Temperature Measurement Devices

Rick Sellens

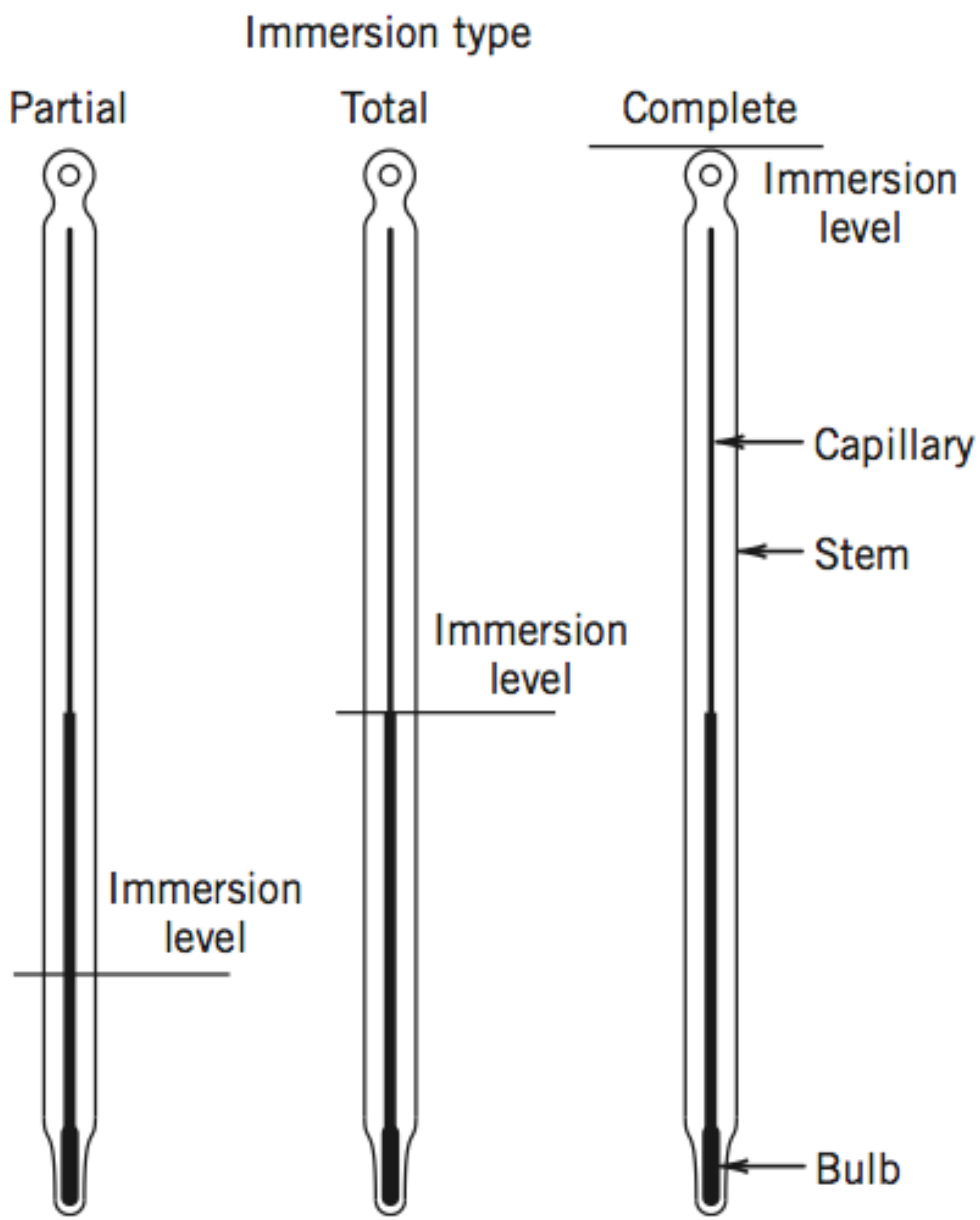


Figure 8.2 Liquid-in-glass thermometers.

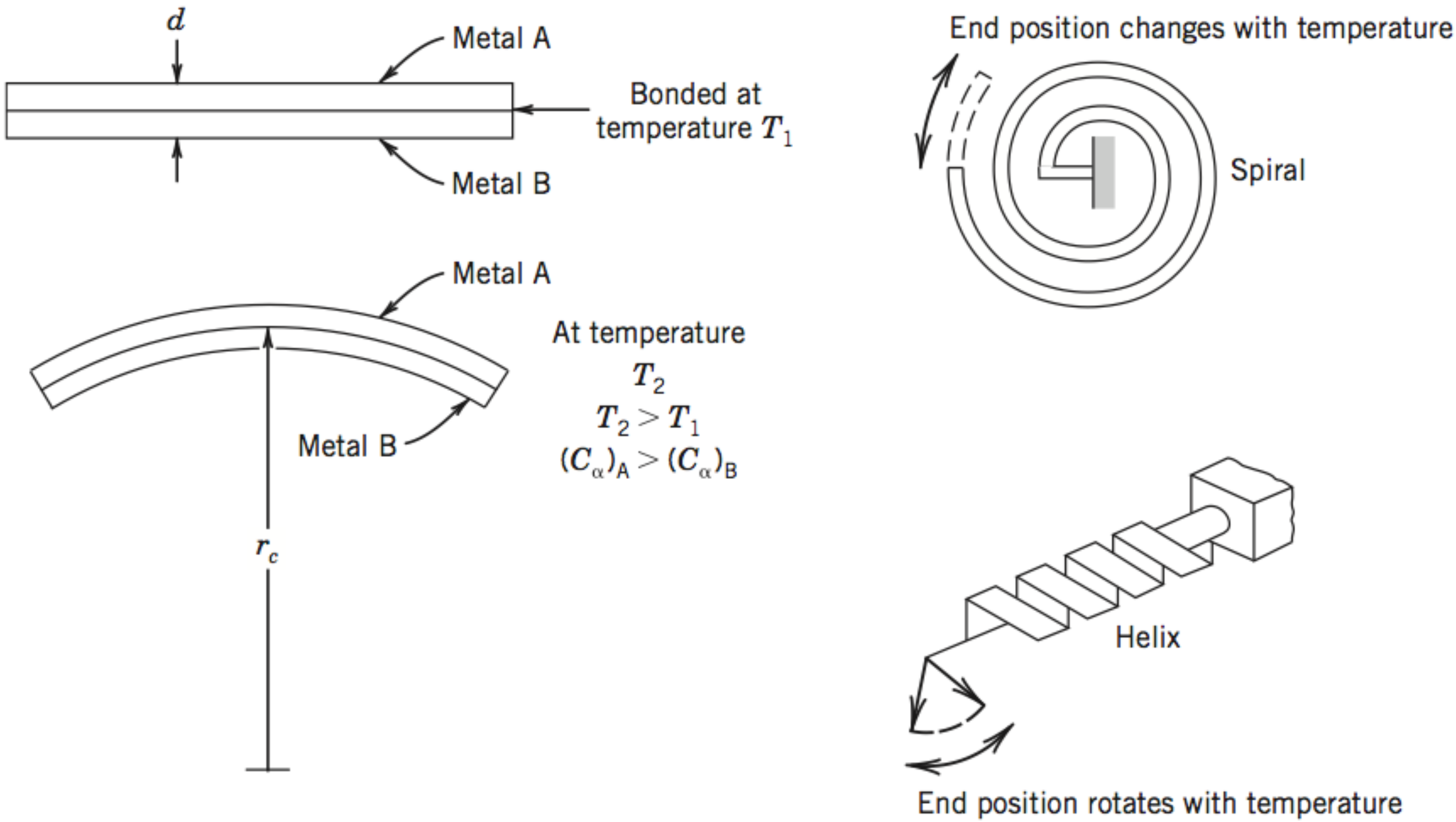


Figure 8.3 Expansion thermometry using bimetallic materials: strip, spiral, and helix forms.

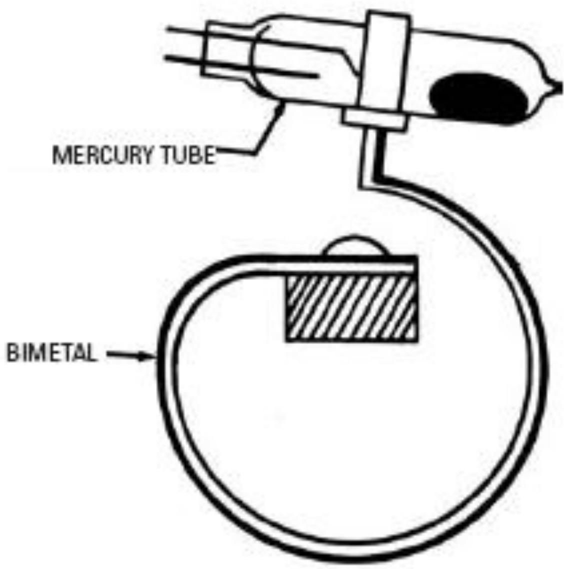


Figure 4-8 Mercury tube switch method in a two-wire thermostat. *(Courtesy Coleman Co., Inc.)*

Why wouldn't we want mercury in our control systems?

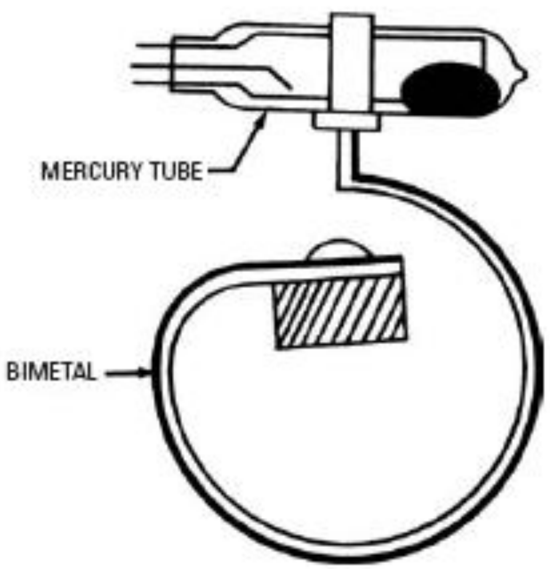
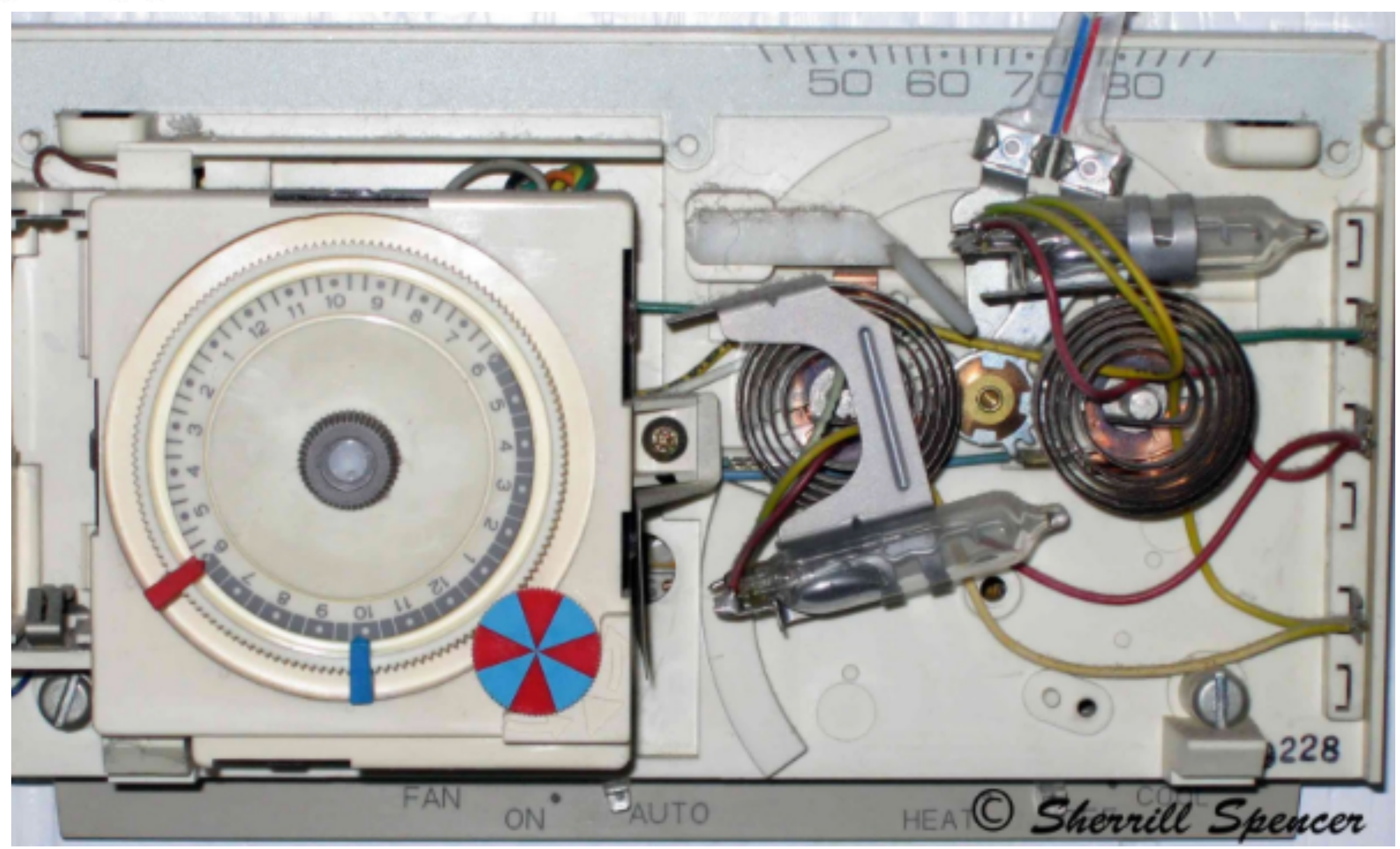


Figure 4-9 Mercury tube switch method in a three-wire thermostat. *(Courtesy Coleman Co., Inc.)*



Analog IC Sensors

Can be used in pure analog control applications

- Typically rely on temperature sensitivity of integrated circuit components
- Transistors of different sizes for TMP 36

TMP35/TMP36/TMP37 Data Sheet

FUNCTIONAL DESCRIPTION

An equivalent circuit for the TMP3x family of micropower, centigrade temperature sensors is shown in Figure 22. The core of the temperature sensor is a band gap core that comprises transistors Q1 and Q2, biased by Q3 to approximately 8 μA. The band gap core operates both Q1 and Q2 at the same collector current level; however, because the emitter area of Q1 is 10 times that of Q2, the V_{BE} of Q1 and the V_{BE} of Q2 are not equal by the following relationship:

$$\Delta V_{BE} = V_T \times \ln\left(\frac{A_{E,Q1}}{A_{E,Q2}}\right)$$

Resistors R1 and R2 are used to scale this result to produce the output voltage transfer characteristic of each temperature sensor and, simultaneously, R2 and R3 are used to scale the V_{BE} of Q1 as an offset term in V_{OUT}. Table 4 summarizes the differences in the output characteristics of the three temperature sensors.

The output voltage of the temperature sensor is available at the emitter of Q4, which buffers the band gap core and provides load current drive. The current gain of Q4, working with the available base current drive from the previous stage, sets the short-circuit current limit of these devices to 250 μA.

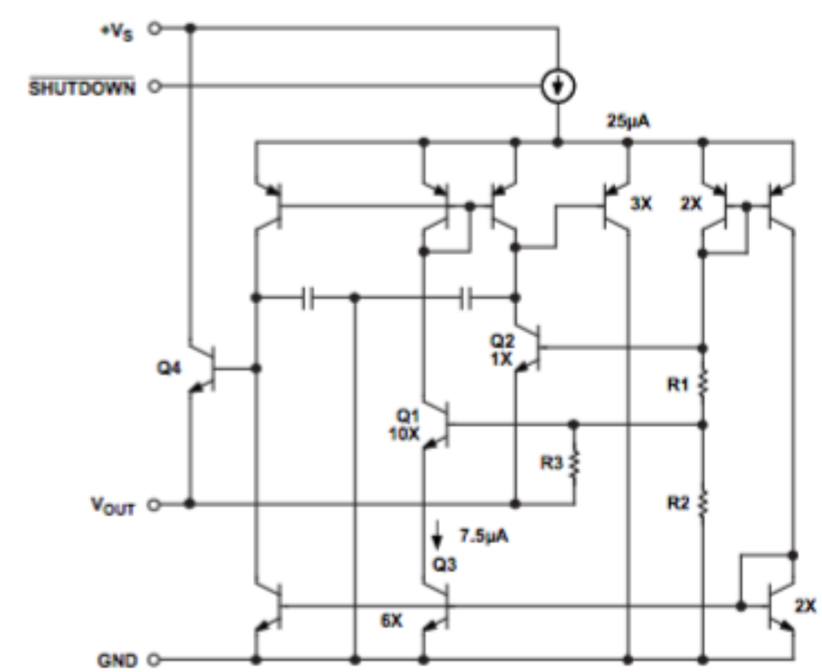


Figure 22. Temperature Sensor Simplified Equivalent Circuit

Table 4. TMP3x Output Characteristics

Sensor	Offset Voltage (V)	Output Voltage Scaling (mV/°C)	Output Voltage at 25°C (mV)
TMP35	0	10	250
TMP36	0.5	10	750
TMP37	0	20	500

TMP36 about $1.50 in quantity 1

Low Voltage Temperature Sensors

Data Sheet **TMP35/TMP36/TMP37**

FEATURES

Low voltage operation (2.7 V to 5.5 V)
Calibrated directly in °C
10 mV/°C scale factor (20 mV/°C on TMP37)
±2°C accuracy over temperature (typ)
±0.5°C linearity (typ)
Stable with large capacitive loads
Specified −40°C to +125°C, operation to +150°C
Less than 50 μA quiescent current

FUNCTIONAL BLOCK DIAGRAM

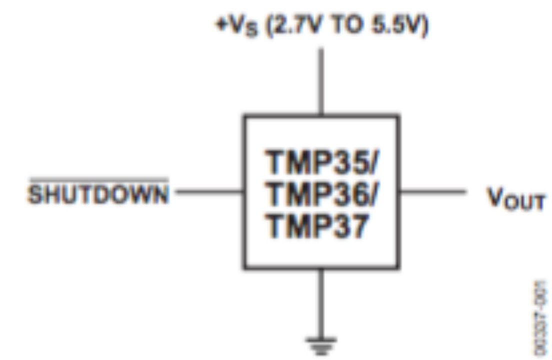


Figure 1.

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.

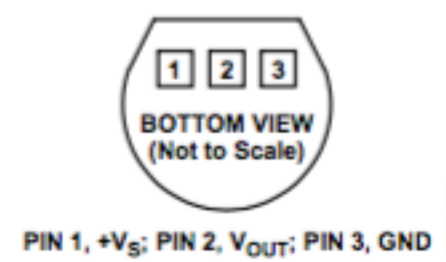


Figure 4. T-3 (TO-92)

D00337-0-11/13(G)

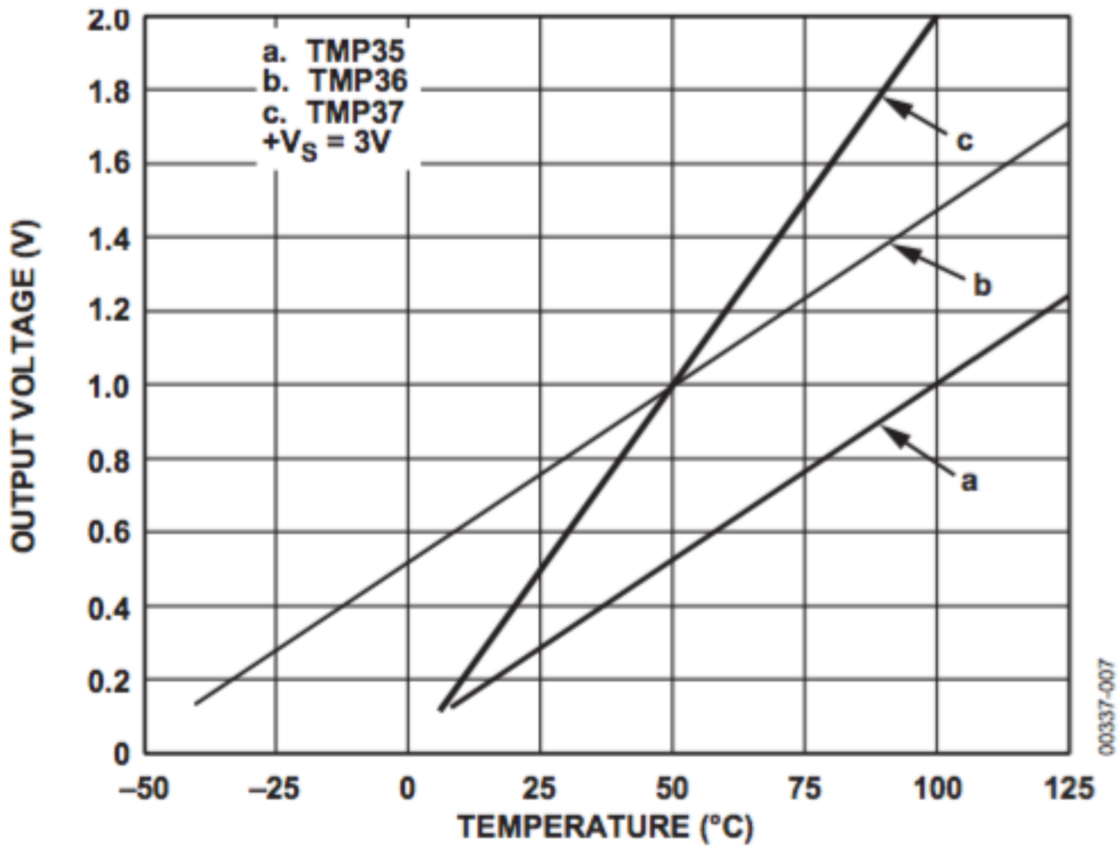


Figure 6. Output Voltage vs. Temperature

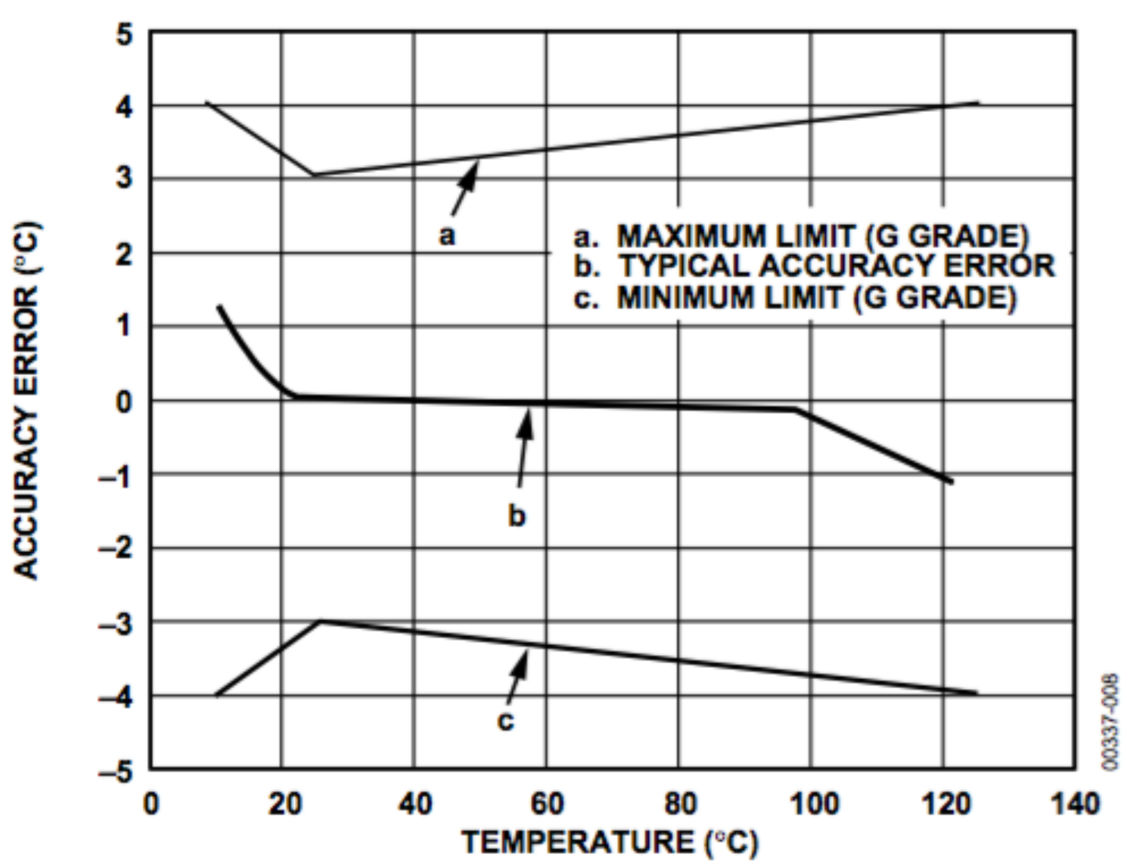


Figure 7. Accuracy Error vs. Temperature

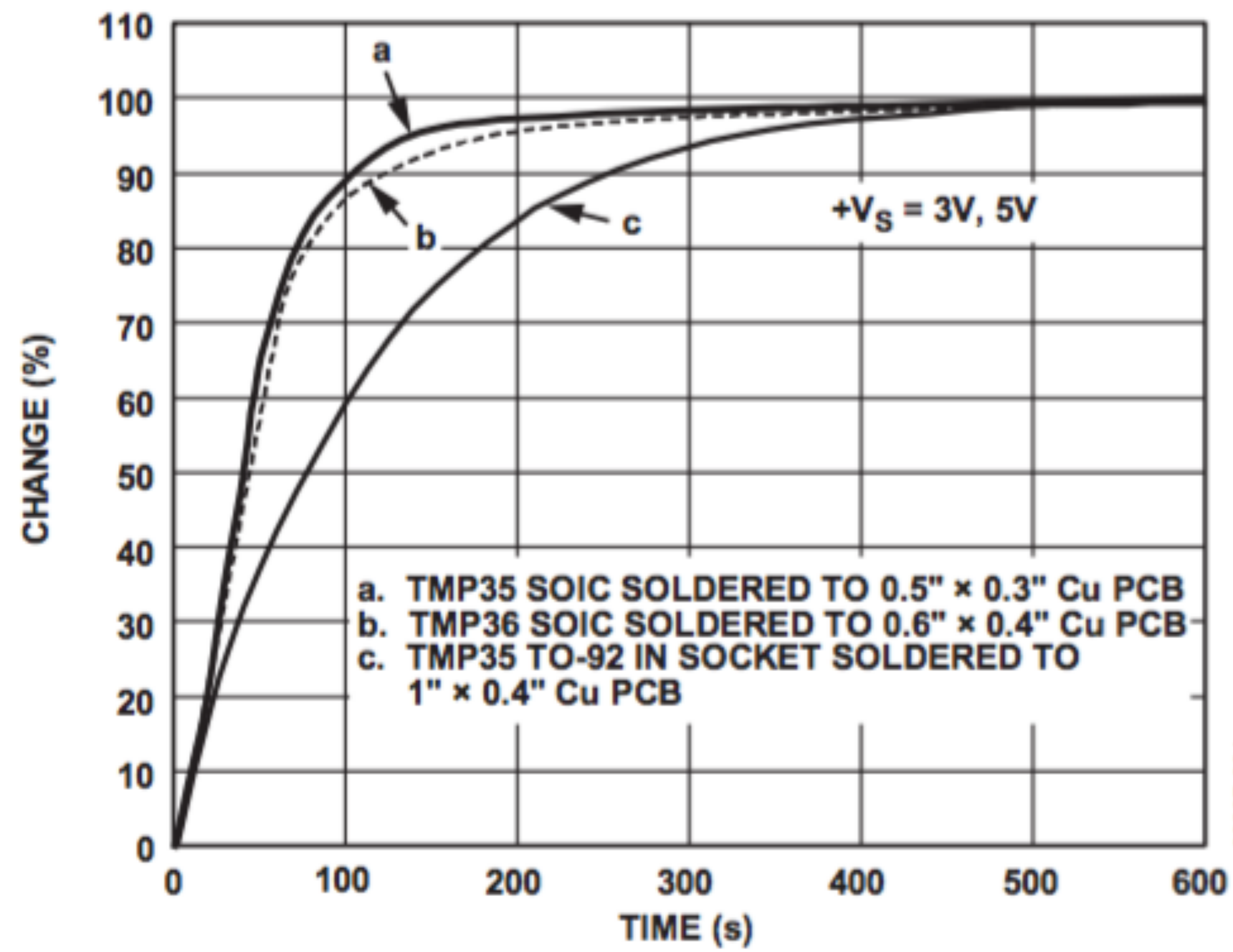


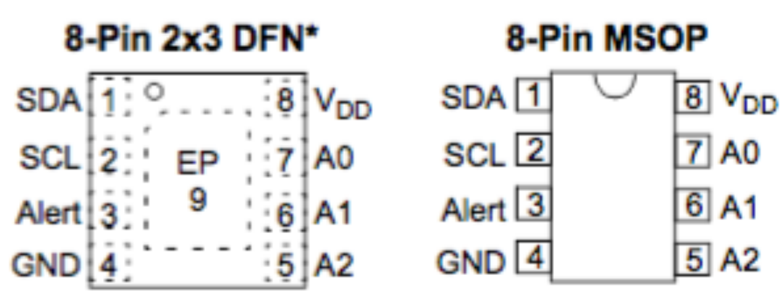
Figure 17. Thermal Response Time in Still Air

Digital IC Sensor

- Adds computational ability to communicate digitally

This sensor has an industry standard 400 kHz, 2-wire, SMBus/I^{2}C compatible serial interface, allowing up to eight or sixteen sensors to be controlled with a single serial bus (see Table 3-2 for available Address codes). These features make the MCP9808 ideal for sophisticated, multi-zone, temperature-monitoring applications.

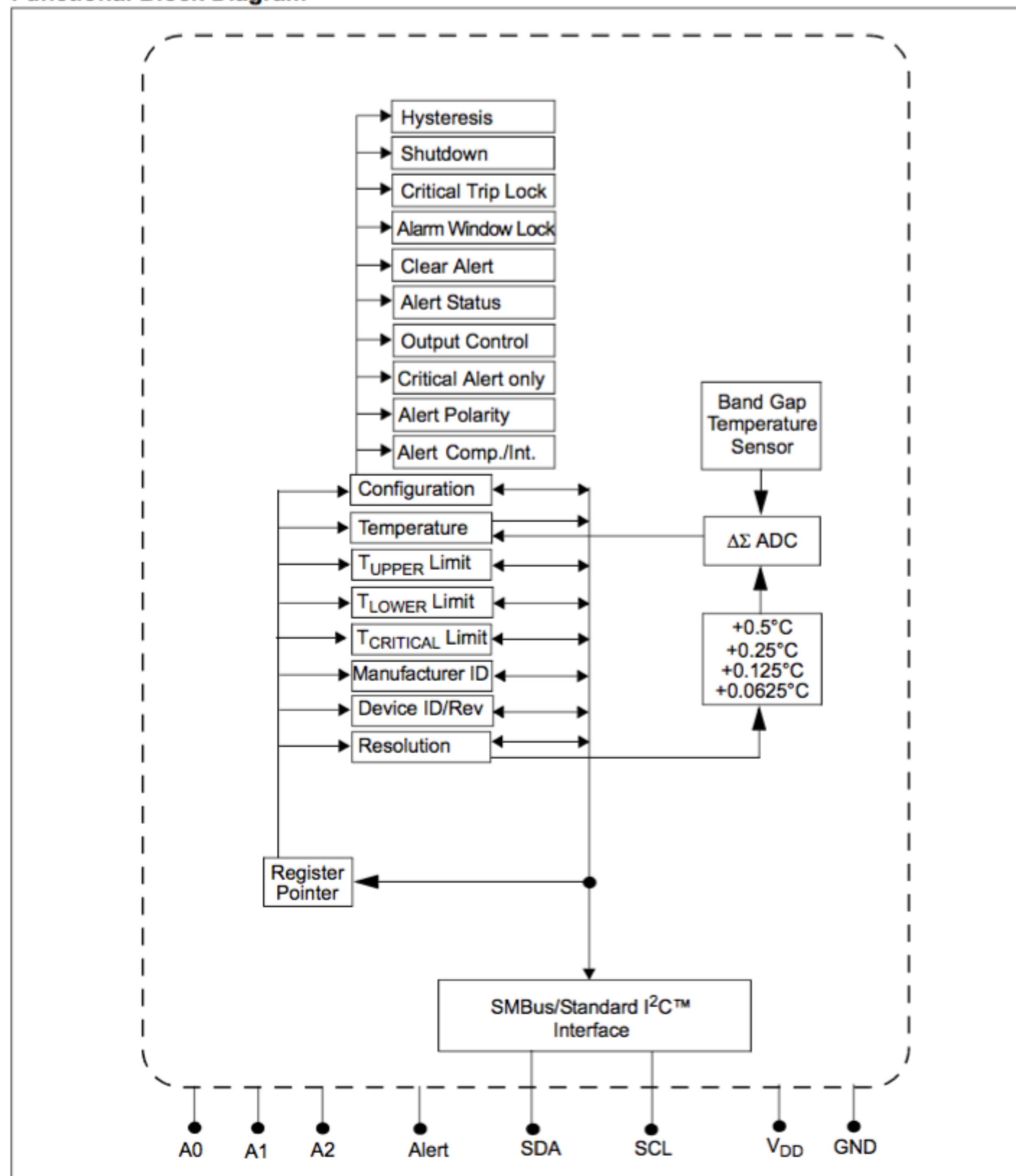
Package Types



* Includes Exposed Thermal Pad (EP); see Table 3-1.

MCP9808

Functional Block Diagram



About $1 in quantity 1

MCP9808

±0.5°C Maximum Accuracy Digital Temperature Sensor

Features

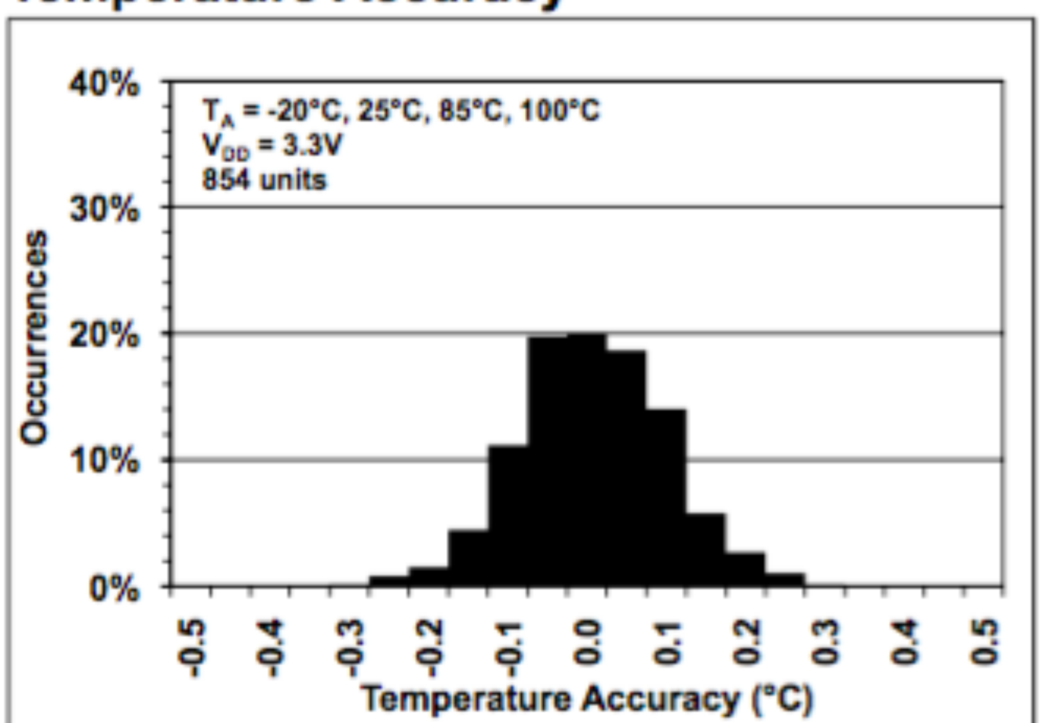
- Accuracy:
  - ±0.25 (typical) from -40°C to +125°C
  - ±0.5°C (maximum) from -20°C to 100°C
  - ±1°C (maximum) from -40°C to +125°C
- User-Selectable Measurement Resolution:
  - +0.5°C, +0.25°C, +0.125°C, +0.0625°C

Description

Microchip Technology Inc.'s MCP9808 digital temperature sensor converts temperatures between -20°C and +100°C to a digital word with ±0.25°C/±0.5°C (typical/maximum) accuracy.

The MCP9808 comes with user-programmable registers that provide flexibility for temperature sensing

Temperature Accuracy



Analog Temperature Transducers

- Changes in resistance or voltage require additional electric circuits to make a machine readable signal
- Changes in other conditions (e.g. strain) may also change resistance/voltage
- Long analog cable runs are vulnerable to noise!

Materials used in Resistance Sensors

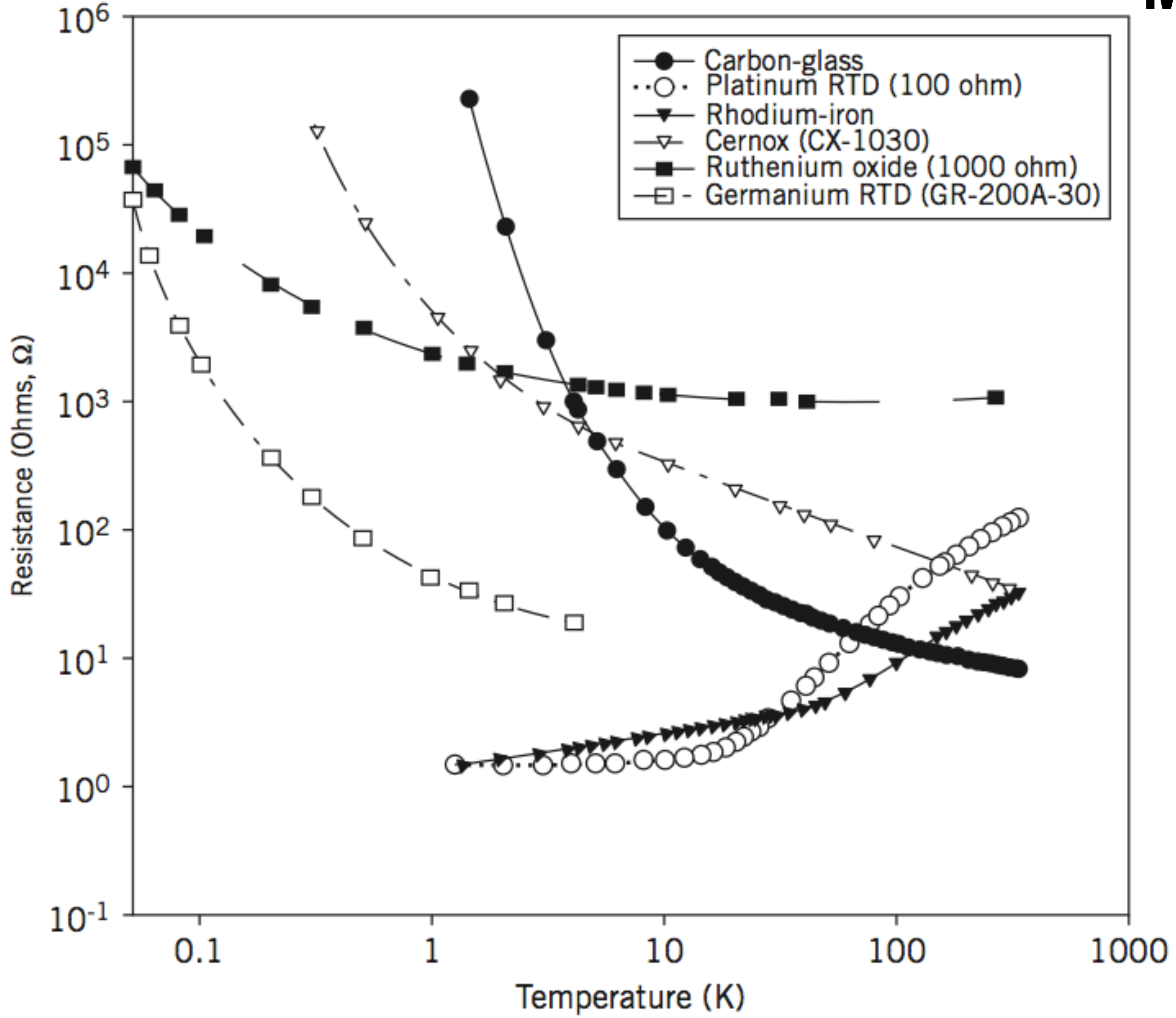


Figure 8.4 Resistance as a function of temperature for selected materials used as temperature sensors. (Adapted from Yeager, C. J., and S. S. Courts, A Review of Cryogenic Thermometry and Common Temperature Sensors, *IEEE Sensors Journal*, 1(4), 2001.)

Thermistors

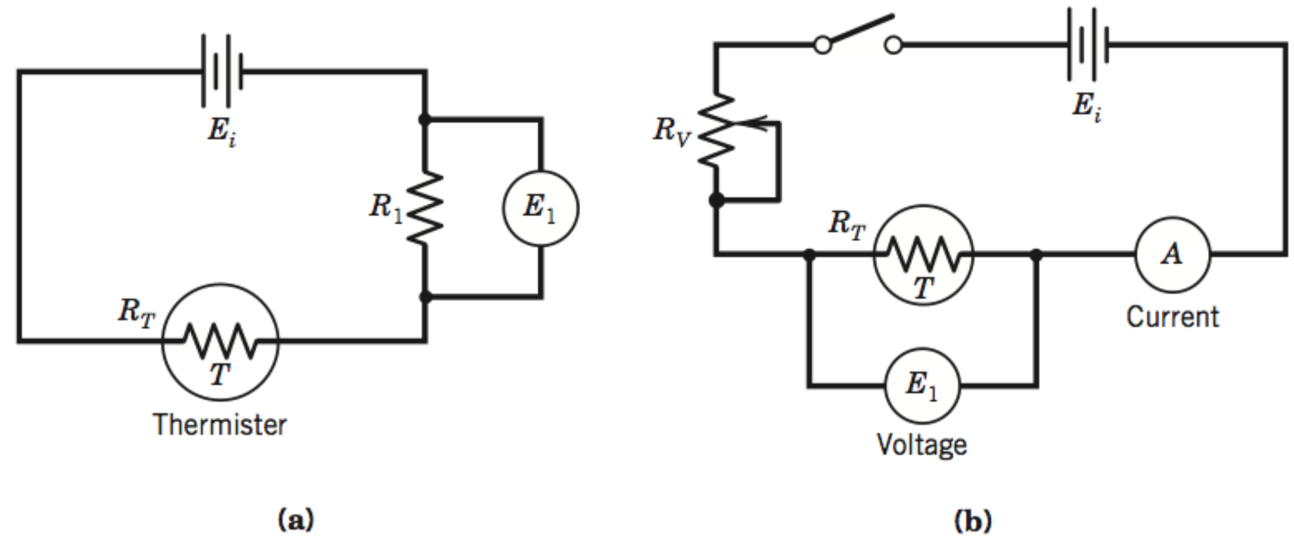
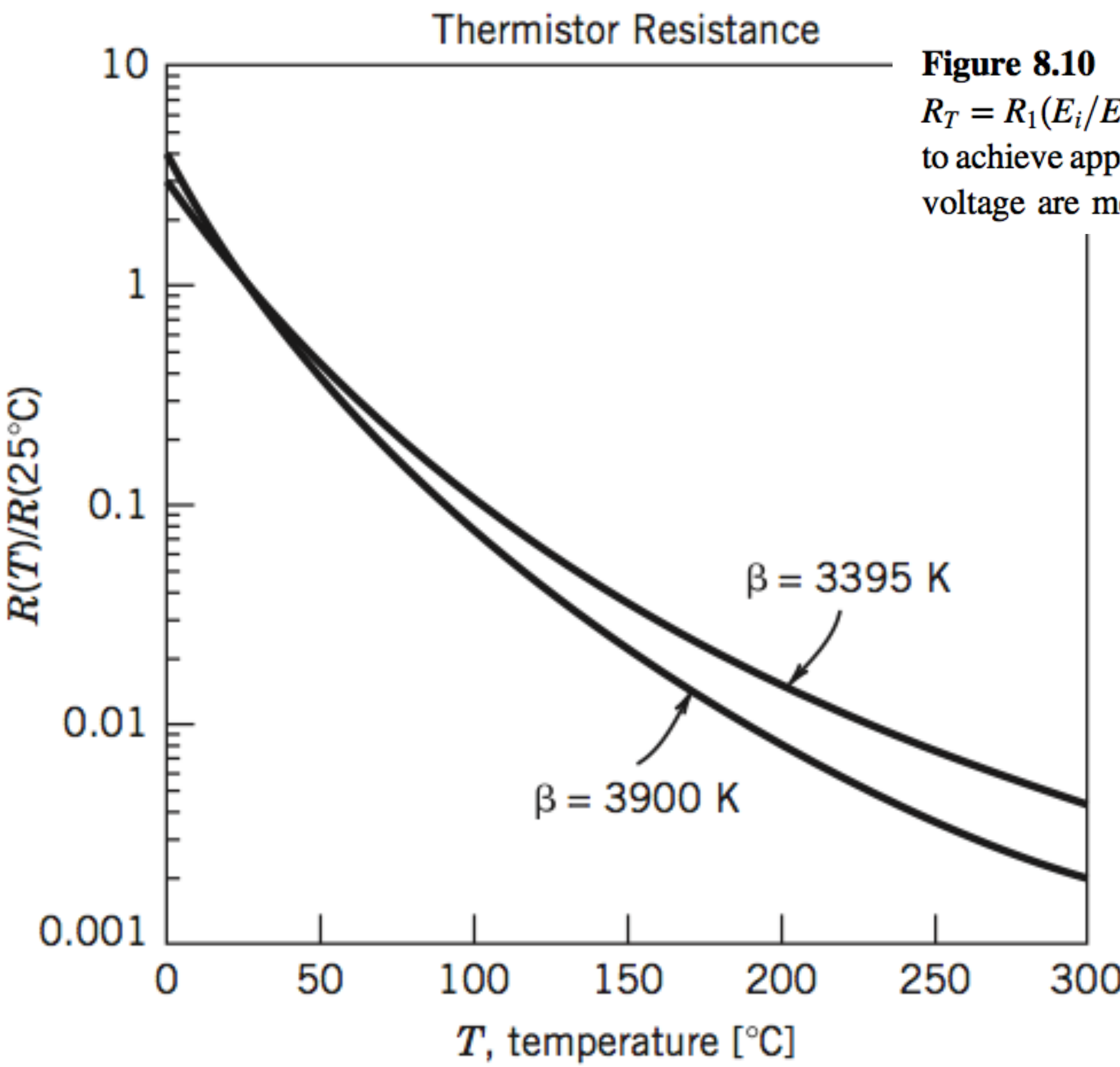
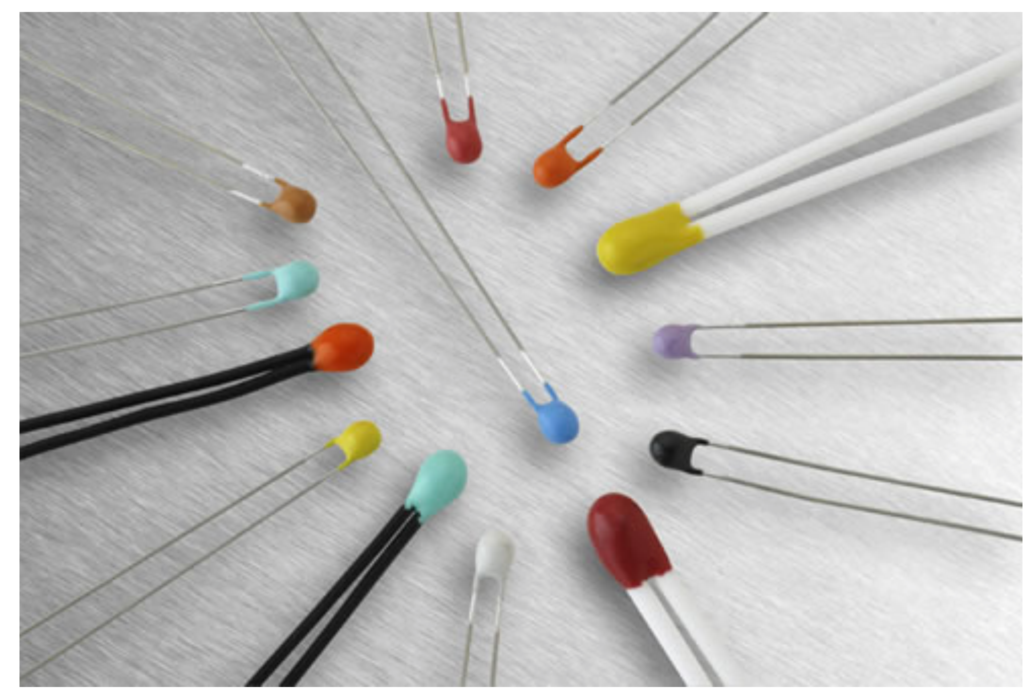


Figure 8.10 Circuits for determining β for thermistors. **(a)** Voltage divider method: $R_T = R_1(E_i/E_1 - 1)$. Note: Both R_1 and E_i must be known values. The value of R_1 may be varied to achieve appropriate values of thermistor current. **(b)** Volt-ammeter method. Note: Both current and voltage are measured.





ussensor.com

Figure 8.9 Representative thermistor resistance variations with temperature.

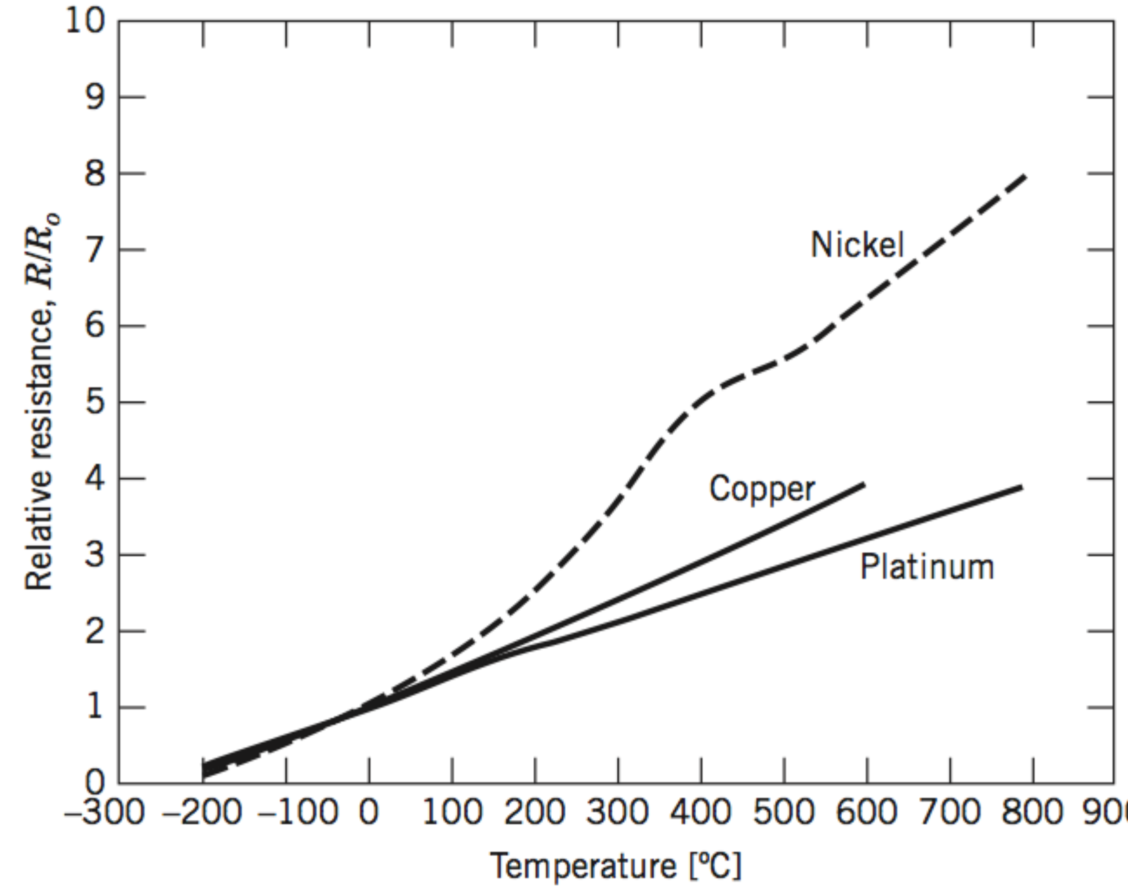
Sealed Metal Platinum RTD Capsules

Model Numbers:
- 29258
- 29259
- 29260

Ready-to-use Platinum RTD capsules are sealed in stainless steel. These capsules can outperform traditional more costly RTD assemblies over the –50°C to +232°C temperature range. Standard sheath diameters are completely sealed and ready to use. The void free construction assures fast response. The leadwire is stranded nickel-plated copper with TFE Teflon® insulation. These all-purpose capsules are especially suitable for wet or shallow immersion applications.

rdfcorp.com

Traditional Platinum Wire RTD



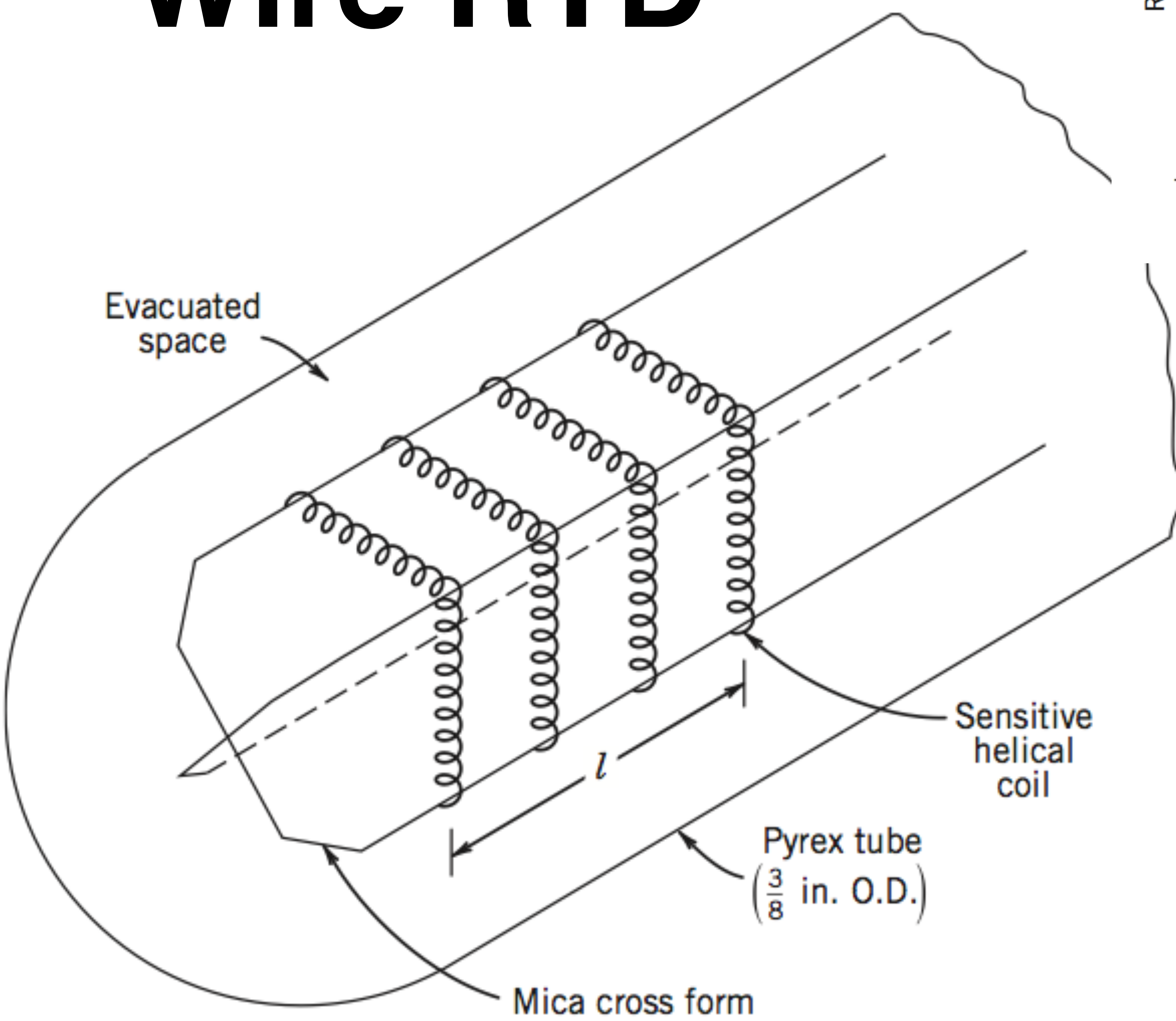


Figure 8.5 Construction of a platinum RTD. (From Benedict, R. P., *Fundamentals of Temperature, Pressure, and Flow Measurements*, 3rd ed. Copyright © 1984 by John Wiley and Sons, New York.)

Thermocouples

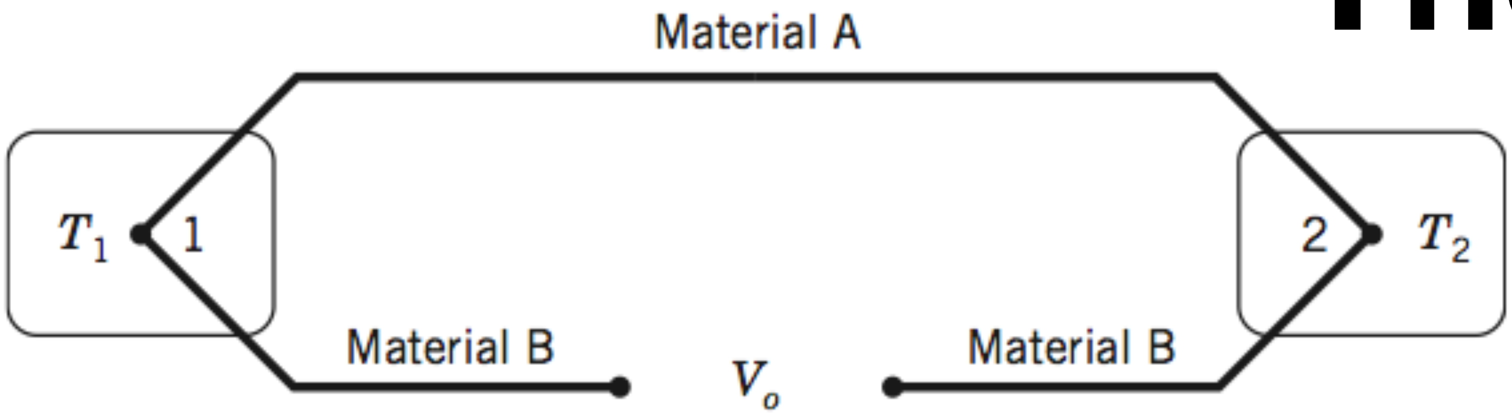


Figure 8.13 Basic thermocouple circuit.

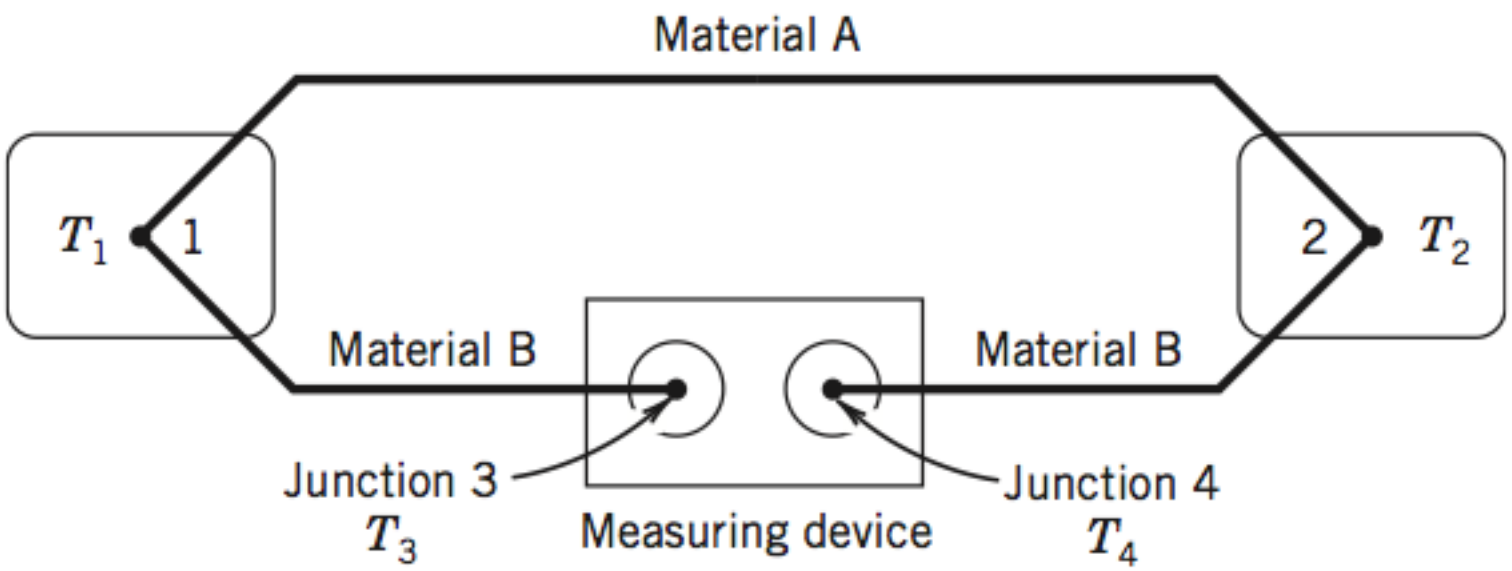
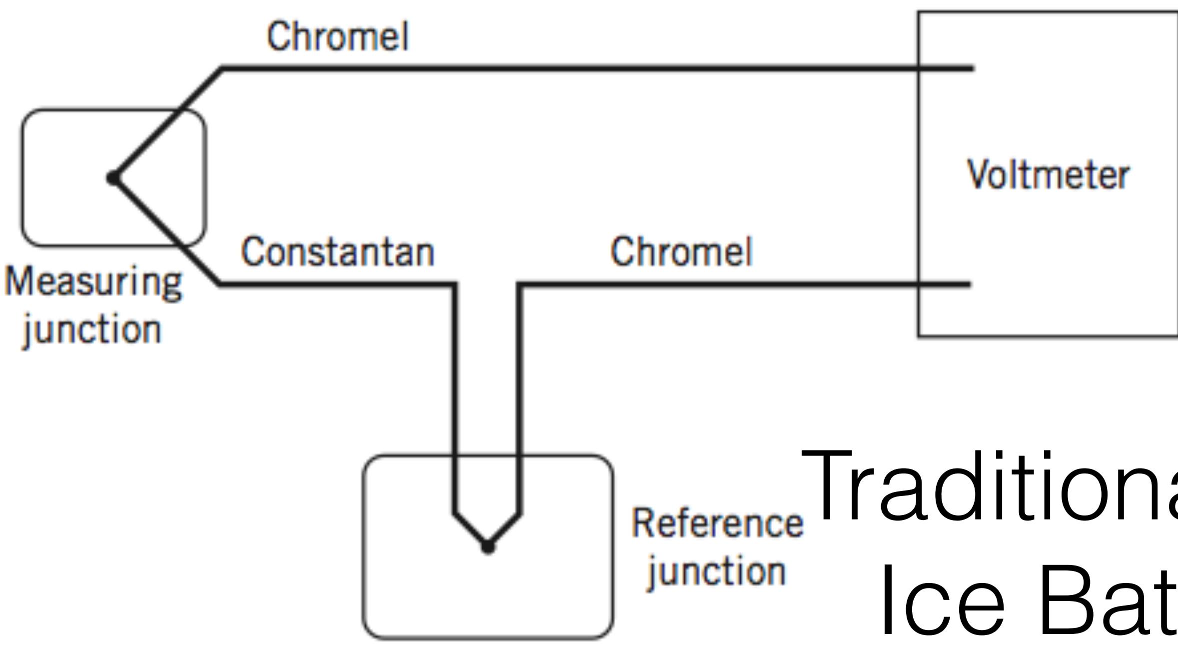


Figure 8.16 Typical thermocouple measuring circuit.

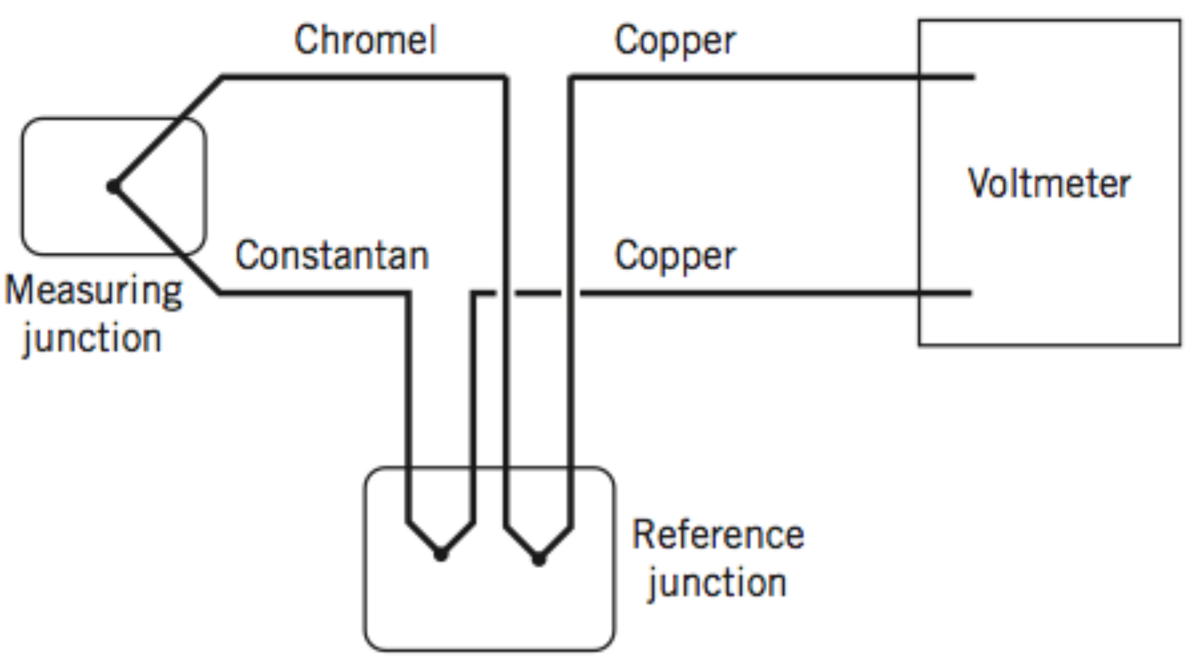
If T1 = T2 then the voltage will be zero, otherwise it will simply be small and hard to measure

Cold Junction Compensation



(a)

Traditionally Ice Bath



(b)

More likely to be a data acquisition system or microcontroller, with another temperature transducer to monitor the temperature of the reference junction

$$V_{meter} = V_m - V_r$$

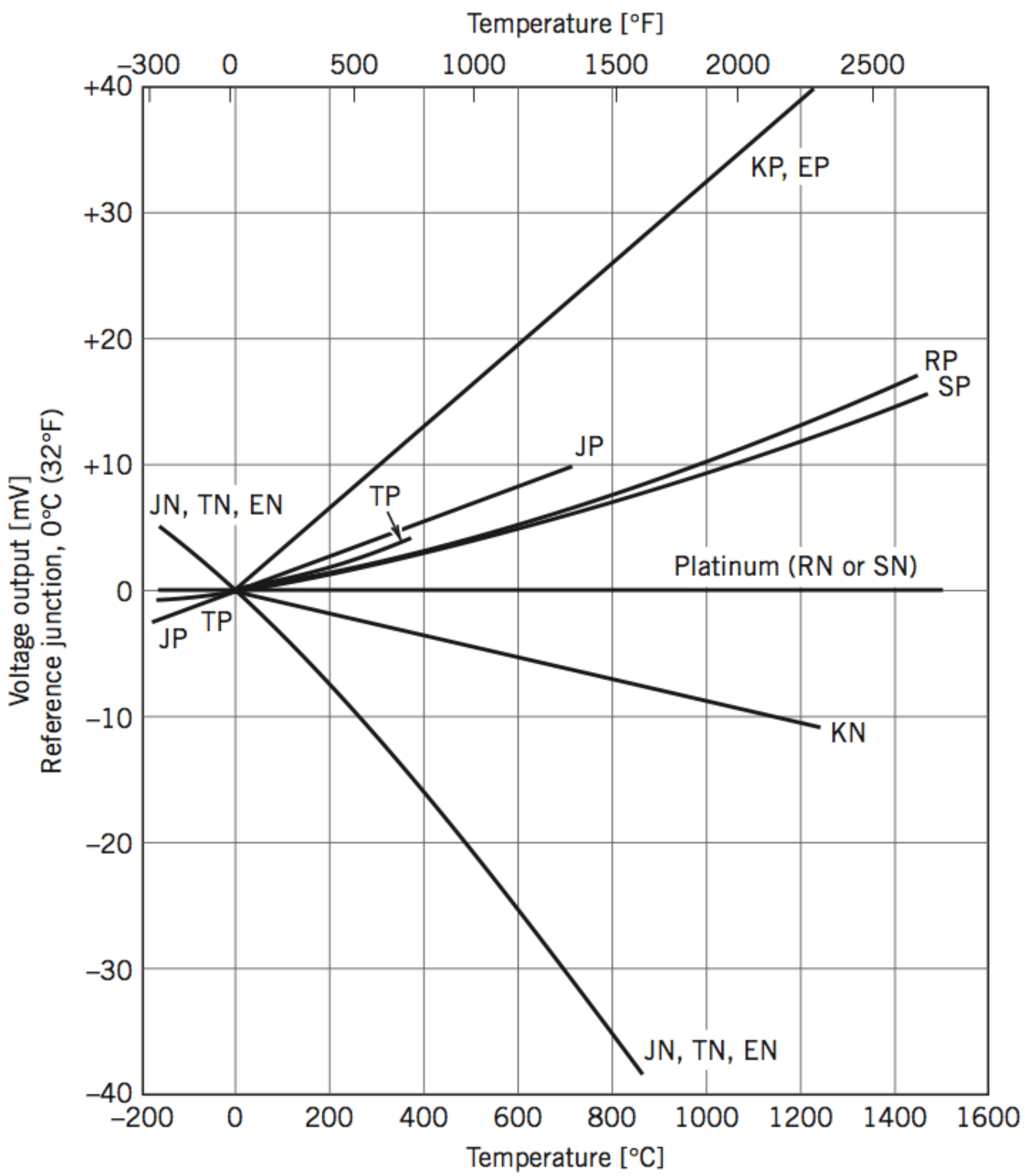
$$V_{meter} + V_r = V_m$$

add the reference voltage to the meter voltage and go into the tables or curve fit to get the corresponding temperature

Figure 8.17 Thermocouple temperature measurement circuits.

Table 8.4 Thermocouple Designations

	Material Combination		
Type	Positive	Negative	Applications
E	Chromel(+)	Constantan(−)	Highest sensitivity (<1,000 °C)
J	Iron(+)	Constantan(−)	Nonoxidizing environment (<760 °C)
K	Chromel(+)	Alumel(−)	High temperature (<1,372 °C)
S	Platinum/10% rhodium	Platinum(−)	Long-term stability high temperature (<1,768 °C)
T	Copper(+)	Constantan(−)	Reducing or vacuum environments (<400 °C)



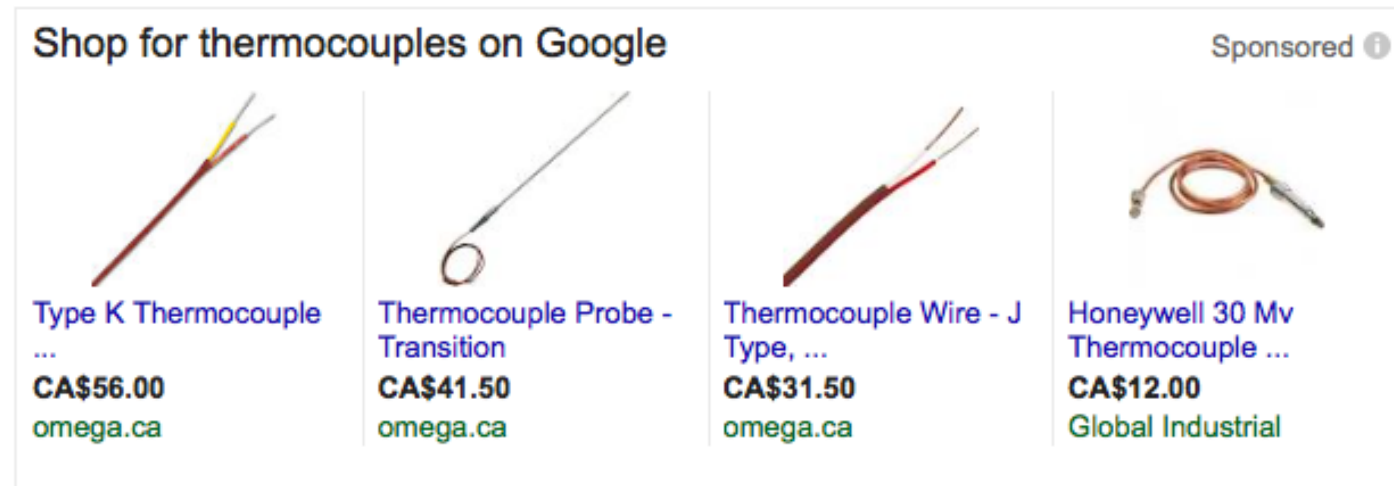
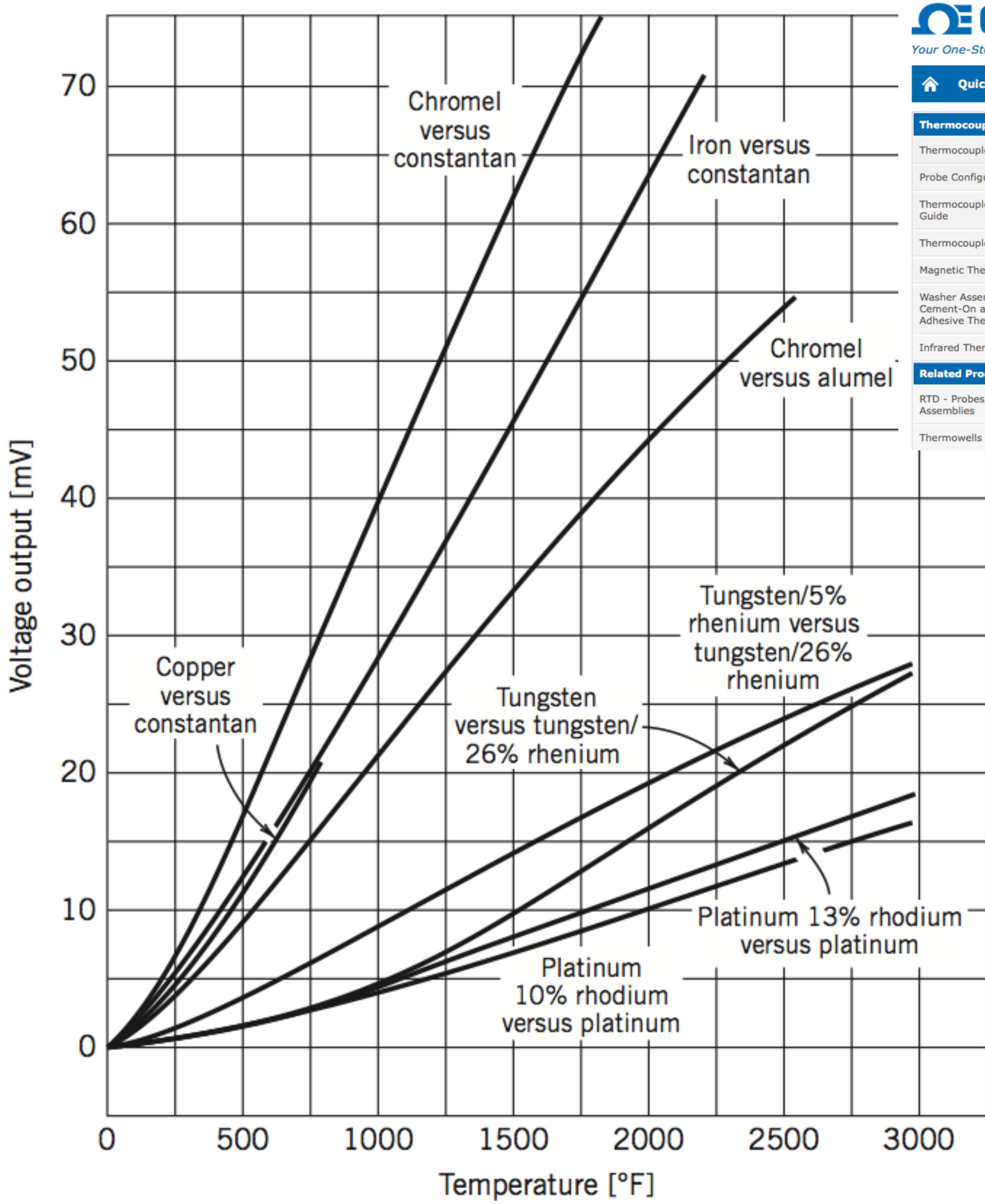
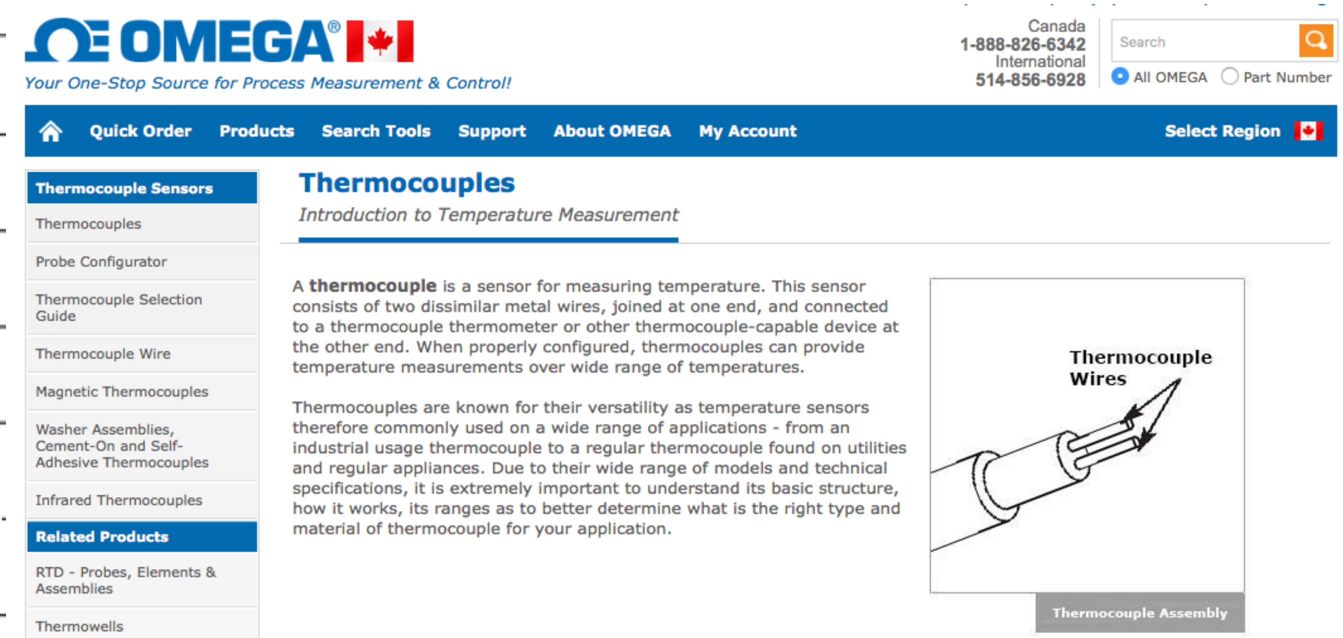


Figure 8.19 Thermal voltage of thermocouple materials relative to platinum-67. Note: For example, JP indicates the positive leg of a J thermocouple, or iron. JN indicates the negative leg of a J thermocouple, or constantan. All other notations are similar for each type of thermocouple. (Adapted from Benedict, R. P., *Fundamentals of Temperature, Pressure, and Flow Measurements*, 3rd ed. Copyright © 1984 by John Wiley and Sons, New York. Reprinted by permission.)





omega.ca

Platinum, tungsten, rhodium, rhenium are not cheap or common metals, but they can stand high temperatures

Figure 8.20 Thermocouple voltage output as a function of temperature for some common thermocouple materials. Reference junction is at 32 °F (0 °C). (Adapted from Benedict, R. P., *Fundamentals of Temperature, Pressure and Flow Measurements*, 3rd ed. Copyright © 1984 by John Wiley and Sons, New York. Reprinted by permission.)

MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
– 328 to 2282°F
– 200 to 1250°C
Extension Grade
32 to 392°F
0 to 200°C
LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
Special: 1.1°C or 0.4%
COMMENTS, BARE WIRE ENVIRONMENT:
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermocouple Grade

Nickel-Chromium vs. Nickel-Aluminum

Extension Grade

Revised Thermocouple Reference Tables

TYPE K

Reference Tables N.I.S.T. Monograph 175 Revised to ITS-90

Z

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-260
-250	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-250
-240	-6.404	-6.399	-6.393	-6.388	-6.382	-6.377	-6.370	-6.364	-6.358	-6.351	-6.344	-240
-230	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-230
-220	-6.262	-6.252	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-220
-210	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-210
-200	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-200
-190	-5.891	-5.876	-5.861	-5.845	-5.829	-5.813	-5.797	-5.780	-5.763	-5.747	-5.730	-190
-180	-5.730	-5.713	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.588	-5.569	-5.550	-180
-170	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.435	-5.415	-5.395	-5.374	-5.354	-170
-160	-5.354	-5.333	-5.313	-5.292	-5.271	-5.250	-5.228	-5.207	-5.185	-5.163	-5.141	-160
-150	-5.141	-5.119	-5.097	-5.074	-5.052	-5.029	-5.006	-4.983	-4.960	-4.936	-4.913	-150

°C	0	1	2	3	4	5	6	7	8	9	10	°C
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390

omega.ca

Table 8.7 Reference Functions for Selected Letter Designated Thermocouples

The relationship between voltage and temperature is provided in the form of a polynomial in temperature [9]

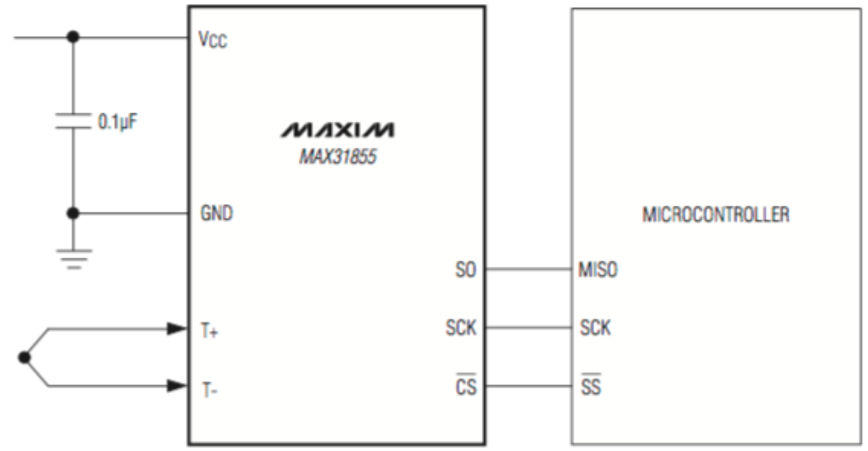
$$E = \sum_{i=0}^{n} c_i T^i$$

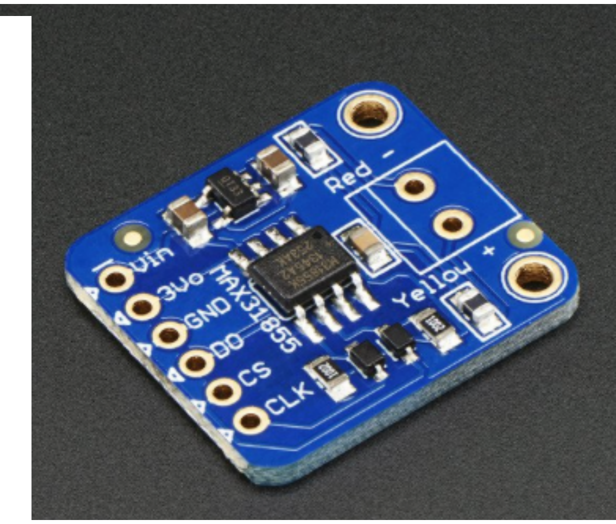
where E is in μV and T is in °C. Constants are provided below.

Thermocouple Type	Temperature Range	Constants
J-type	−210 to 760 °C	$c_0 = 0.000\,000\,000\,0$ $c_1 = 5.038\,118\,7815 \times 10^{1}$ $c_2 = 3.047\,583\,693\,0 \times 10^{-2}$ $c_3 = -8.568\,106\,572\,0 \times 10^{-5}$ $c_4 = 1.322\,819\,529\,5 \times 10^{-7}$ $c_5 = -1.705\,295\,833\,7 \times 10^{-10}$ $c_6 = 2.094\,809\,069\,7 \times 10^{-13}$ $c_7 = -1.253\,839\,533\,6 \times 10^{-16}$ $c_8 = 1.563\,172\,569\,7 \times 10^{-20}$

9. Burns, G. W., M. G. Scroger, and G. F. Strouse, Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90, *NIST Monograph* 175, April 1993 (supersedes NBS Monograph 125).

Thermocouples made easy





MAXIM
INNOVATION DELIVERED®

19-5793; Rev 2; 2/12

about $5 in quantity 1

MAX31855

Cold-Junction Compensated Thermocouple-to-Digital Converter

General Description

The MAX31855 performs cold-junction compensation and digitizes the signal from a K-, J-, N-, T-, S-, R-, or E-type thermocouple. The data is output in a signed 14-bit, SPI-compatible, read-only format. This converter resolves temperatures to 0.25°C, allows readings as high as +1800°C and as low as -270°C, and exhibits thermocouple accuracy of ±2°C for temperatures ranging from -200°C to +700°C for K-type thermocouples. For full range accuracies and other thermocouple types, see the *Thermal Characteristics* specifications.

Features

- **Cold-Junction Compensation**
- **14-Bit, 0.25°C Resolution**
- **Versions Available for K-, J-, N-, T-, S-, R-, and E-Type Thermocouples (see Table 1)**
- **Simple SPI-Compatible Interface (Read-Only)**
- **Detects Thermocouple Shorts to GND or V_{CC}**
- **Detects Open Thermocouple**

Choosing Temperature Sensors

- IC sensors are cheap, easy to implement, not so rugged, limited temperature range
- Thermistors are cheap, non-linear, have a large resistance change, go to higher temperatures
- Platinum RTDs are expensive, but high accuracy if you are careful to measure the very small resistance changes
- Thermocouples are cheap, low voltage, need cold junction compensation, but can be very small, and thus much faster responding, go up to flame temperatures