

# AIM5

## Isolated Low-Level Analog Input Module

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The AIM5 Isolated Low-level Analog Input Module is designed to accept inputs from  $\pm 5\text{mV}$  to  $\pm 100\text{mV}$ , including signals from thermocouples. Isolated input permits the connection of signals with high common mode voltages--up to 500V DC or peak AC--and provides normal mode input protection up to 130V. Channel-to-channel isolation is 500V DC or peak AC. The input bandwidth is below 2Hz, reducing sensitivity to 50/60 cycle AC noise.

There are four input channels on the AIM5 module, each with individually adjustable gain amplification. The module is shipped from the factory with a preset gain of x100 volts/volt, appropriate for thermocouple types B,E,J,K,R,S, and T. This gain can be reset for each channel by changing the value of the gain-setting resistor.

The AIM5 is equipped with cold junction reference circuitry, which allows accurate measurement of the junction temperature, eliminating the need for ice-bath reference junctions.

The AIM5 may be placed in slots 3-10 of the baseboard (slots 2-10 if AMM1 is used). To install the module, remove the top cover of the mainframe and insert the module in the desired slot with the component side facing the power supply. Place the AIM5 as far away from the power supply as possible to minimize noise or thermal effects.

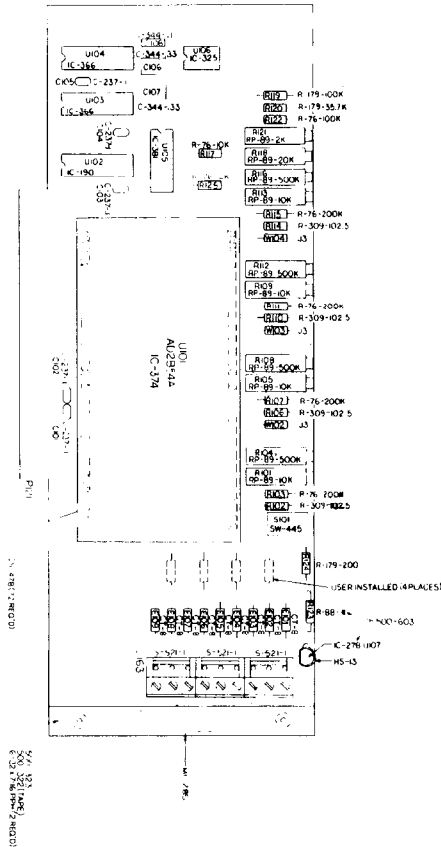
**CAUTION: Always turn off the system power before installing or removing modules. To minimize the possibility of EMI radiation, never operate the system with the top cover removed. Short the input terminals of unused channels together.**

### User-Configured Components

Overall gain is factory set to x100. Gain amplification for each channel can be modified by changing resistors in the locations provided on the AIM5 module card. Installing optional resistors provides current to voltage conversion, allowing connection of current loop inputs. All inputs are connected to a bank of screw terminals, with positive and negative (high and low) terminals for each of the four input channels (see Table 1 and Figure 1).

**Table 1. Summary of User-Configured Components**

Name	Designation	Function
Switch 101	S101	x1/x100 gain (channel 0)
Resistors	R102, R106, R110, R114	Per channel gain resistors
Resistors	User-installed	Optional resistors for current to voltage conversion
Screw Terminals	J163	Input terminals for channels 0-3



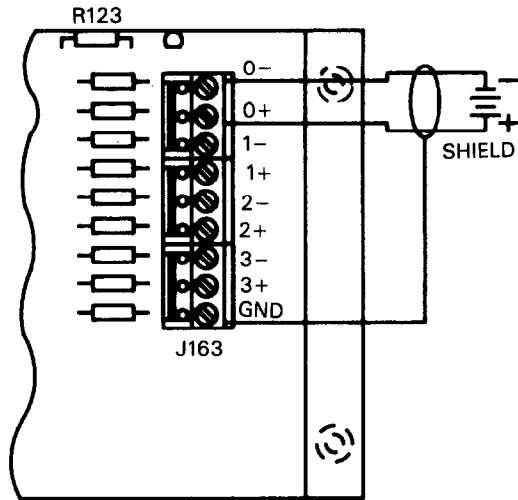
**Figure 1. AIM5 Module Configuration**

**Connections**

Connecting terminals for the AIM5 are marked on the module board. Figure 2 shows typical connections. The use of shielded cable for input connections is recommended to minimize noise pickup and the possibility of EMI radiation. Connect the shield to AIM5 ground only.

**WARNING:** Dangerous user-supplied voltages may be present on the input terminals.

**CAUTION:** Maximum input voltage is 50mV with x100 gain.



**Figure 2. Typical AIM5 Connections**

### Gain Adjustment

When shipped from the factory, the AIM5 module will have resistors installed in locations R102, R106, R110, and R114, providing a gain factor of x100 for each input channel. The x100 gain enables the AIM5 module to accommodate thermocouples of types B,E,J,K,R,S, and T, as well as other low-level signals with similar ranges. These resistors can be removed or replaced to provide alternate gains.

The following formula describes the relationship of the gain to resistance in this circuit:

$$G = 1 + 10,000/R_T$$

Where G equals the gain, and  $R_T$  the total resistance.

To provide accurate trimming for this gain, potentiometers P1, P3, P5, and P7 have been installed parallel to resistors R1-R4. The total resistance for any channel is a function of both the value of the resistor and the value of the potentiometer installed on that channel. This relationship is described by the following formula:

$$R_T = \frac{R_R R_P}{R_R + R_P}$$

Where  $R_T$  is the effective parallel resistance,  $R_R$  is the value of the gain resistor, and  $R_P$  is the value of the potentiometer.

### Current to Voltage Conversion

With the installation of optional resistors in user-installed locations the AIM5 can be

configured to accept floating current loop inputs. The resistors are installed between the high and low input terminals, converting the current range of the signal to an appropriate voltage range.

Because the AIM5 module can accept input signals with a full scale range of  $\pm 5\text{mV}$  to  $\pm 100\text{mV}$ , the resistor installed should yield a voltage range of  $\pm 100\text{mV}$ . A local gain of  $\times 50$  can then be applied via resistors to bring the voltage output to a range of  $\pm 5\text{V}$ , the maximum output range of the module. If the input range of the A/D converter is set to  $\pm 10\text{V}$ , the PGA on the AIM1 module can be used to apply a supplementary gain of  $\times 2$ .

The selection of user-installed resistor should be based on Ohm's law:

$$E = I \cdot R$$

**Voltage (volts) = current (amps) \* Resistance (ohms)**

Where E is set to  $100\text{mV}$ , and I to the maximum value of the current input range. If, for example, the range of the input signal is  $4\text{-}20\text{mA}$ , I should be set to  $20\text{mA}$ , and the formula solved as follows:

$$100\text{mV} = 20\text{mA} \cdot R$$

$$R = 5$$

Thus, a  $5\Omega$  resistor should be installed on that channel.

Note that additional loads in series with the current loop can be connected on either side of the isolated input.

### 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:  $0^\circ\text{C}$ ). 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  $0^\circ\text{C}$ .

If the temperature of the reference junction is known, however, it is not necessary that it be maintained at  $0^\circ\text{C}$ . 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. Therefore, the output of the thermocouple will be too small. Adding the voltage equivalent of a 25°C difference voltage output of the thermocouple will compensate for the temperature of the reference junction.

Cold junction reference circuitry on the AIM5 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 Celsius so that at 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 compensation 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 the table to determine the compensation voltage produced at 25°C. If the thermocouple was type T (Copper/Constantan), the voltage at 25°C would be 0.99mV. 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 AIM5 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 value 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.

The AIM5 is factory configured to provide a gain of x100 volts/volt on each input channel, suitable for the connection of thermocouples types J, K, R, S, and T. Other thermocouples can be accommodated by replacing resistors R1-R4. Modifications of this sort are described in the section dealing with gain adjustment.

When an appropriate global gain is applied via the PGA on the AIM1 module, the A/D converters can achieve an average resolution of less than 1 degree across the generally accepted useful temperature range for each thermocouple type. Table 2 indicates the average temperature represented by each digital step of the A/D converter (a 12-bit converter expect when measuring the full temperature range of a thermocouple with the AIM5.

The table assumes that a local gain of x100 is applied by resistors on the AIM5 module, and a global gain is applied by the AIM1 or AMM1 module, as recommended.

**Table 2. Average Temperature Value of Conversion Step (resolution)**

Type	Gain (PGA)	t (above 0 °C)	t (below 0 °C)
J	x2	.4323 °C/lsb	.5993 °C/lsb
K	x2	.6016 °C/lsb	.8000 °C/lsb
R	x5	.8297 °C/lsb	NA
S	x5	.9378 °C/lsb	NA
T	x10	.2051 °C/lsb	.2991 °C/lsb

Greater resolution can be achieved with any of the following modifications: using the thermocouple with a smaller temperature range and increasing the applied gain, setting the A/D converter to a smaller input range (for example, 0 to 5V, when temperatures below 0°C will not be measured), using a 14-bit AID converter (available on the ADM2 module) instead of a 12-bit converter, and replacing resistors R1-R4 to provide a different local gain factor. When selecting a gain, remember that the maximum output range of the AIM5 is  $\pm 5V$ . This range can be extended to  $\pm 10V$  by applying a global gain of x2 at the AIM1 module.

Type B thermocouples can be connected to the AIM5 module provided that a measurement resolution between 1 and 2°C is adequate. Type E thermocouples can also be connected to the AIM5, but should not be used to measure temperatures higher than 660°C, or the voltage will exceed the input range of the module. Selecting other gain factors (by installing different resistors) will eliminate these constraints (see Table 3).

**Table 3. Useful Range and Associated Voltages**

Type	Material	Range (°C)	Range (emf)
B	Platinum/6% Rhodium Platinum/30% Rhodium	38 to 1800	-0.001mV to 13.585mV
E	Chromel-constantan	0 to 982	0.0mV to 75.007mV
J	Iron-constantan	-184 to 760	-7.508mV to 42.922mV
K	Chromel-alumel	-184 to 1232	-5.624mV to 50.990mV
R	Platinum-platinum/13% Rhodium	0 to 1593	0.00mV to 18.759mV
S	Platinum-platinum/10% Rhodium	0 to 1538	0.00mV to 16.021mV
T	Copper-constantan	-184 to 400	-3.923mV to 9.523mV

### Maintaining Accuracy

Each of the four inputs on the AIM5 module has a separate isolated input stage, each of which feed the signal to a common output stage. Each input stage has a separate adjustment potentiometer, making it possible to null the input offset. A single adjustment takes care of any output offset. To maximize AIM5 accuracy, the following procedure may be used.

1. Connect a jumper wire between the + and - inputs of channel 0.
2. Set the gain calibration switch (S101) to the x1 position. Adjust the output offset control (R119) so that a value of 0 is read back from the module.
3. Set S101 to the x100 position.

4. Adjust the channel 0 input offset potentiometer (R104) for a 0 reading.
5. Short channels 1-3 inputs and adjust respective input offset potentiometers for a zero reading. (R108 = Chan 1, R112 = Chan 2, R116 = Chan 3).
6. The gain potentiometer for each channel can now be adjusted for x100 gain (50mV input = 5V output).

R101 = Channel 0 Gain  
 R105 = Channel 1 Gain  
 R109 = Channel 2 Gain  
 R113 = Channel 3 Gain

### Input Attenuation

The AIM5 module may be modified to apply a 100:1 attenuation factor to the input signal, thus allowing the module to measure voltages up to  $\pm 500V$ . To modify the AIM5, install a 10k $\Omega$  resistor in the user installed location for the channel in question. Then remove the input inductor for that channel (E102 for channel 0, E104 for channel 1, E106 for channel 2, E108 for channel 3) and in its place, install a 990k $\Omega$  resistor. To maintain system accuracy, both resistors should have a maximum tolerance of  $\pm 0.1\%$ .\*

When reading data back from a modified channel, you must correct for the attenuation factor in order to obtain a correct reading. When using commands listed in this manual, simply multiply the voltage reading obtained by a factor of 100. When using the Soft500 system, a similar correction factor must be applied. These correction factors are exclusive of other factors necessary because of other parameters within the system such as the global gain applied by the AIM1 module.

\*May be obtained from Keithley Data Acquisition and Control. Order part number R-263-10k for the 10k $\Omega$  resistor. Order R-282-90k and R-282-900k and connect in series to make up 990k $\Omega$ .

## Commands

The AIM5 module command is summarized in Table 4. Locations for slotdependent commands are presented in Table 5.

**Table 4. Commands Used with the AIM5 Module**

Command	Location
SELECT CHANNEL	CMDA (Slot-dependent)

**Table 5. Locations for Slot-dependent CMDA**

<b>Slot</b>	<b>Location</b>
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 location is used by all analog input modules to select individual channels for A/D conversion. When selecting a channel, the number of that channel is written into the CMDA location. On the AIM5 module, four channels, numbered 0-3, can be selected with this command.

When using the AIM5 module (and also the AIM3 and AIM7), writing the value 32 to this location directs the converter to read the output of the cold junction reference circuitry, rather than one of the input channels. The use of this information is described in the section on thermocouples.

SELECT CHANNEL always either follows or precedes the SELECT SLOT command, which should be issued with the number of the slot in which the AIM5 module is installed. This command affects the global multiplexer on the AIM1, and is described in the reference section for that module.

When measuring the same channel repeatedly, the SELECT CHANNEL command need not be reissued for every measurement. Similarly, when several channels on the same module are read in succession, the SELECT SLOT command need only be issued once at the start of the sequence. Both the SELECT SLOT and SELECT CHANNEL must be issued before starting any A/D conversions, or the data will be invalid (see Table 6).

**Table 6. Values Written to SELECT CHANNEL**

<b>Function</b>	<b>Binary</b>	<b>Hex</b>	<b>Decimal</b>
Channel 0	00000	H0	0
Channel 1	00001	H1	1
Channel 2	00010	H2	2
Channel 3	00011	H3	3
Cold Junction	100000	H20	32



## AIM5 Module Calibration

Use the procedure below along with the information in Figure 3 to calibrate the output offset control (R118) for a reading of  $0.000 \pm 1$  count.

1. Place the AIM5 module in slot 4.
2. Connect the DMM high input to the AIM5 analog output (W101). Connect the DMM low lead to module ground.
3. Connect jumper wires between the + and - terminals of all four channels.
4. POKE the SELECT CHANNEL location (CFF86) with a value of 0 to select channel 0.
5. Place the calibration switch (S101) to the x1 position and adjust the output offset control (R118) for a reading of  $0.000 \pm 1$  count on the DMM.
6. Place S101 in the x100 position and adjust the channel 0 input offset control (R104) for a reading of  $0.000 \pm 1$  count on the DMM.
7. Adjust the offset controls for the remaining three channels in a similar manner. POKE the SELECT CHANNEL location with the value for the desired channel (1 = channel 1, 2 = channel 2, 3 = channel 3). Adjust the input offset control for a reading of  $0.000 \pm 1$  count on the DMM. (R108 = channel 1, R112 = channel 2, R116 = channel 3).
8. Remove the shorting jumper from channel 0 terminal, but leave S101 in the x100 position. Leave the inputs of the other three channels shorted.
9. Connect the calibrator high terminal to the + input of channel 0. Connect the calibrator low terminal to the - input of channel 0.
10. POKE the SELECT CHANNEL location with a value of 0. Set the calibrator output to a value of 50mV.
11. Adjust the channel 0 gain control for a reading of  $5V \pm 1mV$  on the DMM.
12. Repeat steps 10-12 for the three remaining channels. Remove the jumper only from the channel being calibrated. The calibrator must be connected to the channel being calibrated, and the SELECT CHANNEL location must be POKED with the correct value for that channel. Adjust the corresponding channel gain control for a reading of  $5V \pm 1mV$  on the DMM with a 50mV input from the calibrator. Note that the inputs of the three channels not being calibrated must remain shorted.

Temperature calibration of the AIM5 may be performed as follows:

1. Connect DMM high to W101. Connect DMM low to module ground. Apply thermal grease to the temperature probe tip.
2. POKE the SELECT CHANNEL location (CFF86) with a value of 32.
3. Touch the temperature probe of the digital thermometer to the case of the cold junction reference IC (U107). Allow five minutes for the reading to stabilize.
4. Adjust the cold junction offset (R121) for a reading of  $100mV \times T^{\circ}C$  on the DMM. For example, at  $20^{\circ}C$ , you would adjust for 2V.



## Theory of Operation

See drawing number 500-176 for the AIM5 schematic diagram.

The central component of the AIM5 module is U101, a four-channel isolated input circuit (AD 2B54). U101 contains both signal conditioning and multiplexing circuitry, providing independent resistor programmed gains for each input channel. All channels are electrically isolated from system ground and from other input channels.

Resistors R102, R106, R110 and R114 are installed to provide x100 gain for each channel, but can be reconfigured to provide alternate gains. Potentiometers R101, R105, R109 and R113 trim the gain of the amplifiers (internal to U101) of channels 0-3, respectively; potentiometers R104, R108, R112 and R116 trim the input offset of these amplifiers. Potentiometer R118 provides offset trim for U101.

The output of U101 is connected to one input of U105, a one-to-two analog switch (ADG200). The second input of U105 is the output of the cold junction reference-generator circuitry, comprised of U106 and U107. U105 is driven by U104, a quad transparent data latch (74LS75) which stores the status of D5. The output of U105 is routed to the AN OUT signal path leaving the module.

The temperature at the reference junction is measured by U107, a precision semiconductor temperature sensor with an output of  $1\mu\text{A}$  per degree centigrade. Amplifier U106B converts this current to a voltage output of 100mV per degree centigrade, so that at  $0^\circ\text{C}$ , the output of U106B is 0V, and at  $50^\circ\text{C}$ , the output is 5V. U106B is driven by the +10V reference bus buffered by U106A. The circuit is trimmed by potentiometer R121.

Channel selection is controlled by U102 and U103. U103 is a quad transparent data latch (74LS75) that stores the values of bits D0 and D1, set up by the SELECT CHANNEL command (signal line CMDA). The output of U103 is connected to U102, a one-of-four binary to decimal decoder (74LS139), which produces four outputs, Y0-Y3, that drive channel selection in U101.

## AIM5 Specifications

Input channels: 4 low level, isolated from each other and ground

Input characteristics:

Gain:  $\times 100$ , user configurable for other gains with optional resistor

Input range:

$\times 1$ ,  $\pm 100\text{mV}$  max

$\times 100$ ,  $\pm 50\text{mV}$  max

Accuracy:

Gain:  $\pm 0.2\%$ , adjustable to 1 lsb

Gain linearity:  $\pm 0.02\%$  max

Input offset:  $\pm 20\mu\text{V}$  max, adjustable to zero

Output offset:  $\pm 12\text{mV}$  max, adjustable to zero

Temperature coefficient:

Gain:  $\pm .005\%/^{\circ}\text{C}$

Input offset:  $\pm 2.5\mu\text{V}/^{\circ}\text{C}$

Output offset:  $\pm 50\mu\text{V}/^{\circ}\text{C}$

Input noise voltage:  $1\mu\text{V}$  p-p, 0.01Hz to 100Hz, R,  $1\text{k}\Omega$

Input bias current:  $+8\text{nA}$  max

Input resistance:  $100\text{M}$

Protection:  $130\text{V}$  RMS max, normal mode

Isolation:  $500\text{V}$  peak, channel to channel or channel to ground

Common mode rejection:  $130\text{dB}$ , R,  $<100\Omega$ ,  $f \leq 60\text{Hz}$

Normal mode rejection:  $55\text{db}$ ,  $f \geq 50\text{Hz}$

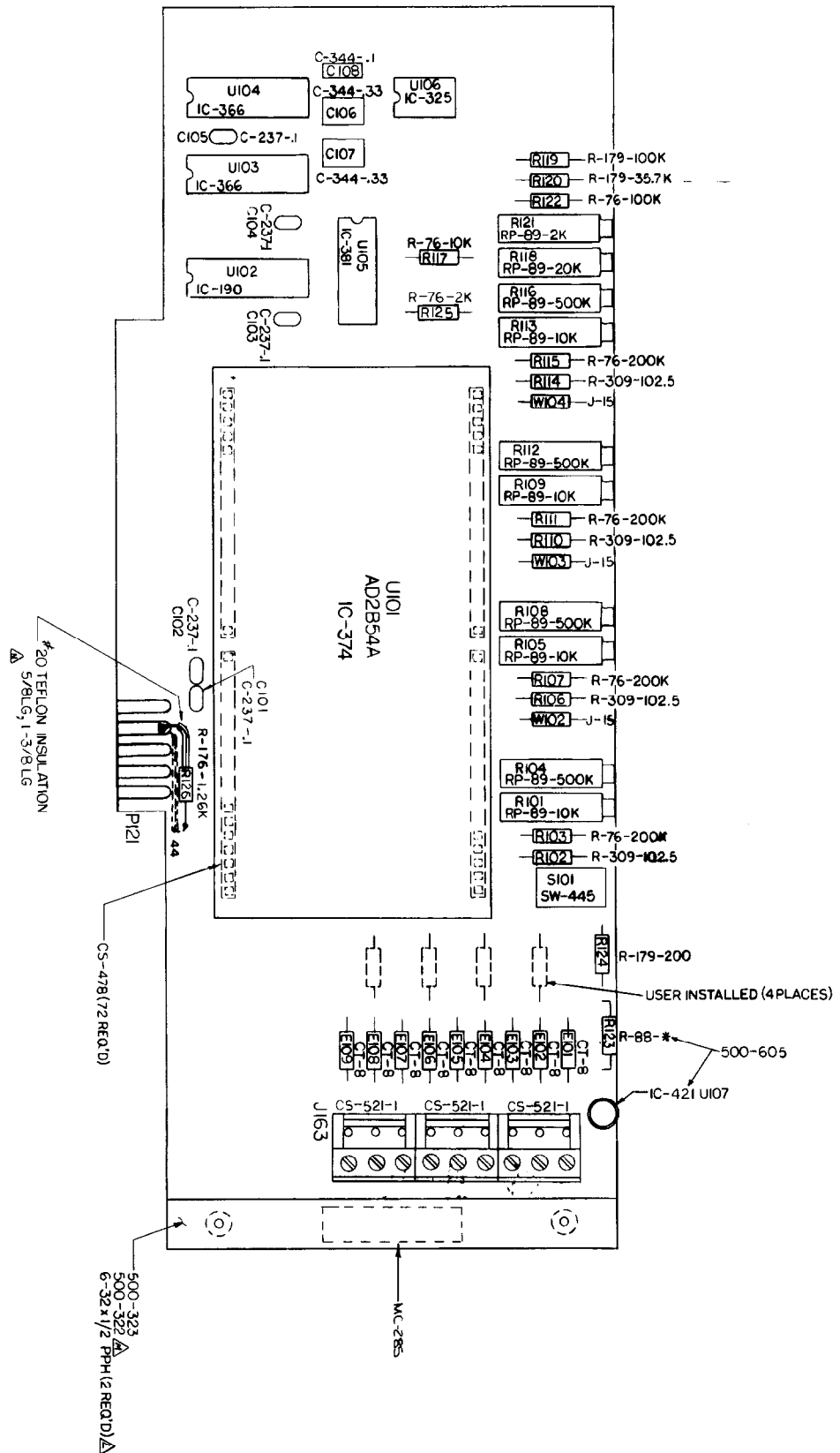
Settling time after channel selection: 2.5msec to 0.01% assuming settled input

Temperature reference junction sensor:

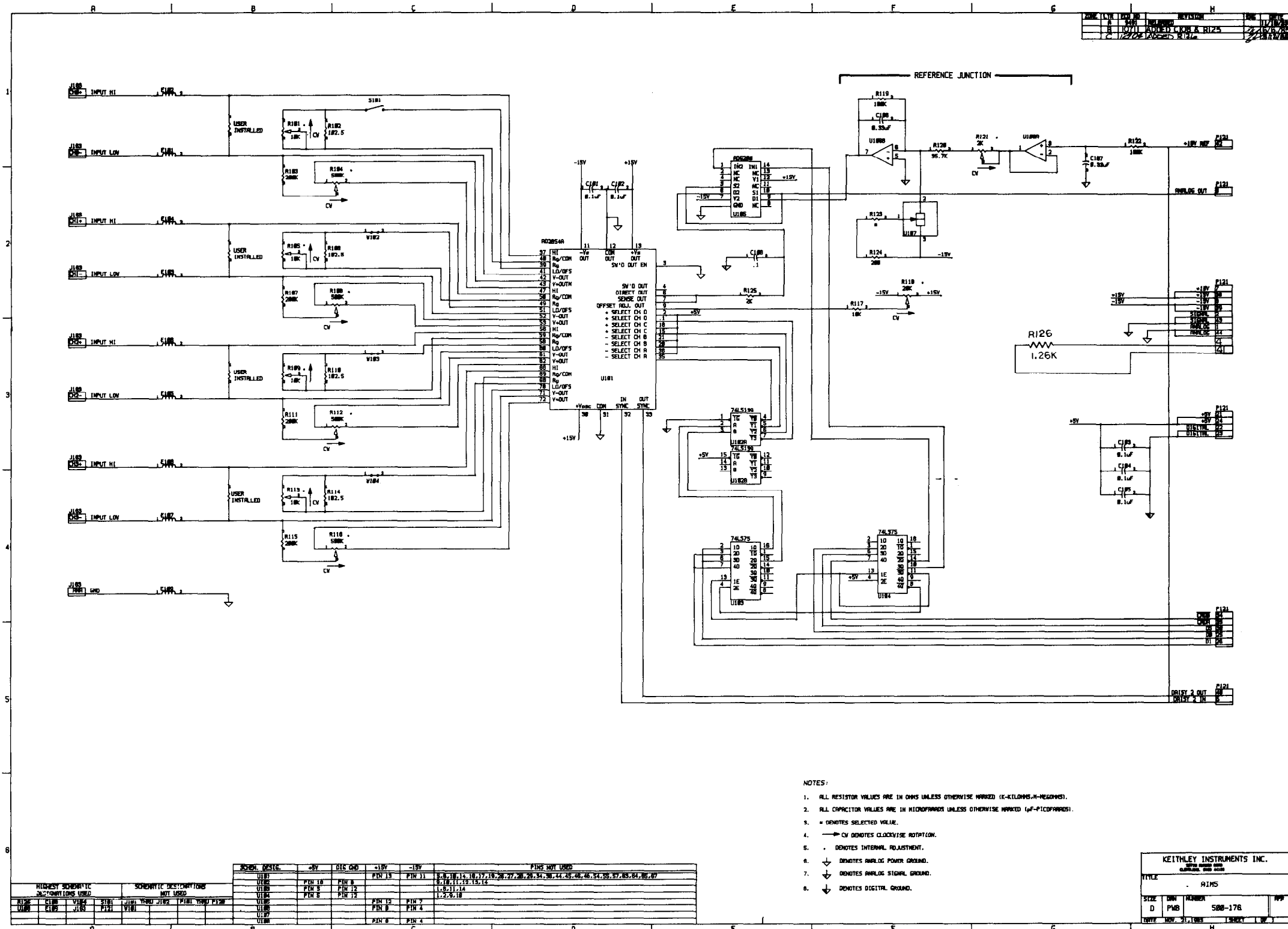
Output:  $100\text{mV}/^{\circ}\text{C}$

Accuracy:  $\pm 0.25^{\circ}\text{C}$

Temperature coefficient:  $0.1^{\circ}\text{C}/^{\circ}\text{C}$



**AIM5 COMPONENT LAYOUT**



AIM5 SCHEMATIC DIAGRAM