal to module ground.

5. POKE the SELECT CHANNEL location with a value of 0 in order to select channel 0. (CFF86)
6. Use the Procedure in Table 7 to calibrate the module in the order listed. Switches S101 and S102 are used to select module gain.

Table 7. AIM3 Calibration Procedure

Step	Input Voltage	Local Gain	Adjustment	DMM Reading
1*	0V	x100	x100 Offset (R118)	0V ±1mV
2*	0V	x1	x1 Offset (R120)	0V ±1mV
3	10V	x1	x1 Gain (R109)	10V ±1mV
4	1V	x10	x10 Gain (R116)	10V ±1mV
5	100mV	x100	x100 Gain (R113)	10V ±1mV

*Repeat steps 1 and 2 until no adjustment is required in step 1.

Calibrate the AIM3 temperature function as follows:

1. Connect DMM high to TP1. Connect DMM low to module ground.
2. Apply thermal grease to the probe tip.
3. Touch the probe of the digital thermometer to the case of U102 (cold junction reference). Allow five minutes for the reading to stabilize.
4. Adjust the ice point adjust (R102) for a reading of 100mV × T°C on the DMM. For example, at 20°C, a reading of 2V should be obtained.

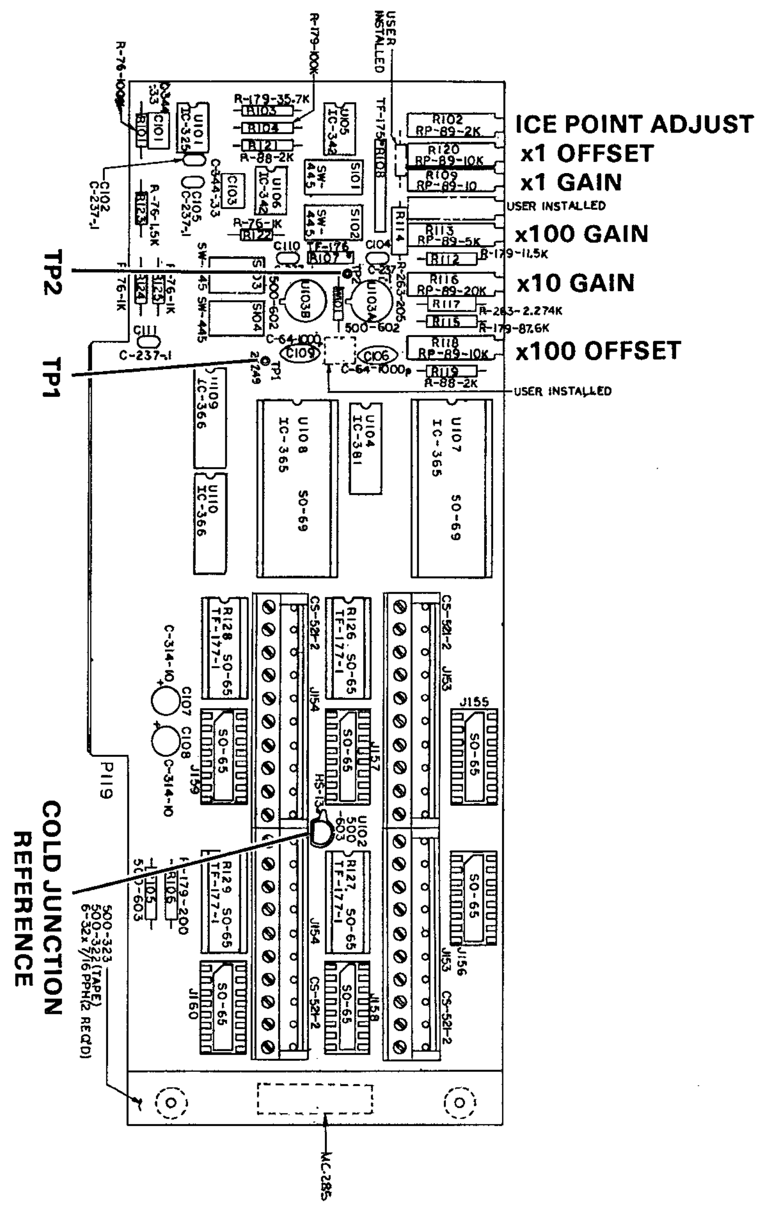


Figure 4. AIM3 Calibration Adjustmets

Theory of Operation

A schematic diagram of the AIM3 module may be found on drawing number 500-156.

Two analog multiplexers, U107 and U108, select channels on the AIM3 module. Each multiplexer selects 1 from a group of 16 differential or 32 single-ended signals. In the single-ended mode, an enable line to each of the multiplexers selects which one will be active, and, therefore, which of the two groups of 16 signals will be accessed. In this way the module can accommodate up to 32 single-ended input channels. In the differential mode, switch S104 configures the enable lines so that both multiplexers are always active.

The multiplexers are driven by U109, a quad transparent data latch (74LS75) which stores the status of data lines F0-F3. The enable lines are driven by U110, also a quad transparent data latch (74LS75), which stores the status of F4. Data lines F0-F4 are set up by the SELECT CHANNEL command (signal line CMDA).

The outputs of multiplexers U107 and U108 are routed to switch S103, which configures the AIM3 to operate in either single-ended or differential mode. The output of S103 is directed to the noninverting inputs of the instrumentation amplifier made up of U103 and U105.

When operating in single-ended mode, the positive, or non-inverting, terminal of U103B is connected to analog ground, and the output of U107 and U108 (depending on which is active) drives the positive, or non-inverting, input of U103A. Hence, in single-ended mode, all 32 signals are measured with respect to system ground.

When S104 is set to the differential mode, U108 multiplexes the low or negative side of the input signals, and its output drives the noninverting input of U103B. U107 multiplexes the high, or positive side of the signals and drives the noninverting input of U103A. This differential configuration measures the voltage between sources connected to the high and low terminals of an input channel; the high input source is measured with respect to the low input, rather than with respect to system ground.

The gain factor for the instrumentation amplifier is set by S101 and S102 and associated resistors. Gain factors of x1, x10 and x100 volts/volt are available by these switches. Installation of an optional resistor and potentiometer permits the selection of alternate gain factor gain formula is $A = 1 + 20{,}000/R$. x10 gain is adjusted with R116, and x100 gain is adjusted with R113. R109 sets x1 gain.

R118 is the x100 offset trim, and R109 is the x1 offset trim for the instrumentation amplifier, U103 and U105.

The output of U105 is directed to one of U104, a one-of-two analog switch (Analog Devices ADG200). The second input of U104 is the output of the cold junction reference generator circuitry comprised of U101 and U102. The output of U104 drives the AN OUT pathway exiting the module. U104 is driven by the output of one latch of U116, which stores the status of data line F5.

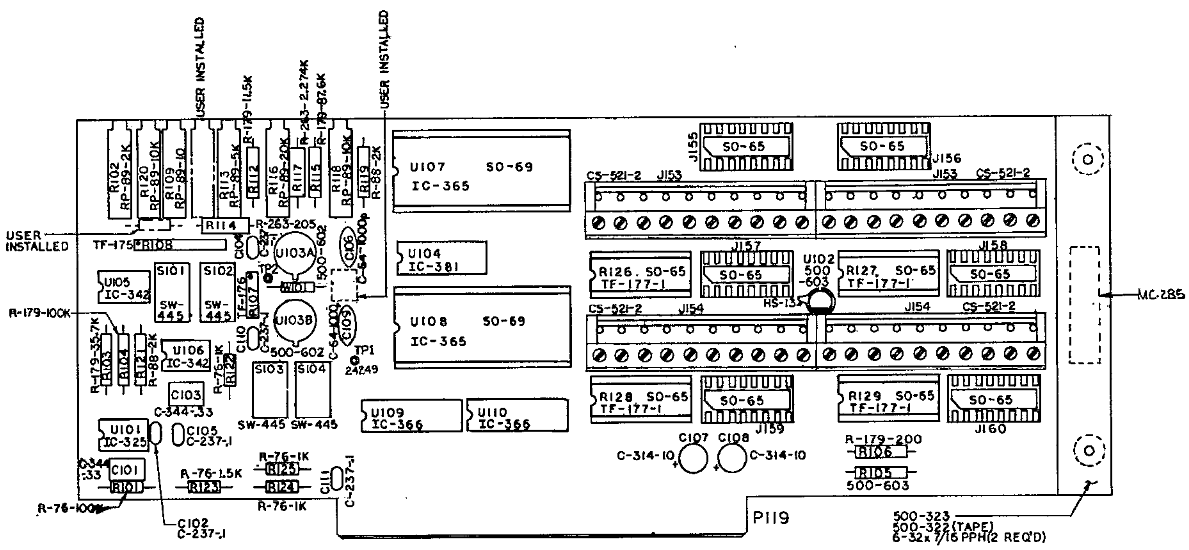
The 10V reference bus, buffered by voltage follower U101A, drives amplifier U101B, configured as a current to voltage converter with current source U102. U102 is a precision semiconductor temperature sensor with an output of 1μA per degree centigrade. U101B converts this current to a voltage output of 100mV per degree centigrade, such that at 0°C the output is 0V, and at 50°C the output is 5V. U101 offset is adjusted by R102.

The guard out terminal is actively driven at the common voltage of the selected signal by U104, an operational amplifier configured as a voltage follower. This op amp has the low output impedance necessary to drive the guard output of the module.

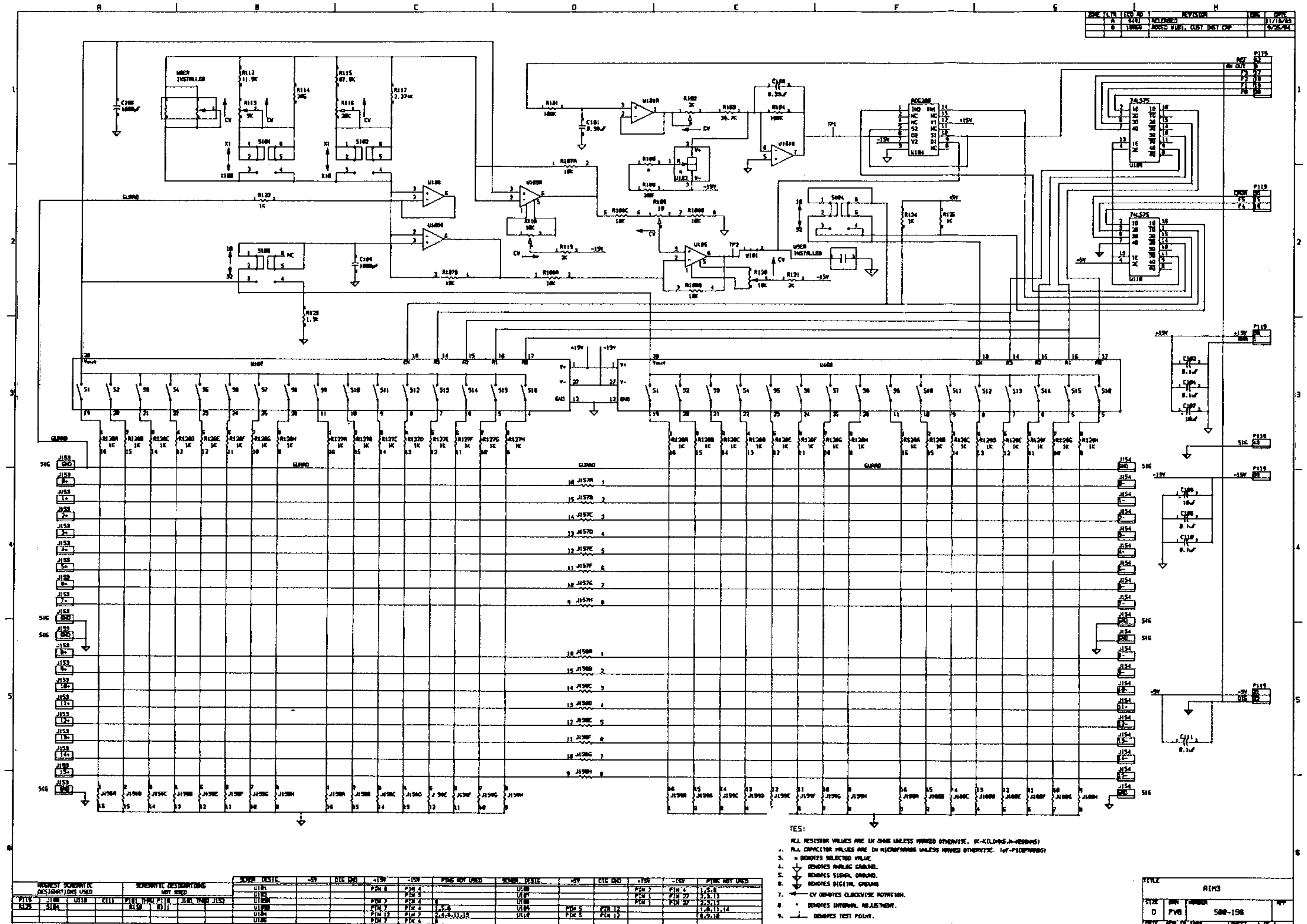
AIM3 Specifications

Input channels: 16 differential or 32 single-ended
Input characteristics:
- Switch selectable gains: x1, x10, x100
- Input range:
  - x1, ±10V
  - x10, ±1V
  - x100, ±100mV
- Input protection:
  - ±30V max (Powered)
  - ±10V max (Unpowered)
- Accuracy:
  - x1, ±(0.01% + 20μV)
  - x10, x100, ±(0.01% + 10μV)
- Non-linearity: 0.005% of F.S.
- Temperature coefficient:
  - x1, ±(0.001% + 10μV)/°C
  - x10, ±(0.002% + 4μV)/°C
  - x100, ±(0.002% + 2μV)/°C
- Common mode rejection ratio: >80dB, DC to 60Hz
- Input bias current: <1nA
- Input resistance: >100MΩ
- Input noise voltage:
  - 5μV p-p, 0.1Hz to 10Hz
  - 10μV rms, 10Hz to 30kHz
- Settling time to 0.01%:
  - x1, 15μs
  - x10, 30μs
  - x100, 75μs
- Slew rate (x1): 10V/μs
- Small signal bandwidth: 130kHz
- Reference junction sensor:
  - Output: +100mV/°C
  - Accuracy: ±0.25°C
  - Temperature coefficient: +0.1°C/°C

Note: All amplifier specifications with respect to input.



AIM3 COMPONENT LAYOUT



AIM3 SCHEMATIC DIAGRAM