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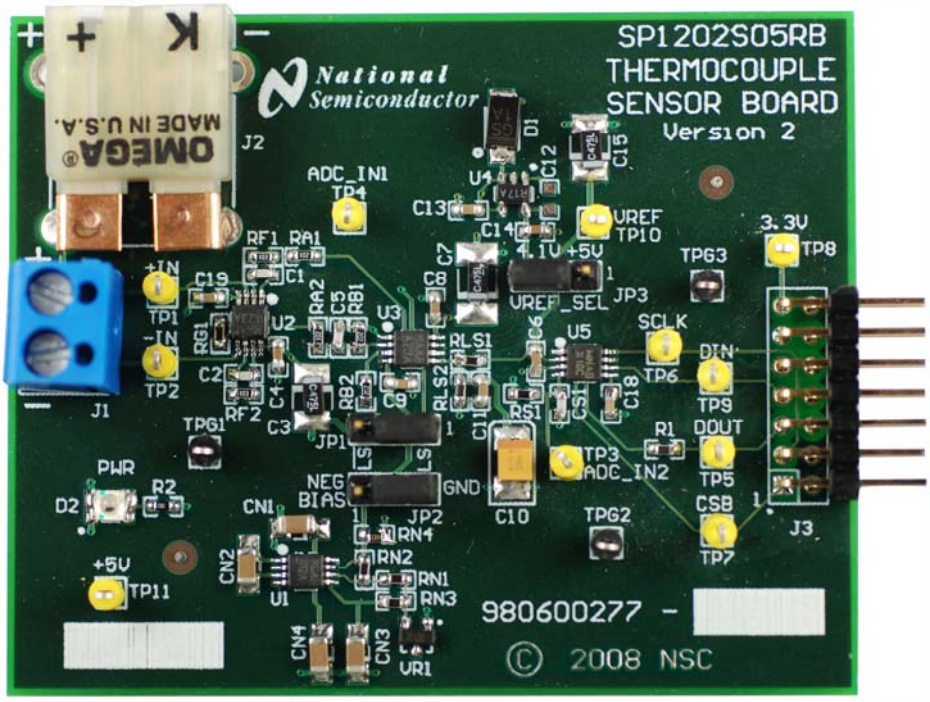
Thermocouple Sensor Board Version 2
SP1202S05RB
Users' Guide



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1.0 Introduction

The Thermocouple Sensor Board Version 2 (SP1202S05RB) along with the Sensor Signal Path Control Panel (Sensor Panel) software and SPUSI2 USB Interface Dongle are designed to ease the design of circuits using various thermocouple sensors with National's amplifiers and Analog-to-Digital converters (ADCs). Use the WEBENCH® Thermocouple Sensor Designer tool to determine appropriate IC's and passives to achieve your signal path requirements: http://www.national.com/analog/webench/sensors/thermocouple

See *Figure 1* for component placement and *Figure 2* for example board schematic. The thermocouple sensor can be connected to header J1 or J2. The differential voltage at the thermocouple sensor output is digitized and can be captured and displayed on the computer monitor with the accompanying Sensor Panel software, which operates under Microsoft Windows XP. The amplified thermocouple sensor voltage may be measured at TP3 relative to ground. The software can provide gain and offset correction for the entire circuit, including the sensor.

2.0 Board Assembly

This Thermocouple Sensor Board Version 2 comes as a bare board that must be assembled. Refer to an example Bill of Materials for a description of component values, to *Figure 1* for major component placement and to *Figure 2* for the example Board schematic.

3.0 Quick Start

Refer to *Figure 1* for locations of test points and major components.

1. Place the jumpers on the following positions

Table 1 – Jumper Default Positions		
Jumper	**Pins Shorted**	**FUNCTION**
JP1	2 - 3	Level Shifting
JP2	2 - 3	Negative Bias Generator
JP3	2 - 3	ADC Reference Select

2. Connect the Thermocouple Sensor Board Version 2 to a SPUSI2 (USB Interface Dongle) via 14-pin header J3 and connect a USB cable between the SPUSI2 board and a PC USB port. Red LEDs D2 on the Thermocouple Sensor Board Version 2 and D1 on the SPUSI2 board should come on if the PC is on.
4. Connect the thermocouple sensor to connector J1 or J2 of the board.
5. If not already installed, install the Sensor Panel software on the PC. Run the software.

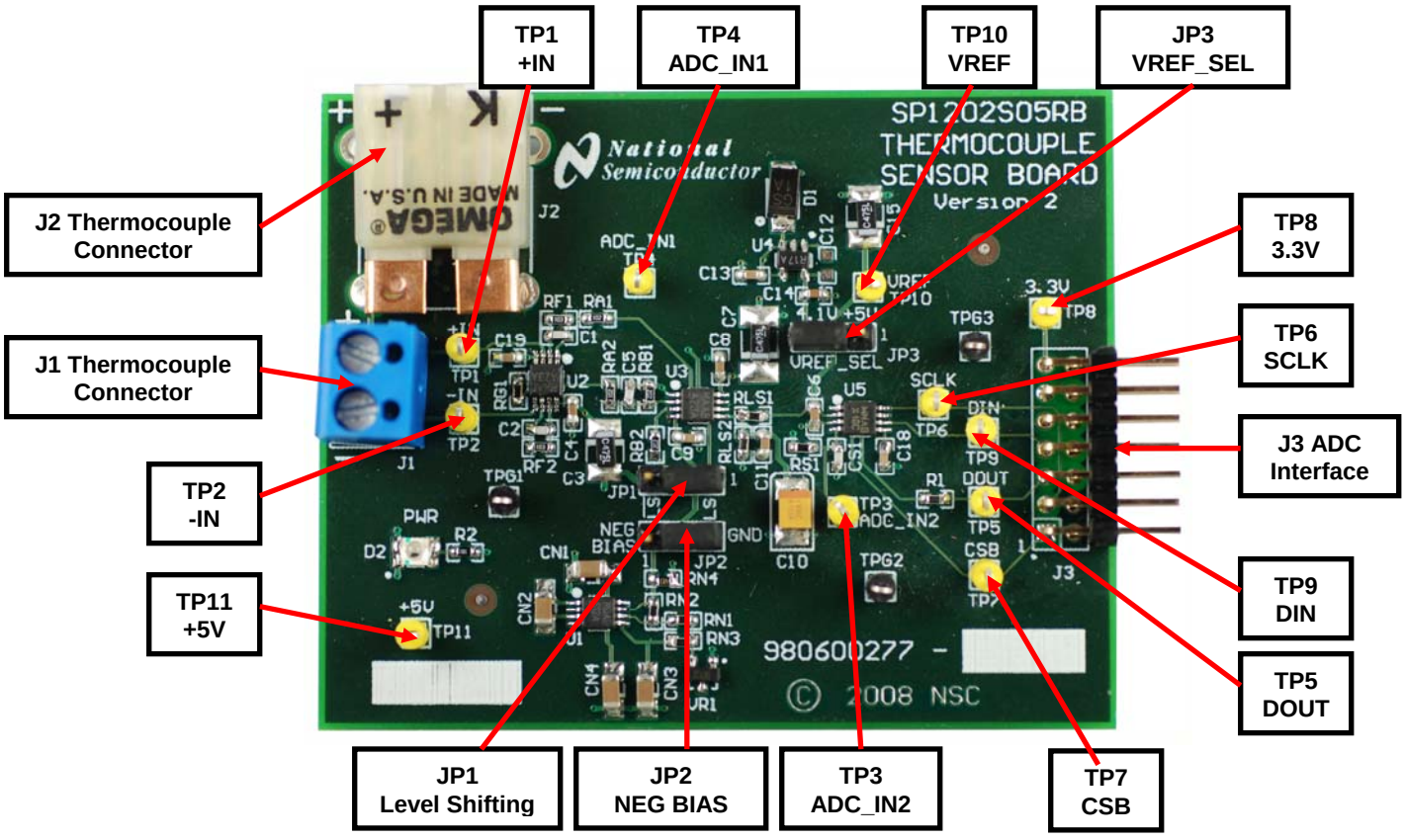

Figure 1. Component and Test Point Locations

4.0 Functional Description

The Thermocouple Board Version 2 component and test point locations are shown in *Figure 1*. The board schematic is shown in *Figure 2*.

4.1 Operational Modes

This board may be use in one of two modes: the Computer Mode using the SPUSI2 USB Interface Dongle or the Stand-Alone Mode without the use of the SPUSI2 USB Interface Dongle and a PC.

4.1.1 The Computer Mode

The board is intended for use in the Computer Mode with a SPUSI2 board. The Sensor Panel software controls the measurements by communicating with the ADC via the device's SPI interface. Power to both boards is provided via USB.

4.1.2 The Stand-Alone Mode

The Stand-Alone Mode does not use the SPUSI2 board to capture data and upload it to a PC. To use the board this way, the user must provide +5V at pin 14 of header J3 as well as provide ADC clock, Chip Select, and Data In signals to the ADC at pins 3, 1, and 7 respectively, of J3. ADC data output is available at pin 5 of J3. Test Points TP6, TP7, TP9 and TP5 may also be used to insert/read these signals. The range of frequencies for the ADC clock is 1 MHz to 4 MHz. The CS rate can be as low as desired, but no faster than 17 times the ADC clock rate.

4.2 Signal Conditioning Circuitry

The sensor output voltage is amplified and digitized by U5, an ADC. The full-scale value of this voltage after amplification will depend upon the maximum sensor output and the component values. This amplified voltage is presented to the ADC (U5), whose output is at header J3.

4.2.1 Instrumentation Amplifier

If considerable noise pickup is expected on the thermocouple sensor line an instrumentation amplifier configuration will offer good common mode rejection (CMR). To set up the board in the instrumentation amplifier configuration without supplying negative bias to the amplifier or level shifting the thermocouple sensor voltage ensure the jumpers are in the following position

Table 2 – Jumper Default Positions

Jumper	Pins Shorted	FUNCTION
JP1	2 - 3	Level Shifting
JP2	2 - 3	Negative Bias Generator
JP3	2 - 3	ADC Reference Select

Opamps U2A and U2B form a difference-in, difference-out amplifier which amplifies the differential output of the thermocouple sensor. The gain of the difference amplifier, assuming $R_{F1} = R_{F2}$, is the classic

$$\text{Differential Gain} = 1 + 2 * R_{F1} / R_{G1}.$$

The differential output is converted to a single-ended signal with amplifier U3A. The gain of the U3A circuit, assuming $R_{B1} = R_{B2}$ and $R_{A1} = R_{A2}$, is the well-known

$$\text{Single-Ended Gain} = – R_{B1} / R_{A1}.$$

The overall gain from the sensor to the ADC input, then, is

$$\text{Overall Gain} = (1 + 2 * R_{F1} / R_{G1}) \times R_{B1} / R_{A1}.$$

Due to the way the difference amplifier is connected to the single-ended amplifier, the overall gain is positive.

A low pass filter is formed by C1 = C2, and RF1 = RF2 which has a cutoff frequency of

$$\text{Cutoff Frequency} = 1 / (2 * \text{pi} * RF1 * C1)$$

Additional filtering can also be provided by C5 and RB1 and has a cutoff frequency of

$$\text{Cutoff Frequency} = 1 / (2 * \text{pi} * RB1 * C5)$$

The WEBENCH Thermocouple Sensor Designer tool will provide appropriate component values to achieve your application gain and cutoff frequency requirements.

4.2.2 Level Shifting

In many thermocouple applications the thermocouple sensor is used in a temperature range where only a positive output at the (+) terminal with respect to the (-) terminal or only a negative output is expected. If both positive and negative voltage is expected the board allows for an offset which is provided from a level shifting circuit. The level shifting voltage is set up by VREF and the RLS1-RLS2 voltage divider, then buffered through amplifier U3B. The level shifting voltage is

$$VLS = (VREF * RLS2) / (RLS2 + RLS1)$$

The Webench® Thermocouple Sensor Designer tool will provide appropriate component values to achieve your application level shifting requirements.

To add level shifting to the instrumentation amplifier configuration change the following jumper

Table 3 – Level Shifting Jumper Positions

Jumper	Pins Shorted	FUNCTION
JP1	1 - 2	Level Shifting

4.2.3 Offset and Gain Correction

The circuitry does not provide adjustment for offset voltages. However, the Sensor Panel software does allow for this correction.

4.3 Cold Junction Reference Temperature Sensor

A thermocouple sensor has the ability to measure a temperature differential between the measured temperature point and the reference temperature point at the reference junction often referred to as the cold junction. Due to this fact in order to determine the correct absolute temperature at the measuring point it is necessary to know the cold junction reference temperature. This is accomplished on board by the LM94022 Analog Temperature Sensor, U6, who's output is fed to the first channel of the ADC, U5. The Sensor Panel software takes this data then calculates the correct absolute temperature at the measuring point. The LM94022 mV/C transfer function can be found in the LM94022 datasheet. The sensor is hard wired for gain setting GS = 11.

4.4 Power Supply

In Computer Mode, power to this board is supplied through header J3 and ultimately from the host PC via USB. In most cases, the only voltage needed for the Thermocouple Sensor Board Version 2 is the +5V from the USB connection. Diode D1 provides protection against reverse polarity in the Stand-Alone mode where an external supply is used.

The supply voltage source for the ADC (VREF on the schematic) is selected with JP3 to be either the 4.1V from U4, or +5V from J3.

4.5 Negative Bias Generation

In the case where the measured temperature is close to the ambient cold junction reference temperature and the output voltage of the amplifying amplifiers are very low it is possible that the amplifier output may saturate. To avoid amplifier output saturation the board allows for a negative bias to be applied to the V- terminal of the amplifiers. The LM2687 voltage inverter, U1, produces a voltage of apx. – 0.25V. To add negative bias generation to the circuit change the following jumper

Table 6 – Neg. Bias Generator Jumper Positions

Jumper	Pins Shorted	FUNCTION
JP2	1 - 2	Negative Bias Generator

4.6 ADC Reference Circuitry

The single-ended dual channel ADCXX2SXX1 uses its supply voltage as its reference, so it is important that its supply voltage be stable and quiet. A 4.1V reference voltage is provided by U4, an accurate LM4120-4.1.

4.7 ADC Serial Clock

The ADC clock signal (SCLK) is provided external to the board at header J3 on pin 3 or TP6. The requirements for SCLK can be found in the respective ADC datasheet.

4.8 ADC Chip Select Bar

The ADC chip select bar (CSB) is provided external to the board at header J3 on pin 1 or on TP7. The requirements for CSB with respect to SCLK can be found in the respective ADC datasheet.

4.9 Digital Data Output/Input

The digital output data from the ADC is available at 14-pin header J3 on pin 5 or on TP5. The digital input data to the ADC is available at 14-pin header J3 on pin 7 or on TP9.

4.10 Power Requirements

Voltage and current requirements for the Thermocouple Sensor Board Version 2 are:

- Pin 14 of J3: +5.0V at 30 mA
- Pins 2 and 4 of J3: Ground

5.0 Installing and Using the Thermocouple Sensor Board Version 2

The Thermocouple Sensor Board Version 2 requires power as described above. The thermocouple sensor should be connected to J1 or J2.

5.1 Board Set-up

Refer to *Figure 1* for locations of connectors, test points and jumpers on the board.

1. Connect The Thermocouple Sensor Board Version 2 to a SPUSI2 USB Interface Dongle.
2. Be sure all jumpers are in place per *Table 2*.
3. Connect the thermocouple sensor to J1 or J2.
4. Connect a USB cable to the SPUSI2 board and a PC.
5. Confirm that Red LED D2 on the Thermocouple Sensor Board Version 2 is on, indicating the presence of power to the board.

5.2 Quick Check of Analog Functions

Refer to *Figure 1* for locations of connectors and test points and jumpers on the board. If at any time the expected response is not obtained, see Section 5.5 on Troubleshooting.

1. Perform steps 1 through 4 of Section 5.1.
2. Check for 5.0V at TP11 and for 4.1V at TP10.
3. Apply a known voltage, Vin, at J1 or J2 connector and based on chosen gain, Av, of circuit confirm that voltage, Vout, at TP3 is as expected (Vin x Av = Vout).
4. Check temperature sensor output voltage at TP4 is as expected according to the transfer table found in the LM94022 datasheet. Room temp is apx. 2.3V.
5. Check negative bias generator output voltage at pin 1 of JP2 is apx. -0.25V.
6. Check level shifting output voltage at pin 1 of JP1 is VLS = (VREF * RLS2) / (RLS2 + RLS1)

This completes the quick check of the analog portion of the evaluation board.

5.3 Quick Check of Software and Computer Interface Operation

1. Perform steps 1 through 4 of Section 5.1.
2. Run the Sensor Panel software.
3. Select the SPI202S05RB
4. Manually enter the following data:
    - Thermocouple Type
    - Amplifier Configuration
    - Gain
    - Level Shifting Voltage
    - Number of bits
    - ADC Reference Voltage

The software will display the cold junction reference temperature and the thermocouple measured temperature.

This completes the quick check of the software and computer interface.

5.4 Sensor Panel Software

The Sensor Panel software is available on the web at http:\\www.national.com

Upon loading the software and running it, it is necessary to configure it for the board you are using. See the Sensor Panel software User's Guide for more details.

5.5 Troubleshooting

If there is no output from the board, check the following:

- Be sure that the proper voltages and polarities are present at TP11 (+5V) and TP10 (+4.1V or +5V, as selected with JP3).
- Be sure there is a clock signal at TP6 when trying to capture data.
- Confirm thermocouple sensor is connected properly.

If the ADC output is zero or a single code, check the following:

- Be sure that the proper voltages and polarities are present at TP11 (+5V) and TP10 (+4.1V or +5V, as selected with JP3).
- Be sure that J3 is properly connected to a SPUSI2 USB Interface Dongle, and that there is a jumper on JP3.
- Confirm thermocouple sensor is connected properly.

If excessive noise is seen on the board, check the following:

- Locate and remove possible noise sources (Laptop AC Adapters, Equipment, etc.)
- Connect ground of board (i.e. TPG1) to an external ground source.

6.0 Evaluation Board Specifications

Board Size:	2.85" x 2.30" (7.2 cm x 5.8 cm)
Power Requirements:	+5V (30mA) at J3 pin 14

7.0 Example Hardware Schematic

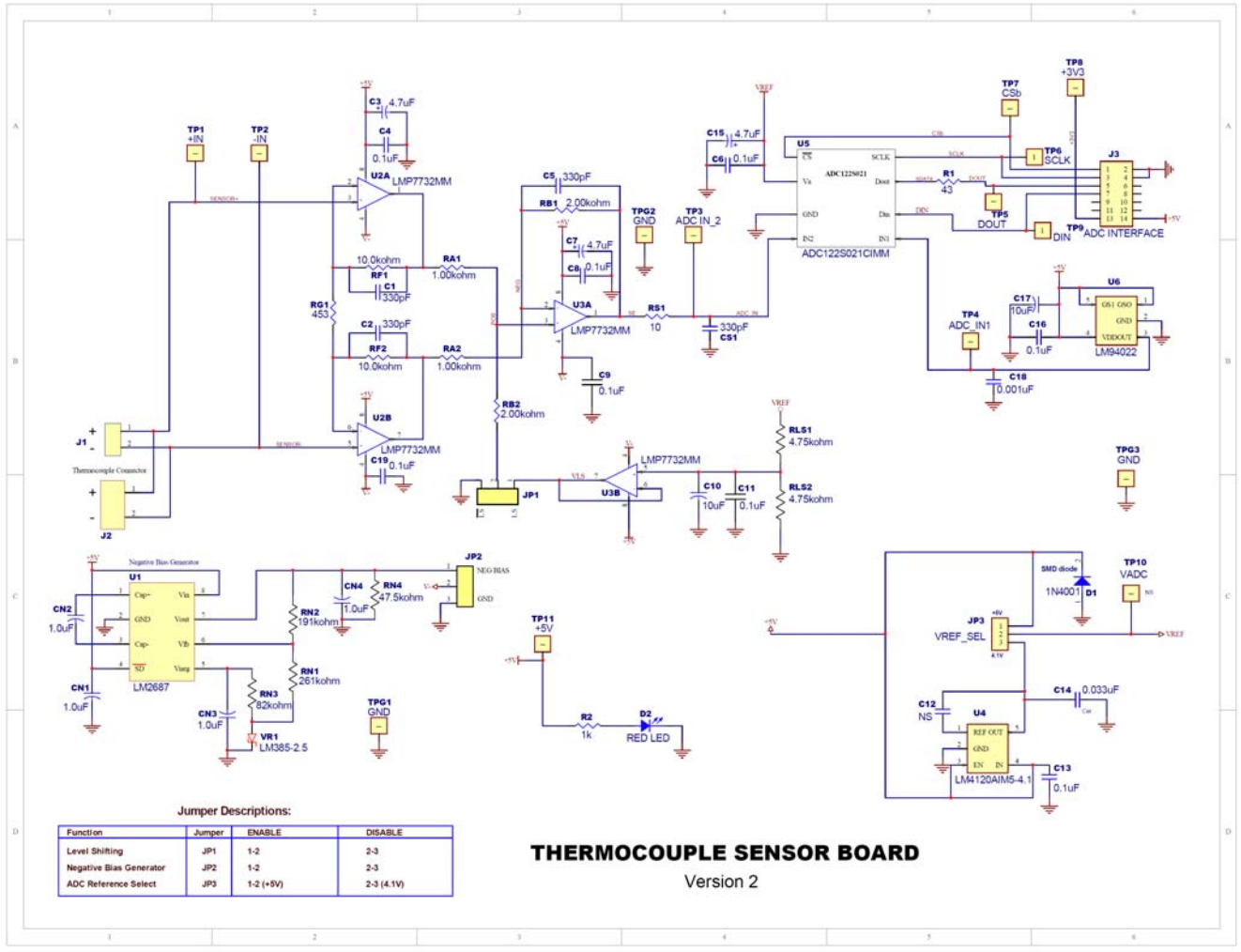

Figure 2. Thermocouple Sensor Board Version 2 Schematic

8.0 Thermocouple Sensor Board Version 2 Example Bill of Materials

Item #	Quantity	Reference	Part	Reference
1	4	C1, C2, C5, CS1	Capacitor, Ceramic, 330pF, SMT, 0603,NPO, 50V, 5%	MURATA # GRM1885C1H331JA01D Digi-key # 490-1439-1-ND
2	3	C3, C7, C15	Capacitor, Tantalum, 4.7uF, SMT, 3528, 10V, 10%	VISHAY # 293D475X9010B2TE3 Digi-Key # 718-1147-1-ND
3	8	C4, C6, C8, C9, C11, C13, C16, C19	Capacitor, Ceramic, 0.1uF, SMT, 0603, X7R, 25V, 10%	TDK # C1608X7R1E104K Digi-key # 445-1316-1-ND
4	2	C10, C17	Capacitor, Tantalum, 10uF, SMT, 3528, 10V, 10%	VISHAY # 293D106X9010B2TE3 Digi-key # 718-1122-1-ND
5	1	C12	NOT STUFFED	
6	1	C14	Capacitor, Ceramic, 0.033uF, SMT, 0603, X7R, 50V, 10%	MURATA # GRM188R71H333KA61D Digi-key # 490-3286-1-ND
7	1	C18	Capacitor, , Ceramic, 0.001uF, SMT, 0603, X7R, 50V, 10%	KEMET # C0603C102K5RACTU Digi-key # 399-1082-1-ND
8	4	CN1, CN2, CN3, CN4	Capacitor, Ceramic, 1uF, SMT, 1206, 16V, 10%	JOHANSON # 160R18W105KV4E Digi-key # 709-1068-1-ND
9	1	D1	DIODE, 50V, 1A	MCC # GS1A-TP Digi-key # GS1A-TPCT-ND
10	1	D2	RED LED	LITE-ON # LTST-C930KAKT Digi-key # 160-1461-1-ND
11	1	J1	Terminal Block	ON SHORE # ED120/2DS Digi-key # ED1609-ND
12	1	J2	Thermocouple Connector	OMEGA #PCC-SMP
13	1	J3	ADC INTERFACE	TYCO # 87230-7 Digi-key # A26599-ND
14	3	JP1, JP2, JP3	3-PIN HEADER	Waldom/Molex # 22-28-4033 Digi-key # WM6503-ND
15	1	R1	Resistor, SMT, 0603, 1%, 43.0 ohm	Panasonic # ERJ-3EKF43R0V Digi-key # P43.0HCT-ND
16	1	R2	'Resistor, SMT, 0603, 1%, 1.00Kohm	Panasonic # ERJ-3EKF1001V Digi-key # P1.00KHCT-ND
17	2	RA1, RA2	'Resistor, SMT, 0603, 0.1%, 1.00Kohm	Panasonic # ERA-3AEB102V Digi-key # P1.0KDBCT-ND
18	2	RB1, RB2	Resistor, SMT, 0603, 0.1%, 2.00Kohm	Panasonic # ERA-3AEB202V Digi-key # P2.0KDBCT-ND
19	2	RF1, RF2	'Resistor, SMT, 0603, 0.1%, 10.0Kohm	Panasonic # ERA-3AEB103V Digi-key # P10KDBCT-ND
20	1	RG1	Resistor, SMT, 0603, 1%, 453ohm	Panasonic # ERJ-3EKF4530V Digi-key # P453HCT-ND
21	2	RLS1, RLS2	Resistor, SMT, 0603, 1%, 4.75Kohm	Panasonic # ERJ-3EKF4751V Digi-key # P4.75KHCT-ND
22	1	RN1	Resistor, SMT, 0603, 1%, 261Kohm	Panasonic # ERJ-3EKF2613V Digi-key # P261KHCT-ND
23	1	RN2	Resistor, SMT, 0603, 1%, 191Kohm	Panasonic #ERJ-3EKF1913V Digi-key # P191KHCT-ND
24	1	RN3	Resistor, SMT, 0603, 1%, 82.0Kohm	Panasonic # ERJ-3EKF8202V Digi-key # P82.0KHCT-ND
25	1	RN4	Resistor, SMT, 0603, 1%, 47.0Kohm	Panasonic #ERJ-3EKF4702V Digi-key # P47.0KHCT-ND
26	1	RS1	Resistor, SMT, 0603, 1%, 10ohm	Panasonic # ERJ-3EKF10R0V Digi-key # P10.0HCT-ND
27	14	TP1-TP11, TPG1-TPG3	TEST POINTS (NOT STUFFED)	
28	1	U1	LM2687	NSC # LM2687MM/NOPB Digi-key # LM2687MMCT-ND
29	2	U2, U3	LMP7732MM	NSC # LMP7732MM/NOPB Digi-key # LMP7732MA-ND
30	1	U4	LM4120AIM5-4.1	NSC # LM4120AIM5-4.1/NOPB Digi-key # LM4120AIM5-4.1CT-ND
31	1	U5	ADC122S021CIMM	NSC # ADC122S021CIMM Digi-key # ADC122S021CIMMCT-ND
32	1	U6	LM94022	NSC # LM94022QBIMG/NOPB Digi-key # LM94022QBIMGCT-ND
33	1	VR1	LM385-2.5	NSC # LM385M3-2.5/NOPB Digi-key # LM385M3-2.5CT-ND

APPENDIX

Summary Tables of Test Points and Connectors

Test Points on the Thermocouple Sensor Board Version 2

Identifier	Name	Function
TP 1	+IN	+IN of U2A amplifier
TP 2	-IN	+IN of U2B amplifier
TP 3	ADC_IN2	ADC Channel 2 input voltage
TP 4	ADC_IN1	ADC Channel 1 input voltage
TP 5	DOUT	DOUT output from ADC
TP 6	SCLK	SCLK input for ADC
TP 7	CSb	CSb input for ADC
TP 8	+3V3	+3.3V from SPUSI2 Board (not used on this board)
TP 9	DIN	DIN input for ADC
TP 10	VREF	Supply/Reference voltage of ADC
TP 11	+5V	Overall supply for board from SPUSI2 Board

J1/J2 Connector - Sensor Interface

Identifier	Name	Function
J1/J2-1	+Out	+ Output from Sensor
J1/J2-2	-Out	- Output from Sensor

J3 Connector - Connection to SPUSI2 Board

J3 Pin Number	Voltage or Signal
1	CSb input to ADC
2	Ground
3	SCLK input to ADC
4	Ground
5	SDATA output from ADC
6	no connection
7	DIN input to ADC
8	no connection
9	no connection
10	no connection
11	no connection
12	no connection
13	+3.3V from SPUSI2 USB Interface Dongle
14	+5V from SPUSI2 USB Interface Dongle

Summary Tables of Test Points and Connectors (cont'd)

JP1 Jumper – Level Shifting

Shorted Positions	Results
1 - 2	Level shifting enabled
2 - 3	Level shifting disabled

JP2 Jumper – Negative Bias Generator

Shorted Positions	Results
1 - 2	Negative bias generation enabled
2 - 3	Negative bias generation disabled

JP3 Jumper – ADC Reference Select

Shorted Positions	Results
1 - 2	+5V for ADC supply and reference voltage
2 - 3	+4.1V for ADC supply and reference voltage

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The Thermocouple Sensor Board Version 2 is intended for product evaluation purposes only and is not intended for resale to end consumers, is not authorized for such use and is not designed for compliance with European EMC Directive 89/336/EEC.

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