MSI-P442

12-CHANNEL THERMOCOUPLE &
12-BIT 4-CHANNEL A/D &
1-CHANNEL D/A CARD

USER MANUAL

PC/104 Embedded
Industrial Analog I/O Series

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CONTENTS

I. INTRODUCTION

The MSI-P442 is a low cost, high performance card that provides twelve K-type thermocouple inputs, four 12-bit analog inputs and one 12-bit analog output designed for use with all PC/104 embedded systems. Several models permit different combinations of these functions. Software programmable analog input ranges are 0-5V, 0-10V, ±5V and ±10V with a linearity of 1/2 LSB. The analog output range is 0-5V. A block diagram of the card is shown in Figure 1.

The thermocouple inputs are conditioned by Analog Devices AD597 devices which provide built-in ice point compensation with temperature proportional operation of 10 mV/°C in the temperature range of -200°C to 1000°C. The analog inputs are single-ended with an input impedance of 1MOhms. The analog output is provided by an Analog Devices AD5341 IC.

The card employs two Maxim MAX197 eight-channel A/D converters that provide inputs for the thermocouples (12 channels) and analog inputs (4 channels). Each incorporates a precision 2.5V reference source with buffer amp, an internal 1.56 MHz clock, and successive approximation and internal input track/hold circuitry to convert the analog signal of each

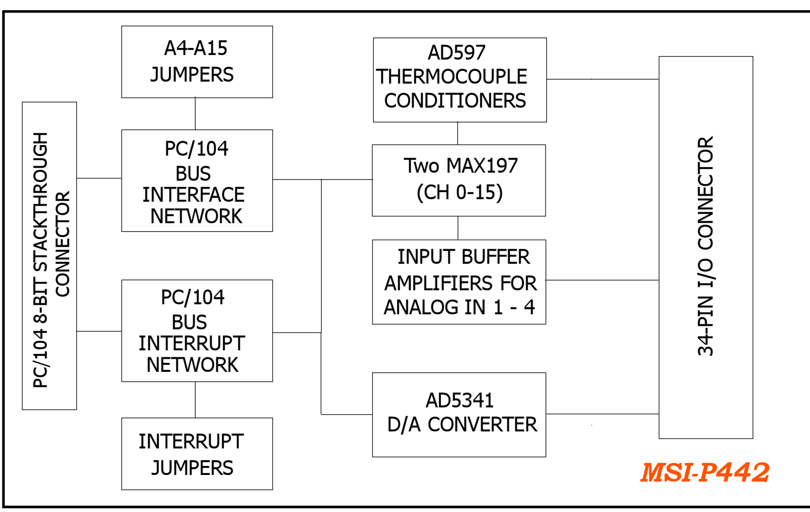

Figure 1. Block Diagram of the MSI-P442.

channel into a 12-bit digital signal. Low span and offset errors result in no adjustments being required for these functions. Typical total conversion times of 12 us gives a sample rate of 83 ksps for each group times of 12 us gives a sample rate of 83 ksps for each group of eight channels yielding rates up to 166 ksps for 16 input channels.

An Analog Devices AD5341 provides the 12-bit 0-5V analog output signal. The 2.5V reference voltage is supplied from one of the MAX197 devices.

The card is I/O mapped using 16-bit addressing to select the input channels and device status. Option jumpers are provided by JP1 for specifying the card address (A4 - A15) and interrupt processing is provided for IRQ4 thru IRQ7 and IRQ9 using options jumpers, as described in the next section.

II. HARDWARE DESCRIPTION

A. Card Configuration

The MSI-C442 card is a CMOS design using through-hole and surface-mounted devices. The card configuration is shown in Figure 2 and a circuit diagram of the network is given in the Appendix. Connector J1 provides connections of the thermocouple input signals T/C 1 thru T/C 12, for ANALOG IN 1 thru ANALOG IN 4 input voltages, and the ANALOG OUTPUT voltage.

Jumper block JP1 is used for address selection (Pins 1 thru 24) and interrupt configuration (Pins 25 thru 34), as described below.

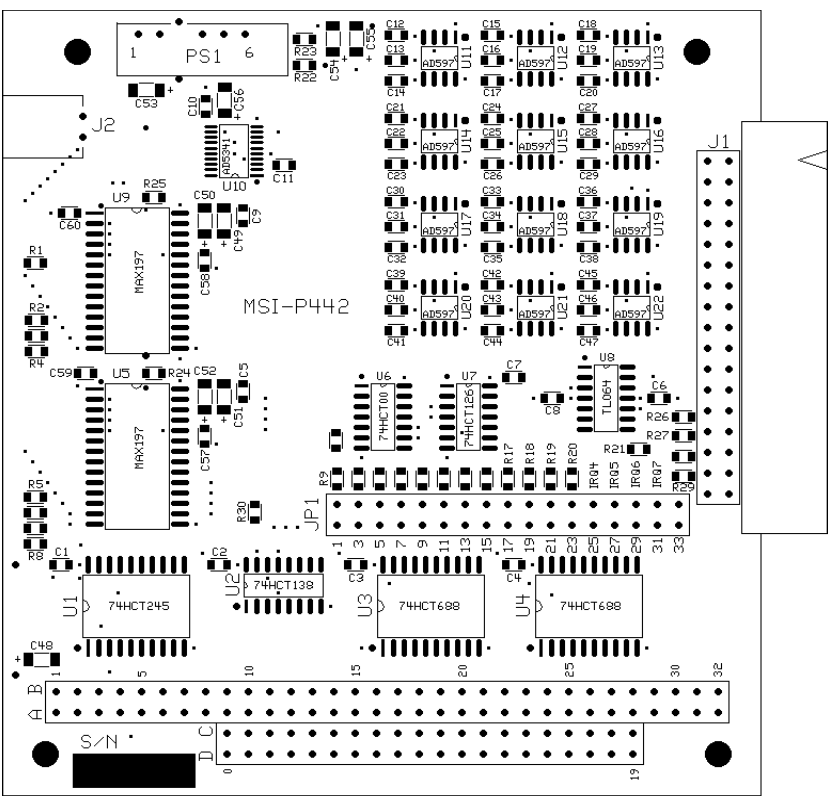

Figure 2. MSI-P442 card outline.

B. Card Addressing

The card address is set by installing appropriate jumpers on JP1, pins 1 thru 24, as shown in Fig. 3. An uninstalled jumper for a given address bit sets the bit to 0 (false) and an installed jumper sets the bit equal to 1 (true). Addresses A4 thru A15 are jumper selectable for defining the *base address* of the card from 0000H to FFF0H on integral 10H boundaries, where H denotes a hexadecimal number. To assign a base address of 3040H, for example, install jumpers JP1-A13, JP1-A12, and JP1-A6. Pins 25 thru 34 are used to configure the interrupt connections, if interrupts are used, as described in the Section II.D.

C. MAX197 A/D Converters for Thermocouple and Analog Inputs.

The MAX197 converters each have two registers for performing data conversions, a control output register (C) and an input data register (I). A third register implemented on the card for denoting interrupt status is called the status register (S). The addresses of the control, input data (C/I) and status for each channel are given in Table 1. The functions of the control, the input data (hi and lo bytes),

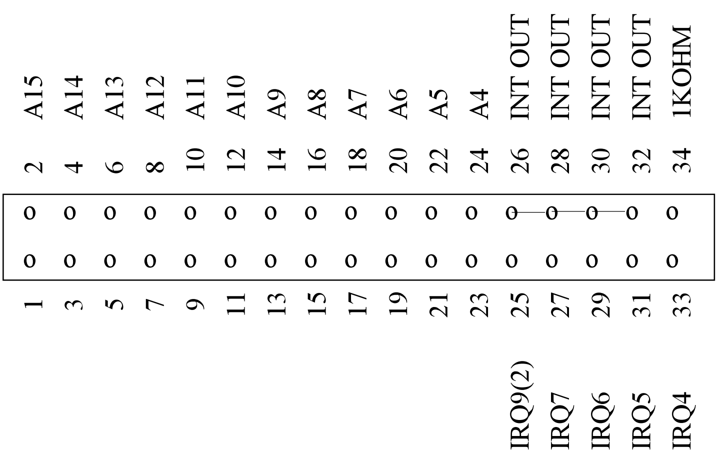

Figure 3. Jumper block JP1 configuration for base address and interrupt selection.

and status registers are described in the Section III.

Table 1. MAX197 Analog Converters Control Register Addresses.

Channels	Control Output (C)	Data Input (I)	Status (S) / Bit
0-7	base+0	base+0 (lo) base+1 (hi)	base+4 / 0
8-15	base+2	base+2 (lo) base+3 (hi)	base+4 / 1

D. Interrupt Connections for Thermocouple and Analog Inputs.

Interrupt connections are implemented by pins 25 thru 34 of JP1. The steps in the procedure are as follows.

1) Pins JP1-26, JP1-28, JP1-30 and JP1-32 (INT OUT) are connected and have the composite interrupt signal from the analog converters (see circuit diagram in Appendix). Any one of these can be jumpered to a single desired interrupt, IRQ4 thru IRQ9, of JP1 shown in Fig. 3. This connection causes the interrupt selected to be activated when an end-of-conversion occurs from either analog converter. The interrupt status can be checked to determine which converter interrupt is active, as described in Section III.

3) Pin JP1-32 (1 KOhm pull-down resistor) is used to properly terminate the interrupt line selected in step 1. <u>This pin should be jumpered to the interrupt line selected for only one card in the system.</u>

E. Obtaining a Temperature Reference for the Card.

A temperature reference can be obtained by shorting one of the thermocouple inputs at J1. The resulting measurement for this input is the temperature of the AD597 of this channel.

F. AD5341 D/A Converter for Analog Output.

An AD5341 provides a 12-bit, 0-5V output voltage. The device contains a 12-bit output data register (O) and an output data latch (L). The addresses of the output data register (hi and lo bytes), and the output data latch are given in Table 2. The operations of these registers are described in Section III.

Table 2. AD5341 Output Data, Latch, and Clear Addresses.

Output Data Register(O)	Output Data Latch (L)
base+6 (lo) base+7 (hi)	base+8

G. Connecting Inputs and Output to J1.

Thermocouple inputs, analog inputs and the analog output are interconnected to the card via J1 using a 34-pin flat cable connector. Pin assignments are given in Table 3.

Table 3. Connector J1 Inputs and Output.

Input	J1 Pin	Input	J1 Pin
T/C 1+	1	T/C 10+	19
T/C 1 -	2	T/C 10 -	20
T/C 2+	3	T/C 11+	21
T/C 2 -	4	T/C 11 -	22
T/C 3+	5	T/C 12+	23
T/C 3 -	6	T/C 12 -	24
T/C 4+	7	ANALOG IN 1	25
T/C 4 -	8	GND	26
T/C 5+	9	ANALOG IN 2	27
T/C 5 -	10	GND	28
T/C 6+	11	ANALOG IN 3	29
T/C 6 -	12	GND	30
T/C 7+	13	ANALOG IN 4	31
T/C 7 -	14	GND	32
T/C 8+	15	ANALOG OUT*	33
T/C 8 -	16	GND	34
T/C 9+	17		
T/C 9 -	18		

* Optional connector J2 (Molex 705530001) also provides ANALOG OUT.

III. PROGRAMMING

A. Programming the MAX197 for Thermocouple and Analog Inputs.

Performing data conversions involves a write operation to the control register of the appropriate MAX197, which selects the mux channel and configures the input mode. The data is then read, lo byte and hi byte, when the conversion has been completed.

1. Control Register Format

The control register is an 8-bit (write-only) register that selects the mux channel and mode of the converter. The format is

D7(MSB)	D6	D5	D4	D3	D2	D1	D0(LSB)
□ PD1	PD0	ACQMOD	RNG	BIP	A2	A1	A0

where

PD1, PD0 select the clock and power down mode (Table 4).
ACQMOD - 0 = internally controlled acquisition,
1 = externally controlled acquisition.
RNG selects the full-scale voltage range (Table 5).
BIP selects unipolar or bipolar conversion mode (Table 5).
A2, A1, A0 select the desired input channel 0-7 of the MAX197.

The card is designed to operate using the internal clock with PD1 = 0 and PD0 = 1 in normal operation. The internally controlled acquisition (ACQMOD = 0) is normally used .

Table 4. Clock and Power Down Selection

PD1	PD0	DEVICE MODE
0	0	Normal Operation/External Clock Mode
0	1	Normal Operation/Internal Clock Mode
1	0	Standby Power-down (STBYPD); clock unaffected
1	1	Full Power-down (FULLPD); clock unaffected

Table 5. Range and Polarity Selection

BIP	RNG	INPUT RANGE (V)
0	0	0 to 5
0	1	0 to 10
1	0	±5
1	1	±10

2. Performing a Conversion

Conversions are initiated with a write operation to the control register (Table 1), which selects the mux channel of the desired MAX197 (U9, Channel 0-7 or U5, Channel 8-15) and configures the device mode. Selecting ACQMOD = 0 in the control register selects the internal acquisition mode. This causes the write to the control register to initiate the acquisition interval whose duration is internally timed. Conversion starts when this six-clock-cycle acquisition interval ends. Writing a new control byte during the conversion cycle will abort the conversion and start a new acquisition interval.

3. Reading the Data Register

Conversions are complete when the appropriate status bit (Table 1) becomes 0 following a write to the control register.

Channels 0-7 (U9) are ready when bit 0 at address *base+4* is 0. The data can now be read at the appropriate lo and hi byte addresses for the lo and hi bytes of the channel selected (A2, A1, A0 of the control register). Channels 0-7, addresses *base+0* and *base+1*, respectively, are read.

Channels 8-15 (U5) are ready when bit 1 at address *base+4* is 0. The data can now be read at the appropriate lo and hi byte addresses for the lo and hi bytes of the channel selected (A2, A1, A0 of the control register). Channels 8-15 addresses *base+2* and *base+3*, respectively, are read.

4. Input Data Format

Unipolar Mode - the output data format is binary. In this case, 0 volts input yields 000H, where H denotes a hexadecimal number. The value increases linearly from 000H to FFFH with increasing input voltage. A +FS input (full-scale +5V or +10V ranges) gives FFFH.

Bipolar Mode - the output data format is twos-complement binary. In this case, a -FS input (±5V or ±10V ranges) yields 800H. The value increases linearly from 800H toward FFFH as the input voltage changes from -FS toward 0 volts. At 0 volts input (in the ideal case), the value is 000H. Again, the value increases linearly from 000H toward 7FFH as the input voltage changes from 0 toward +FS volts.

The lo byte read, bits D0 thru D7, of the input data is the low byte B0 thru B7 of the conversion result. The hi byte read of the input data contains bits B8 thru B11 of the conversion result in bits D0 thru D3. Bits D4 thru D7 contain all 0's and all 1's, respectively, for the unipolar and bipolar modes.

5. Power-Down Modes

To save power, the converters can be placed into a low-power shutdown mode between conversions. Two programmable power-down modes are available. Select STDBYPD or FULLPD by programming PD0 and PD1 in the control register. When software power-down is asserted, it becomes effective only after the end of conversion. In both power-down modes, the interface remains active and conversion results may be read. Input overvoltage protection is active. The converter returns to normal operation on the first write to the control register. In STDBYPD each device typically consumes 700uA and in FULLPD 120 uA maximum.

The converter voltage reference remains active in STDBYPD. This is a DC power state that does not degrade after power-down of any duration and any sampling rate can be used without regard to start-up delays. In FULLPD, however, start-up delays will effect the conversion. It is recommended when using this mode that a STDBYPD power-down cycle be performed prior to starting conversions to allow the

6. Example BASIC Programs for MAX197 A/D converters.

Program 1 - A simple BASIC program that continually inputs thermocouple (channels 0 thru 12) for the 5V unipolar mode and lists the results to the console is given below.

```
        BASEADDR=&H8000 ` insert jumper A15 of JP1
        CBYTE = &H40      ` Control Byte for 5V Unipolar Mode
again:
        FOR I = 0 TO 7  ` process channels 0 - 7
        OUT BASEADDR, CBYTE + I  ` Write Control Byte
        WHILE (INP(BASEADDR + 4) AND 1) = 1: WEND  `Test Status Bit 0
        X = INP(BASEADDR)  ` Read LO Byte
        Y = INP(BASEADDR + 1)  ` Read HI Byte
        X = X + 256*(Y AND &HF)  ` Mask off 4 MSB's of HI Byte
        ` Print CH 0 - CH 3, Linefeed, CH 4 - CH 7 in hexadecimal format
        IF I = 3 OR I = 7 THEN PRINT HEX$(X) ELSE PRINT HEX$(X),
        NEXT I
        FOR I = 0 TO 3  ` process channels 8 - 11
        OUT BASEADDR+2, CBYTE + I  ` Write Control Byte
        WHILE (INP(BASEADDR + 4) AND 2) = 2: WEND  `Test Status Bit 1
        X = INP(BASEADDR + 2)  ` Read LO Byte
        Y = INP(BASEADDR + 3)  ` Read HI Byte
        X = X + 256*(Y AND &HF)  ` Mask off 4 MSB's of HI Byte
        ` Print CH 8 - CH 11 in hexadecimal format
        IF I = 3 THEN PRINT HEX$(X) ELSE PRINT HEX$(X),
        NEXT I
        PRINT " "
        GOTO again `Go Again
        END
```

Program 2 - A simple BASIC program that reads the analog inputs (channels 12 thru 15) for unipolar and bipolar modes and lists the results to the console is given below.

```
        BASEADDR=&H300 ` insert jumpers A8 and A9 of JP1.
        ` Control Byte for 5V Unipolar Mode for Ch 12
        OUT BASEADDR+2, &H44  ` Write Control Byte
        WHILE (INP(BASEADDR + 4) AND 2) = 2: WEND  `Test Status Bit 1
        X = INP(BASEADDR + 2)  ` Read LO Byte
        Y = INP(BASEADDR + 3)  ` Read HI Byte
        X = X + 256*(Y AND &HF)  ` Mask off 4 MSB's of HI Byte
        PRINT "CH 12 = "; PRINT HEX$(X)
        ` Control Byte for 10V Unipolar Mode for Ch 13
        OUT BASEADDR+2, &H55  ` Write Control Byte
        WHILE (INP(BASEADDR + 4) AND 2) = 2: WEND  `Test Status Bit 1
        X = INP(BASEADDR + 2)  ` Read LO Byte
```

```
Y = INP(BASEADDR + 3)  ' Read HI Byte
X = X + 256*(Y AND &HF)  ' Mask off 4 MSB's of HI Byte
PRINT "CH 13 = "; PRINT HEX$(X)
' Control Byte for +/-5V Bipolar Mode for Ch 14
OUT BASEADDR+2, &H4E  ' Write Control Byte
WHILE (INP(BASEADDR + 4) AND 2) = 2: WEND  'Test Status Bit 1
X = INP(BASEADDR + 2)  ' Read LO Byte
Y = INP(BASEADDR + 3)  ' Read HI Byte
X = X + 256*(Y AND &HF)  ' Mask off 4 MSB's of HI Byte
PRINT "CH 14 = "; PRINT HEX$(X)
' Control Byte for +/-10V Bipolar Mode for Ch 15
OUT BASEADDR+2, &H5F  ' Write Control Byte
WHILE (INP(BASEADDR + 4) AND 2) = 2: WEND  'Test Status Bit 1
X = INP(BASEADDR + 2)  ' Read LO Byte
Y = INP(BASEADDR + 3)  ' Read HI Byte
X = X + 256*(Y AND &HF)  ' Mask off 4 MSB's of HI Byte
PRINT "CH 15 = "; PRINT HEX$(X)
END
```

7. Example 'C' Program Sequence

For a simple 'C' program illustration using software polling of the device status, consider a case with the following parameters and events.

1) A base address for the card of 8000H (insert jumper A15 of JP1).
2) Read A/D channel 3 (input to U9) in the +5V unipolar mode and store the result in CH_3_INPUT.
3) Read A/D channel 9 (input to U5) in the ±10V bipolar mode and store the result in CH_9_INPUT.

A simple program sequence for this operation is

```
/* Constant declarations */

    #define base_address       0x8000    /* card base address */
    #define control_byte_5     0x40      /* control byte for +5V range */
    #define control_byte_5B    0x48      /* control byte for ±5V range */
    #define control_byte_10    0x50      /* control byte for +10V range */
    #define control_byte_10B   0x58      /* control byte for ±10V range */
    #define delay_count        1000      /* delay count for converter
                                            time-out */
/* Memory assignments */

    int A_D_value, CH_3_INPUT, CH_9_INPUT;
```

```
/* Routine to input A/D channel CHAN(0-15) for control byte C_BYTE and
   returns 0 on a converter time-out error. Stores converted value in
   A_D_value */

int  input_A_D( int CHAN, int C_BYTE )
{
     int converter_error, a, i, ch_group;

     if( 0 <= CHAN && CHAN < 8 ) ch_group = 0;
     else if( 7 < CHAN && CHAN < 16 )
          {ch_group = 2; CHAN = CHAN - 8;}
     outp( base_address + ch_group, C_BYTE + CHAN ); //write control byte
     if( ch_group < 1 ) a = 1; //Ch 0-7
     else a =  2; //Ch 8-15
     i=0;
     do ++i;
     while ( (inp(base_address + 8) & a) && i < delay_count );
     if( i == delay_count ) converter_error = 1;/* converter time-out error
*/
     else converter_error = 0;
     A_D_value = inp( base_address + ch_group ); /* get converter value */
     A_D_value = A_D_value + ((inp(base_address + ch_group + 1) &
          0xf)<<8);
     return( converter_error );
}

void  main( void)
{
          .
          .
          .
     /* Input channel 3 for +5V range and store if no time_out error */
     if( !input_A_D( 3, control_byte_5 ) ) CH_3_INPUT = A_D_value;;

     /* Input channel 9 for ±10V range and store if no time_out error */
     if( !input_A_D( 9, control_byte_10B) ) CH_9_INPUT = A_D_value;;
          .
          .
          .
          .
}
```

The function *input_A_D(int CHAN, int C_BYTE)* above is written in general terms to permit calls from the main routine or from other user defined functions by simply using the appropriate CHAN and C_BYTE values for the input channel desired and the desired input range.

B. Programming the AD5341 for Analog Output.

Performing an analog output is performed by write operations to the AD5341 as described below.

1. Performing an Output Conversion.

An voltage output is performed by loading the Output Data Register with the desired 12-bit value followed by a dummy write (output of any value) to the Output Data Latch to transfer the data to the output. The data register is loaded by performing byte writes to the lo byte and hi byte of the Output Data Register as given in Table 2. The data latch address is also in Table 2.

2. Output Data Format

The 12-bit value of te data register gives an output that changes linearly from 0V for a value of 000H to 5V for a value of FFFH, where H denotes a hexadecimal number. Bits 0 thru 7 of the lo byte are bits 0 thru 7 of the data register. Bits 0 thru 3 of the hi byte are bits 8 thru 11 of the data register. Bits 4 thru 7 of the hi byte are ignored.

The bit resolution for the output is

5V/4096 = 0.001221V or 1.221 mV/Bit

3. Power-on value of the AD5341 D/A converter.

At power-on, the converter has an output value of 0.

4. Example BASIC Program for AD5341 D/A converter.

Program 1 - A simple BASIC program that outputs a value entered from the keyboard to the converter.

```
        BASEADDR=&H3000 ' insert jumpers A14 and A15 of JP1
again:
        INPUT "Enter decimal value to output - ", X
        Y = X AND 255          ' get 8 bits of lo byte
        X = (X - Y)/256 AND 15  ' get 4 bits of hi byte
        OUT BASEADDR + 6, Y     ' write lo byte
        OUT BASEADDR + 7, X     ' write hi byte
        OUT BASEADDR + 8, 0     ' write output latch to transfer data
        GOTO again
        END
```

IV. Temperature vs Thermocouple Input Voltage (Channels 0 thru 12)

The temperature of a thermocouple input on any of channels 0 thru 7 is determined from the voltage that is read on its associated channel. In the case of a K type thermocouple, the voltage varies from -1446 mV to 10000 mV for temperatures of -200°C to 1000°C, respectively. Table 5 gives the temperature vs voltage outputs for both J type and K type thermocouples. In the case of both J type and K type thermocouples, the temperature is approximately given by

Temperature °C □ 100□x (Vin in Volts)

The appropriate converter span (0-5V, ±5V, 0-10V or ±10V) should to be chosen for the temperature range that is being monitored.

Table I. Output Voltage vs. Thermocouple Temperature

Thermocouple Temperature °C	Type J Voltage mV	AD596 Output mV	Type K Voltage mV	AD597 Output mV
–200	–7.890	–1370	–5.891	–1446
–180	–7.402	–1282	–5.550	–1362
–160	–6.821	–1177	–5.141	–1262
–140	–6.159	–1058	–4.669	–1146
–120	–5.426	–925	–4.138	–1016
–100	–4.632	–782	–3.553	–872
–80	–3.785	–629	–2.920	–717
–60	–2.892	–468	–2.243	–551
–40	–1.960	–299	–1.527	–375
–20	–.995	–125	–.777	–191
–10	–.501	–36	–.392	–96
0	0	54	0	0
10	.507	146	.397	97
20	1.019	238	.798	196
25	1.277	285	1.000	245
30	1.536	332	1.203	295
40	2.058	426	1.611	395
50	2.585	521	2.022	496
60	3.115	617	2.436	598
80	4.186	810	3.266	802
100	5.268	1006	4.095	1005
120	6.359	1203	4.919	1207
140	7.457	1401	5.733	1407
160	8.560	1600	6.539	1605
180	9.667	1800	7.338	1801

Table I. Output Voltage vs. Thermocouple Temperature (Con't.)

Thermocouple Temperature °C	Type J Voltage mV	AD596 Output mV	Type K Voltage mV	AD597 Output mV
200	10.777	2000	8.137	1997
220	11.887	2201	8.938	2194
240	12.998	2401	9.745	2392
260	14.108	2602	10.560	2592
280	15.217	2802	11.381	2794
300	16.325	3002	12.207	2996
320	17.432	3202	13.039	3201
340	18.537	3402	13.874	3406
360	19.640	3601	14.712	3611
380	20.743	3800	15.552	3817
400	21.846	3999	16.395	4024
420	22.949	4198	17.241	4232
440	24.054	4398	18.088	4440
460	25.161	4598	18.938	4649
480	26.272	4798	19.788	4857
500	27.388	5000	20.640	5066
520	28.511	5203	21.493	5276
540	29.642	5407	22.346	5485
560	30.782	5613	23.198	5694
580	31.933	5821	24.050	5903
600	33.096	6031	24.902	6112
620	34.273	6243	25.751	6321
640	35.464	6458	26.599	6529
660	36.671	6676	27.445	6737
680	37.893	6897	28.288	6944
700	39.130	7120	29.128	7150
720	40.382	7346	29.965	7355
740	41.647	7575	30.799	7560
750	42.283	7689	31.214	7662
760	–	–	31.629	7764
780	–	–	32.455	7966
800	–	–	33.277	8168
820	–	–	34.095	8369
840	–	–	34.909	8569
860	–	–	35.718	8767
880	–	–	36.524	8965
900	–	–	37.325	9162
920	–	–	38.122	9357
940	–	–	38.915	9552
960	–	–	39.703	9745
980	–	–	40.488	9938
1000	–	–	41.269	10130

V. SPECIFICATIONS

PC/104 16-bit, stackthrough

Thermocouple and Analog Inputs

T/C Channels	12
Analog Input	4
Converter	MAXIM MAX197
Thermocouple I/F	Analog Devices AD597 (K type)
Analog Input Ranges	0-5V, 0-10V, ±5V, ±10V (Single-ended)
Resolution	12 bits
Conversion Rate	82 ksps per 8 channels
Non-linearity	±1/2 LSB
Offset Error	< 0.5% of Span
Gain Error	< 0.5% of Span
Signal-to-Noise	70 dB min
Input Resistance	1 MOhms (Analog Input Channels)

Internal Reference

Ref Out Voltage	4.096 V ±1.5% max.
Temp. Coeff.	40 ppm/°C

Analog Output

Analog Outputs	1
Converter	Analog Devices AD5341
Resolution	12 bits
Settling Time	10us
Ref Voltage In	2.5V

Connector (Model No.)

J1 (MSI-P442-K/I/O)	30334-5502 or eq. (34-pin)
J1 (MSI-P442-K/I)	30334-5502 or eq. (34-pin)
J1 (MSI-P442-K/O)	30334-5502 or eq. (34-pin)
J1 (MSI-P442-K)	30326-5502 or eq. (26-pin)
J2 (MSI-P442-K-8)	30316-5502 or eq. (16-pin)

Interrupts

Channels	One, sharing with tri-state buffer for IRQ4-7, 9

Option Jumpers .025" square posts, 0.1" grid

Electrical & Environmental

+5V @ 50 mA typical
-40° to 85° C

Models

MSI-P442-K/I/O	12 T/C + 4 Analog In + 1 Analog Out
MSI-P442-K/I	12 T/C + 4 Analog In
MSI-P442-K/O	12 T/C + 1 Analog Out
MSI-P442-K	12 T/C
MSI-P442-K-8	8 T/C

APPENDIX

Circuit Diagrams and Data Sheets

See schematics P442-1.pdf and P442-2.pdf

See data sheets MAX197.pdf and AD5341.pdf