Application Note AN2148

Measuring Temperature Using a Thermocouple

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Summary
This Application Note explains how to measure temperature using a J Type Thermocouple with a PSoC. Following the principle, any thermocouple input can be measured.

Introduction
Thermocouples are widely used in industrial applications for the following reasons:

- They are robust
- They measure over a wide range (-270° to 3000° C)
- They are available in a wide variety of packages and probes

Thermocouple Principle
A thermocouple consists of two pieces of dissimilar metals in the form of wire fused at one end. This is called the hot junction. The other end is connected to a measuring circuit. This is called the cold junction. The difference in temperature between the hot and cold junctions causes an EMF to develop. This EMF can be measured by the measuring circuit.

Because the thermocouple is a reference device, the absolute temperature (hot junction) can be measured only if the reference (cold junction) is known. The reference temperature is called the Cold Junction Temperature. Adding the thermocouple equivalent EMF of this temperature to the one measured from the thermocouple is called Cold Junction Compensation.

There are different types of thermocouples such as J, K, T, R, and S just to name a few. Each type has its own temperature coefficient and range of measurement.

The output of the thermocouple is not linear throughout the measurement range.

There are two methods that can be used to acquire an accurate temperature. Using a multi-order polynomial equation (Equation 1), the temperature can be calculated accurately as close as +0.02°C.

$$T = (a_0 + a_1V + a_2V^2 + ... + a_nV^n) \quad \textbf{Equation 1}$$

The polynomial coefficients for different types of thermocouples can be found in Table-3 in the Appendix.

This method is quite complicated and involves high precision mathematics, which heavily taxes the resources of an 8-bit device.

The second method is the use of lookup tables. Here, we divide the whole measurement range of the thermocouple into many regions and identify the coefficient for each region. The higher the number of regions, the better the accuracy. We will use this method in this Application Note.

Steps Involved
The whole process can be broken into the following steps.

1. Find Cold Junction Temperature and thermocouple voltage corresponding to that temperature. This is the Cold Junction Compensation voltage.
2. Measure thermocouple voltage.
3. Add the Cold Junction Compensation voltage to the thermocouple voltage.
4. Find coefficient.
5. Find temperature.

1. Find Cold Junction Compensation:

Many circuits can be used to measure the reference temperature; Thermistor, RTD, and Diode come to mind.

In this circuit, the LM335 Precision Temperature Sensor is used to sense the Cold Junction Temperature. This IC has a linear output of 10 mV/°C and can give excellent accuracy without any calibration. The output of this IC is 0V at absolute zero (0°K). At 0°C, the output voltage is 2.7315V (273.15°K). The LM335 output is connected to P2[1], so that it can be directly configured as an ADC input without using any Continuous Time analog PSoC blocks.

A diode can also be used to sense room temperature. Any common diode like 1N4148 can be used. A diode exhibits a temperature coefficient of –2.2 mV/°C. A single resistance can be used to set the diode current. But the absolute voltage will have some tolerance and will have to be calibrated.

Correlated Double Sampling (CDS) is performed while measuring Cold Junction Temperature. CDS is explained in step #2. First, the ADC input is shorted to AGND and the output measured. The LM335 output is connected to the ADC input and the ADC output is measured. The zero value is subtracted from this value to get an offset-corrected reading.

Now, considering a 12-bit ADC and full-scale voltage of 1.3V (REFHI), the following equation gives the LM335 voltage.

$$V = (1.3V / 2048) * \text{ADC Count} \quad \textbf{Equation 2}$$

The LM335 output is at 10 mV/°C which modifies the equation to:

$$T = (130 / 2048) * \text{ADC Count} \quad \textbf{Equation 3}$$

This yields temperature directly (in °K). As the output of LM335 at 0°C is 2.731V with reference to VSS, and as ADC measurement is with reference to AGND which is 2.6V, subtracting 13 from the calculated value will give Cold Junction Temperature directly in °C.

From this temperature, find the corresponding thermocouple voltage from table reference (coldJunction[]) in the Appendix.

2. Measure Thermocouple Voltage:

The thermocouple input is fed to an INSAMP User Module with a gain of 16. The output of J Type Thermocouple is 69.55 mV at 1200°C. The output of the INSAMP is roughly 1.11V at this temperature. This is fed to an ADCINC12 User Module.

When we have to measure such small voltages, the problems of offset error and signal-to-noise ratio come into consideration. To overcome these problems we will use CDS and Infinite Impulse Response (IIR) filter techniques.

Correlated Double Sampling (CDS):

This method reduces offset errors present in the signal-conditioning amplifiers and the ADC. The following steps are involved.

1. Short the inputs. Measure ADC output. Store as Zero.
2. Connect inputs to thermocouple. Measure output. Store as Signal.
3. Subtract Zero from Signal.

Infinite Impulse Response (IIR) Filter:

This is a low-pass filter implemented in software. This averages and effectively reduces the noise from the input signal.

In this application, the IIR filter constant has been set to 4. This results in poor response time but very good noise rejection. Most industrial applications that measure high temperatures do not need fast response time. For faster response, the filter constant can be reduced.

For details on modifying the filter constant and other IIR techniques, see Application Note AN2099 "Single-Pole IIR Filters. To Infinity And Beyond!"

The ADC output after CDS is passed through the low-pass IIR filter. From the output of this filter, the thermocouple voltage can be calculated by the following formula:

$$\text{volts} = \text{ADC Counts} * \text{Range} / \text{fullScale}$$

Equation 4

For calibration purposes, the range is set to 50 mV and fullScale is the ADC Counts when input is 50 mV. For better resolution, ADC Counts is multiplied by 5,000 and divided by fullScale. The resolution of the result is 10 uV/count.

3. Cold Junction Compensation:

Add the Cold Junction Compensation voltage calculated in step #2 to the measured thermocouple voltage to get a cold junction compensated output.

4. Find Coefficient:

Let us consider a J Type Thermocouple. The EMF table of J Type Thermocouple can be found in Tables-1 and 2 in the Appendix.

First, we have to build a lookup table from the EMF table of the J Type Thermocouple. Let us divide the whole table into 0.64 mV divisions and identify the coefficient for each division. Compiling them will give us the lookup table.

As resolution of the measured voltage is 10 uV, the coefficient is also calculated for °C/10 uV. Multiply this fractional number by 10,000 to convert it to an integer.

As the measured voltage is in tens of microvolts, the thermocouple voltage is divided by 64 to get the lookup table offset. Sixty-four has been selected because it is easier to perform the division by rotating the voltage 6 times to the right.

The procedure of building the lookup table can be found in the Excel .xls file attached with the project.

5. Find Temperature:

Once the thermocouple voltage and coefficient are known, temperature can be calculated by multiplying the thermocouple voltage by the sensitivity coefficient for that type of thermocouple. Some examples of thermocouple sensitivies are given in Table 1.

Table 1. Thermocouple Coefficients

Type	Sensitivity Coefficient
K	41 uV/°C
E	68 uV/°C
R	10 uV/°C
N	10 uV/°C

In PSoC Designer, some assembly routines have been written for 16-bit multiplication and 24-bit division. These routines are called from C. This is to minimize the time taken in math operations. For details on 16-bit multiplication, refer to Application Note AN2038, and for details on 24-bit division, refer to Application Note AN2101.

To support signed division, first the dividend is tested to determine if it is negative. If it is negative, the sign is saved, the value is made positive and division is performed. Then the sign is restored by 2's complementing the result.

Software

The software consists of three main components.

1. ReadAdc()
2. ProcessAdc()
3. CheckCalibration()

ReadAdc():

This routine reads from both the thermocouple and LM335, performs CDS and IIR filtering and updates vTc and vColdJunction.

ProcessAdc():

This routine calculates Cold Junction Temperature from vColdJunction, performs the Cold Junction Compensation on vTc and calculates the temperature after finding the coefficient. It then updates the LCD display with the measured temperature and room temperature.

If the voltage is positive, the coefficient is taken from the positive lookup table. If the voltage is negative, the coefficient is taken from the negative lookup table.

The total time for calculation of temperature and updating the display is 2.7 mS at a CPU speed of 24 MHz.

CheckCalibration():

This routine performs calibration. A push-button switch connected to P2[3] is used for Full Scale Calibration. Another push button connected to P2[5] is used for Zero Calibration.

When the Zero Calibration switch is pressed, the value of vTc is stored as zero.

When the Full-Scale Calibration switch is pressed, the value of vTc is stored as fullScale.

Calibration:

Though CDS takes care of the zero offset error, for optimum accuracy, a software zero calibration has been added. This takes care of any residual offset error.

- Apply 0 mV at the thermocouple input
- Wait until the display stabilizes
- Press the Zero Calibration push button
- Apply 50 mV at the thermocouple input
- Wait until the display stabilizes
- Press the Full-Scale Calibration push button

The instrument is now calibrated and accurate to ±2°C. For test results see Table-4 in the Appendix.

The zero calibration procedure can be omitted if some inaccuracy can be tolerated. In this case, the error can go up to ±4°C.

Conclusion

Using the described method, temperature can be measured for any thermocouple input. As there are minimal external components, a low-cost temperature controller can be built using a PSoC, and adding some keys, a 4-digit LED display, and one or two relay outputs. The controller can be designed to measure various thermocouples like J, K, R, T, etc. A feature can be implemented to select the thermocouple and program the set point using the front panel keys.

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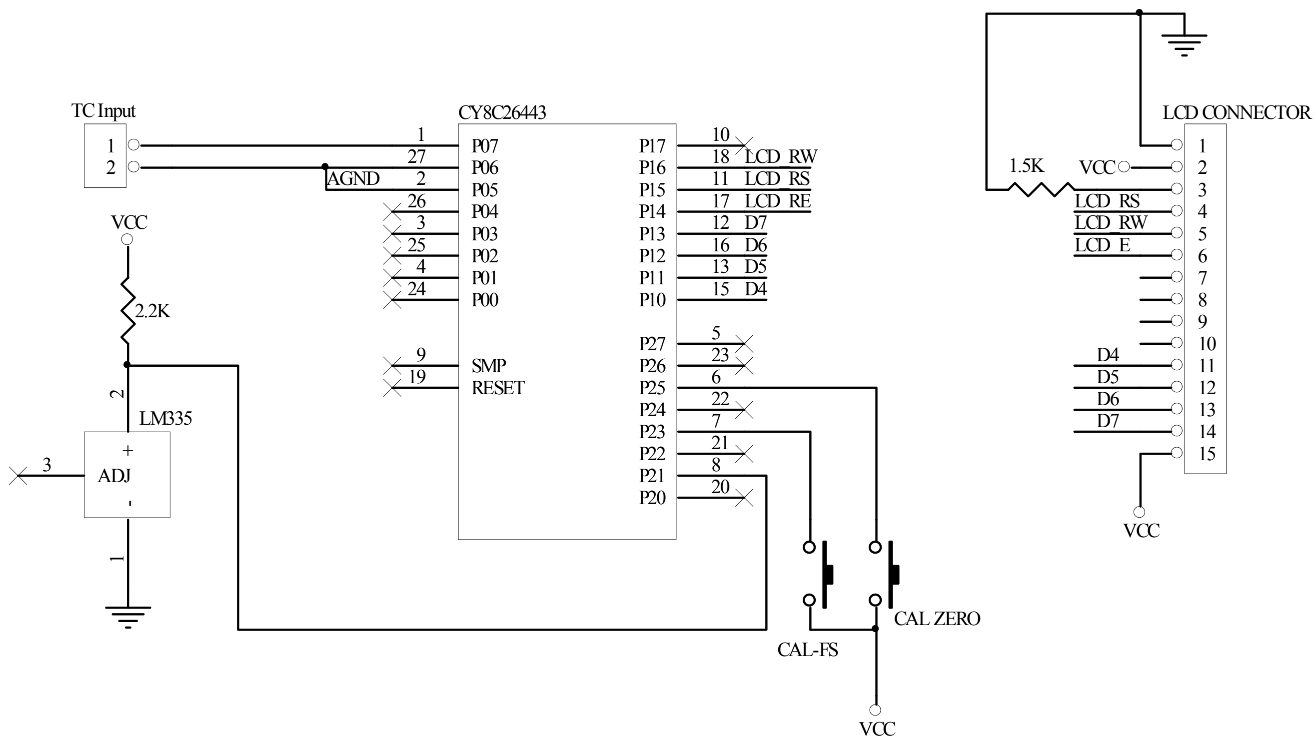

Figure 1. Schematic Diagram

APPENDIX

Table 1. J Type Thermocouple EMF Table for +ve Temperatures (in mV)

°C	0	1	2	3	4	5	6	7	8	9
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456
10	0.507	0.558	0.609	0.660	0.711	0.762	0.814	0.865	0.916	0.968
20	1.019	1.071	1.122	1.174	1.226	1.277	1.329	1.381	1.433	1.485
30	1.537	1.589	1.641	1.693	1.745	1.797	1.849	1.902	1.954	2.006
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596
70	3.650	3.703	3.757	3.810	3.864	3.918	3.971	4.025	4.079	4.133
80	4.187	4.240	4.294	4.348	4.402	4.456	4.510	4.564	4.618	4.672
90	4.726	4.781	4.835	4.889	4.943	4.997	5.052	5.106	5.160	5.215
100	5.269	5.323	5.378	5.432	5.487	5.541	5.595	5.650	5.705	5.759
110	5.814	5.868	5.923	5.977	6.032	6.087	6.141	6.196	6.251	6.306
120	6.360	6.415	6.470	6.525	6.579	6.634	6.689	6.744	6.799	6.854
130	6.909	6.964	7.019	7.074	7.129	7.184	7.239	7.294	7.349	7.404
140	7.459	7.514	7.569	7.624	7.679	7.734	7.789	7.844	7.900	7.955
150	8.010	8.065	8.120	8.175	8.231	8.286	8.341	8.396	8.452	8.507
160	8.562	8.618	8.673	8.728	8.783	8.839	8.894	8.949	9.005	9.060
170	9.115	9.171	9.226	9.282	9.337	9.392	9.448	9.503	9.559	9.614
180	9.669	9.725	9.780	9.836	9.891	9.947	10.002	10.057	10.113	10.168
190	10.224	10.279	10.335	10.390	10.446	10.501	10.557	10.612	10.668	10.723
200	10.779	10.834	10.890	10.945	11.001	11.056	11.112	11.167	11.223	11.278
210	11.334	11.389	11.445	11.501	11.556	11.612	11.667	11.723	11.778	11.834
220	11.889	11.945	12.000	12.056	12.111	12.167	12.222	12.278	12.334	12.389
230	12.445	12.500	12.556	12.611	12.667	12.722	12.778	12.833	12.889	12.944
240	13.000	13.056	13.111	13.167	13.222	13.278	13.333	13.389	13.444	13.500
250	13.555	13.611	13.666	13.722	13.777	13.833	13.888	13.944	13.999	14.055
260	14.110	14.166	14.221	14.277	14.332	14.388	14.443	14.499	14.554	14.609
270	14.665	14.720	14.776	14.831	14.887	14.942	14.998	15.053	15.109	15.164
280	15.219	15.275	15.330	15.386	15.441	15.496	15.552	15.607	15.663	15.718
290	15.773	15.829	15.884	15.940	15.995	16.050	16.106	16.161	16.216	16.272
300	16.327	16.383	16.438	16.493	16.549	16.604	16.659	16.715	16.770	16.825
310	16.881	16.936	16.991	17.046	17.102	17.157	17.212	17.268	17.323	17.378
320	17.434	17.489	17.544	17.599	17.655	17.710	17.765	17.820	17.876	17.931
330	17.986	18.041	18.097	18.152	18.207	18.262	18.318	18.373	18.428	18.483
340	18.538	18.594	18.649	18.704	18.759	18.814	18.870	18.925	18.980	19.035
350	19.09	19.146	19.201	19.256	19.311	19.366	19.422	19.477	19.532	19.587
360	19.642	19.697	19.753	19.808	19.863	19.918	19.973	20.028	20.083	20.139
370	20.194	20.249	20.304	20.359	20.414	20.469	20.525	20.58	20.635	20.69
380	20.745	20.8	20.855	20.911	20.966	21.021	21.076	21.131	21.186	21.241
390	21.297	21.352	21.407	21.462	21.517	21.572	21.627	21.683	21.738	21.793
400	21.848	21.903	21.958	22.014	22.069	22.124	22.179	22.234	22.289	22.345
410	22.4	22.455	22.51	22.565	22.62	22.676	22.731	22.786	22.841	22.896
420	22.952	23.007	23.062	23.117	23.172	23.228	23.283	23.338	23.393	23.449
430	23.504	23.559	23.614	23.67	23.725	23.78	23.835	23.891	23.946	24.001
440	24.057	24.112	24.167	24.223	24.278	24.333	24.389	24.444	24.499	24.555

450	24.61	24.665	24.721	24.776	24.832	24.887	24.943	24.998	25.053	25.109
460	25.164	25.22	25.275	25.331	25.386	25.442	25.497	25.553	25.608	25.664
470	25.72	25.775	25.831	25.886	25.942	25.998	26.053	26.109	26.165	26.22
480	26.276	26.332	26.387	26.443	26.499	26.555	26.61	26.666	26.722	26.778
490	26.834	26.889	26.945	27.001	27.057	27.113	27.169	27.225	27.281	27.337

°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
500	27.393	27.449	27.505	27.561	27.617	27.673	27.729	27.785	27.841	27.897
510	27.953	28.010	28.066	28.122	28.178	28.234	28.291	28.347	28.403	28.460
520	28.516	28.572	28.629	28.685	28.741	28.798	28.854	28.911	28.967	29.024
530	29.080	29.137	29.194	29.250	29.307	29.363	29.420	29.477	29.534	29.590
540	29.647	29.704	29.761	29.818	29.874	29.931	29.988	30.045	30.102	30.159
550	30.216	30.273	30.330	30.387	30.444	30.502	30.559	30.616	30.673	30.730
560	30.788	30.845	30.902	30.960	31.017	31.074	31.132	31.189	31.247	31.304
570	31.362	31.419	31.477	31.535	31.592	31.650	31.708	31.766	31.823	31.881
580	31.939	31.997	32.055	32.113	32.171	32.229	32.287	32.345	32.403	32.461
590	32.519	32.577	32.636	32.694	32.752	32.810	32.869	32.927	32.985	33.044
600	33.102	33.161	33.219	33.278	33.337	33.395	33.454	33.513	33.571	33.630
610	33.689	33.748	33.807	33.866	33.925	33.984	34.043	34.102	34.161	34.220
620	34.279	34.338	34.397	34.457	34.516	34.575	34.635	34.694	34.754	34.813
630	34.873	34.932	34.992	35.051	35.111	35.171	35.230	35.290	35.350	35.410
640	35.470	35.530	35.590	35.650	35.710	35.770	35.830	35.890	35.950	36.010
650	36.071	36.131	36.191	36.252	36.312	36.373	36.433	36.494	36.554	36.615
660	36.675	36.736	36.797	36.858	36.918	36.979	37.040	37.101	37.162	37.223
670	37.284	37.345	37.406	37.467	37.528	37.590	37.651	37.712	37.773	37.835
680	37.896	37.958	38.019	38.081	38.142	38.204	38.265	38.327	38.389	38.450
690	38.512	38.574	38.636	38.698	38.760	38.822	38.884	38.946	39.008	39.070
700	39.132	39.194	39.256	39.318	39.381	39.443	39.505	39.568	39.630	39.693
710	39.755	39.818	39.880	39.943	40.005	40.068	40.131	40.193	40.256	40.319
720	40.382	40.445	40.508	40.570	40.633	40.696	40.759	40.822	40.886	40.949
730	41.012	41.075	41.138	41.201	41.265	41.328	41.391	41.455	41.518	41.581
740	41.645	41.708	41.772	41.835	41.899	41.962	42.026	42.090	42.153	42.217
750	42.281	42.344	42.408	42.472	42.536	42.599	42.663	42.727	42.791	42.855
760	42.919	42.983	43.047	43.111	43.175	43.239	43.303	43.367	43.431	43.495
770	43.559	43.624	43.688	43.752	43.817	43.881	43.945	44.010	44.074	44.139
780	44.203	44.267	44.332	44.396	44.461	44.525	44.590	44.655	44.719	44.784
790	44.848	44.913	44.977	45.042	45.107	45.171	45.236	45.301	45.365	45.430
800	45.494	45.559	45.624	45.688	45.753	45.818	45.882	45.947	46.011	46.076
810	46.141	46.205	46.270	46.334	46.399	46.464	46.528	46.593	46.657	46.722
820	46.786	46.851	46.915	46.980	47.044	47.109	47.173	47.238	47.302	47.367
830	47.431	47.495	47.560	47.624	47.688	47.753	47.817	47.881	47.946	48.010
840	48.074	48.138	48.202	48.267	48.331	48.395	48.459	48.523	48.587	48.651
850	48.715	48.779	48.843	48.907	48.971	49.034	49.098	49.162	49.226	49.290
860	49.353	49.417	49.481	49.544	49.608	49.672	49.735	49.799	49.862	49.926
870	49.989	50.052	50.116	50.179	50.243	50.306	50.369	50.432	50.495	50.559
880	50.622	50.685	50.748	50.811	50.874	50.937	51.000	51.063	51.126	51.188
890	51.251	51.314	51.377	51.439	51.502	51.565	51.627	51.690	51.752	51.815
900	51.877	51.940	52.002	52.064	52.127	52.189	52.251	52.314	52.376	52.438
910	52.500	52.562	52.624	52.686	52.748	52.810	52.872	52.934	52.996	53.057
920	53.119	53.181	53.243	53.304	53.366	53.427	53.489	53.550	53.612	53.673

930	53.735	53.796	53.857	53.919	53.980	54.041	54.102	54.164	54.225	54.286
940	54.347	54.408	54.469	54.530	54.591	54.652	54.713	54.773	54.834	54.895
950	54.956	55.016	55.077	55.138	55.198	55.259	55.319	55.380	55.440	55.501
960	55.561	55.622	55.682	55.742	55.803	55.863	55.923	55.983	56.043	56.104
970	56.164	56.224	56.284	56.344	56.404	56.464	56.524	56.584	56.643	56.703
980	56.763	56.823	56.883	56.942	57.002	57.062	57.121	57.181	57.240	57.300
990	57.360	57.419	57.479	57.538	57.597	57.657	57.716	57.776	57.835	57.894
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1000	57.953	58.013	58.072	58.131	58.190	58.249	58.309	58.368	58.427	58.486
1010	58.545	58.604	58.663	58.722	58.781	58.840	58.899	58.957	59.016	59.075
1020	59.134	59.193	59.252	59.310	59.369	59.428	59.487	59.545	59.604	59.663
1030	59.721	59.780	59.838	59.897	59.956	60.014	60.073	60.131	60.190	60.248
1040	60.307	60.365	60.423	60.482	60.540	60.599	60.657	60.715	60.774	60.832
1050	60.890	60.949	61.007	61.065	61.123	61.182	61.240	61.298	61.356	61.415
1060	61.473	61.531	61.589	61.647	61.705	61.763	61.822	61.880	61.938	61.996
1070	62.054	62.112	62.170	62.228	62.286	62.344	62.402	62.460	62.518	62.576
1080	62.634	62.692	62.750	62.808	62.866	62.924	62.982	63.040	63.098	63.156
1090	63.214	63.271	63.329	63.387	63.445	63.503	63.561	63.619	63.677	63.734
1100	63.792	63.850	63.908	63.966	64.024	64.081	64.139	64.197	64.255	64.313
1110	64.370	64.428	64.486	64.544	64.602	64.659	64.717	64.775	64.833	64.890
1120	64.948	65.006	65.064	65.121	65.179	65.237	65.295	65.352	65.410	65.468
1130	65.525	65.583	65.641	65.699	65.756	65.814	65.872	65.929	65.987	66.045
1140	66.102	66.160	66.218	66.275	66.333	66.391	66.448	66.506	66.564	66.621
1150	66.679	66.737	66.794	66.852	66.910	66.967	67.025	67.082	67.140	67.198
1160	67.255	67.313	67.370	67.428	67.486	67.543	67.601	67.658	67.716	67.773
1170	67.831	67.888	67.946	68.003	68.061	68.119	68.176	68.234	68.291	68.348
1180	68.406	68.463	68.521	68.578	68.636	68.693	68.751	68.808	68.865	68.923
1190	68.980	69.037	69.095	69.152	69.209	69.267	69.324	69.381	69.439	69.496
1200	69.553									

Table 2. J Type Thermocouple EMF Table for -ve Temperatures (in mV)

°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9
-210	-8.095									
-200	-7.890	-7.912	-7.934	-7.955	-7.976	-7.996	-8.017	-8.037	-8.057	-8.076
-190	-7.659	-7.683	-7.707	-7.731	-7.755	-7.778	-7.801	-7.824	-7.846	-7.868
-180	-7.403	-7.429	-7.456	-7.482	-7.508	-7.534	-7.559	-7.585	-7.610	-7.634
-170	-7.123	-7.152	-7.181	-7.209	-7.237	-7.265	-7.293	-7.321	-7.348	-7.376
-160	-6.821	-6.853	-6.883	-6.914	-6.944	-6.975	-7.005	-7.035	-7.064	-7.094
-150	-6.500	-6.533	-6.566	-6.598	-6.631	-6.663	-6.695	-6.727	-6.759	-6.790
-140	-6.159	-6.194	-6.229	-6.263	-6.298	-6.332	-6.366	-6.400	-6.433	-6.467
-130	-5.801	-5.838	-5.874	-5.910	-5.946	-5.982	-6.018	-6.054	-6.089	-6.124
-120	-5.426	-5.465	-5.503	-5.541	-5.578	-5.616	-5.653	-5.690	-5.727	-5.764
-110	-5.037	-5.076	-5.116	-5.155	-5.194	-5.233	-5.272	-5.311	-5.350	-5.388
-100	-4.633	-4.674	-4.714	-4.755	-4.796	-4.836	-4.877	-4.917	-4.957	-4.997
-90	-4.215	-4.257	-4.300	-4.342	-4.384	-4.425	-4.467	-4.509	-4.550	-4.591
-80	-3.786	-3.829	-3.872	-3.916	-3.959	-4.002	-4.045	-4.088	-4.130	-4.173
-70	-3.344	-3.389	-3.434	-3.478	-3.522	-3.566	-3.610	-3.654	-3.698	-3.742
-60	-2.893	-2.938	-2.984	-3.029	-3.075	-3.120	-3.165	-3.210	-3.255	-3.300
-50	-2.431	-2.478	-2.524	-2.571	-2.617	-2.663	-2.709	-2.755	-2.801	-2.847
-40	-1.961	-2.008	-2.055	-2.103	-2.150	-2.197	-2.244	-2.291	-2.338	-2.385

-30	-1.482	-1.530	-1.578	-1.626	-1.674	-1.722	-1.770	-1.818	-1.865	-1.913
-20	-0.995	-1.044	-1.093	-1.142	-1.190	-1.239	-1.288	-1.336	-1.385	-1.433
-10	-0.501	-0.550	-0.600	-0.650	-0.699	-0.749	-0.798	-0.847	-0.896	-0.946
0	0.000	-0.050	-0.101	-0.151	-0.201	-0.251	-0.301	-0.351	-0.401	-0.451

Table 3. Polynomial Constants for Different Thermocouples

	Type					
	E	**J**	**K**	**R**	**S**	**T**
a_0	0.0	0.0	0.0	0.0	0.0	0.0
a_1	1.7057035E-2	1.978425E-2	2.508355E-2	1.8891380E-1	1.84949460E-1	2.592800E-2
a_2	-2.3301759E-7	-2.00120204E-7	7.860106E-8	-9.3835290E-5	-8.00504062E-5	-7.602961E-7
a_3	6.543558E-12	1.036969E-11	-2.503131E-10	1.3068619E-7	1.02237430E-7	4.637791E-11
a_4	-7.3562749E-17	-2.549687E-16	8.315270E-14	-2.2703580E-10	-1.52248592E-10	-2.165394E-15
a_5	-1.7896001E-21	3.585153E-21	-1.228034E-17	3.5145659E-13	1.88821343E-13	6.048144E-20
a_6	8.4036165E-26	-5.344285E-26	9.804036E-22	-3.8953900E-16	-1.59085941E-16	-7.293422E-25
a_7	-1.3735879E-30	5.099890E-31	-4.413030E-26	2.8239471E-19	8.23027880E-20	
a_8	1.0629823E-35		1.057734E-30	-1.2607281E-22	-2.34181944E-23	
a_9	-3.2447087E-41		-1.052755E-35	3.1353611E-26	2.79786260E-27	
a_{10}				-3.3187769E-30		

Table 4. Test Results

Input	Compensated	Expected	Actual	Error	Error on FS
mV	**mV**	**Reading**	**Reading**	**°C**	**%**
-7.90	-6.42	-148	-147	-1	0.08
-4.63	-3.15	-66	-67	1	-0.08
0.00	1.49	29	29	0	0.00
5.27	6.75	127	127	0	0.00
10.78	12.26	227	228	-1	0.08
16.33	17.81	328	328	0	0.00
21.85	23.33	427	428	-1	0.08
27.39	28.88	526	525	1	-0.08
33.10	34.59	625	625	0	0.00
39.13	40.62	724	724	0	0.00
45.49	46.98	824	824	0	0.00
51.88	53.36	924	924	0	0.00
57.95	59.44	1027	1025	2	-0.17
63.79	65.28	1126	1124	2	-0.17
66.68	68.16	1176	1175	1	-0.08

Max Error = 2°C

Test Condition:
Room Temperature = 29°C
Cold Junction Compensation = 1.49 mV

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