EE 4BD4 Lecture 13

Temperature Measurement

Temperature Measurements

- Internal body thermometer
  - Range 30 → 42 ^{O}C, Accuracy 0.1 ^{O}C
- Surface body thermometer
  - Range 10 → 45 ^{O}C, Accuracy 1.0 ^{O}C
- Should biomedical engineers only focus on sensors suitable for these ranges? NO
- A biomedical engineer may have to design instrumentation or equipment that requires temperature regulation outside these ranges

Temperature measurements

- Resistance Temperature Detectors
- Semiconductor Temperature Sensors
- Thermocouples
- Thermistor

TYPES OF TEMPERATURE SENSORS

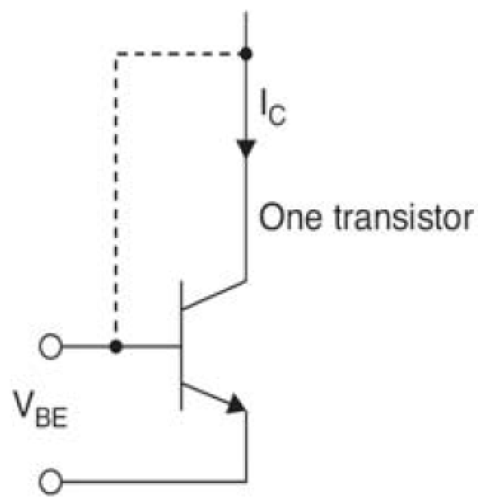
THERMOCOUPLE	RTD	THERMISTOR	SEMICONDUCTOR
Widest Range: –184°C to +2300°C	Range: –200°C to +850°C	Range: 0°C to +100°C	Range: –55°C to +150°C
High Accuracy and Repeatability	Fair Linearity	Poor Linearity	Linearity: 1°C Accuracy: 1°C
Needs Cold Junction Compensation	Requires Excitation	Requires Excitation	Requires Excitation
Low-Voltage Output	Low Cost	High Sensitivity	10mV/K, 20mV/K, or 1μA/K Typical Output

Semiconductor Sensors

All semiconductor temperature sensors make use of the relationship between a bipolar junction transistor's (BJT) base-emitter voltage to its collector current:

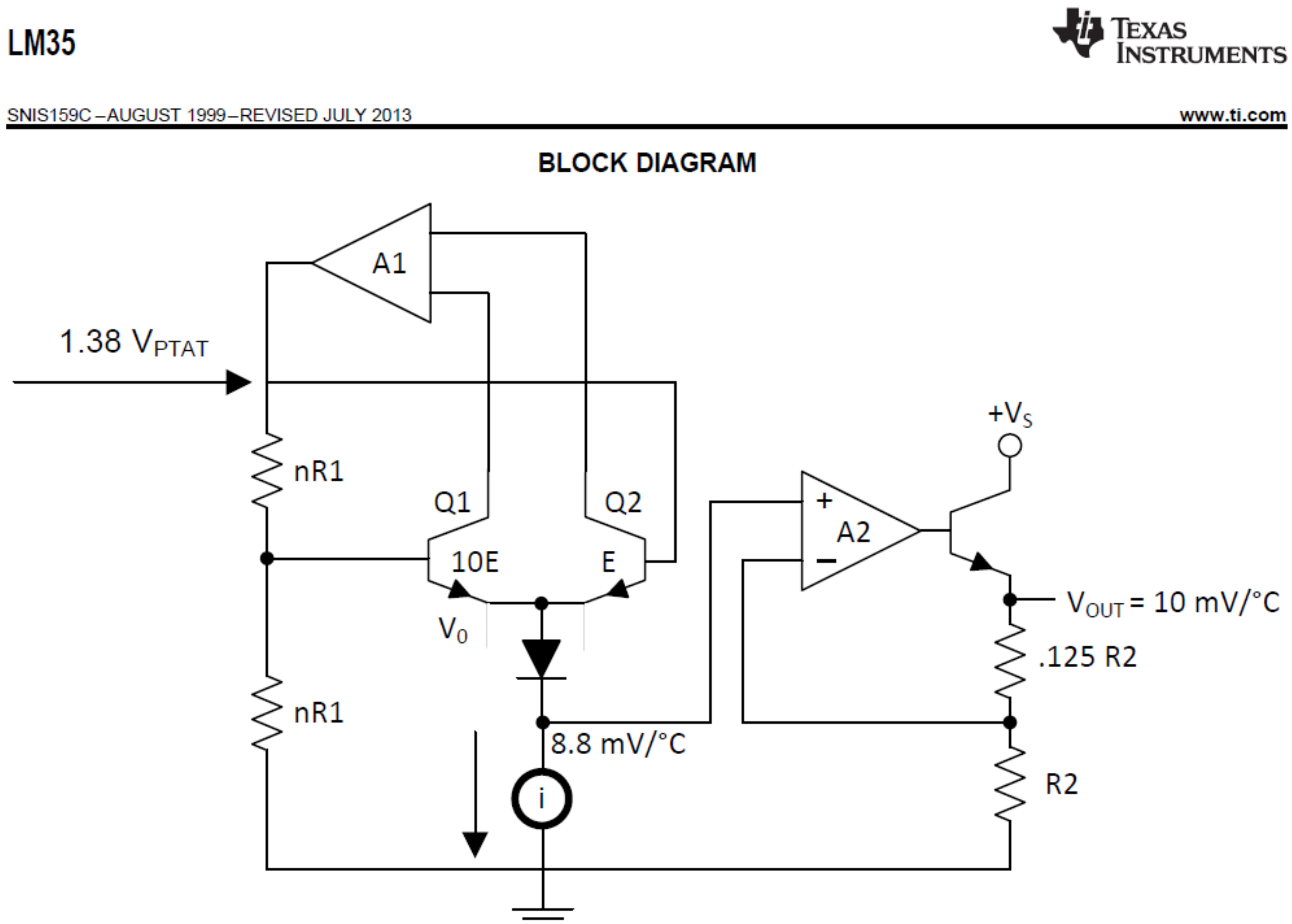
$$V_{BE} = \frac{kT}{q} \ln\left(\frac{I_C}{I_S}\right)$$

where k is Boltzmann's constant, T is the absolute temperature, q is the charge of an electron, and I_S is a current related to the geometry and the temperature of the transistors. (The equation assumes a voltage of at least a few hundred mV on the collector, and ignores Early effects.)



$$V_{BE} = \frac{kT}{q} \ln\left(\frac{I_C}{I_S}\right)$$

Semiconductor Sensor



FEATURES

- Calibrated Directly in ° Celsius (Centigrade)
- Linear + 10 mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at +25°C)
- Rated for Full −55°C to +150°C Range
- Suitable for Remote Applications
- Low Cost Due to Wafer-Level Trimming
- Operates from 4 to 30 V
- Less than 60-μA Current Drain
- Low Self-Heating, 0.08°C in Still Air
- Nonlinearity Only ±¼°C Typical
- Low Impedance Output, 0.1 W for 1 mA Load

Application Circuit

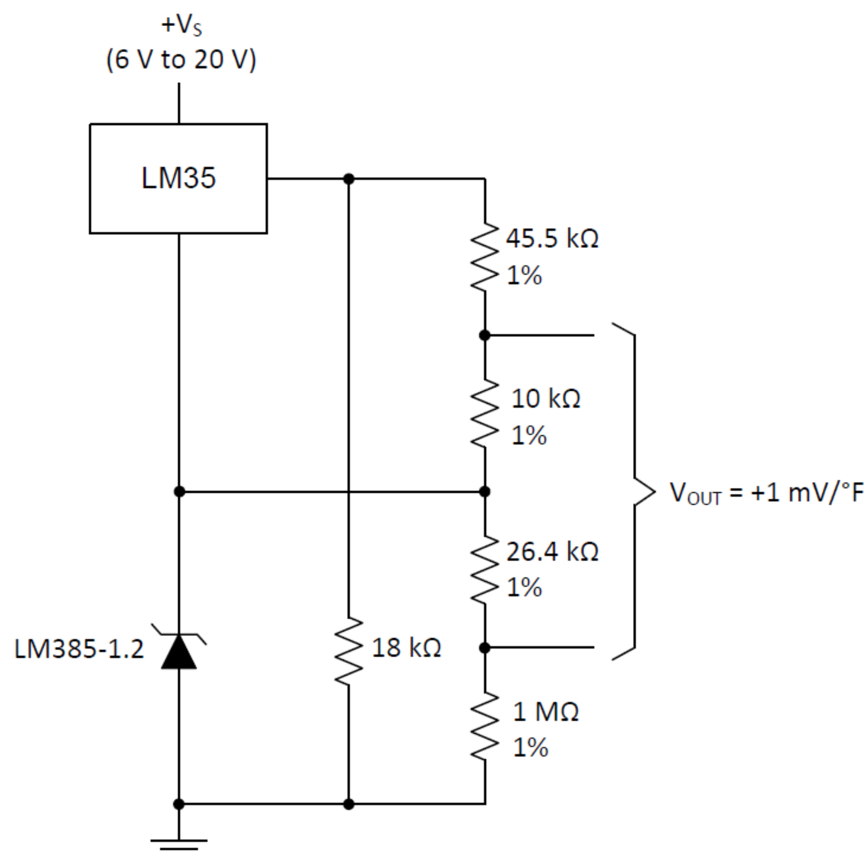


Figure 21. Fahrenheit Thermometer

Simplest Circuit

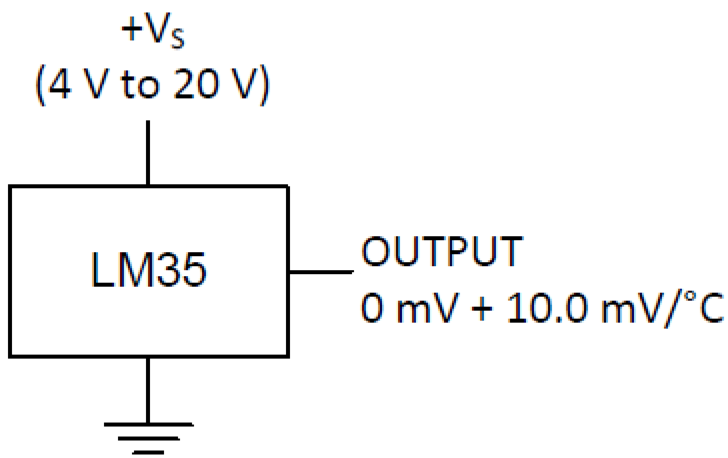


Figure 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)

Temperature measurements Thermocouples

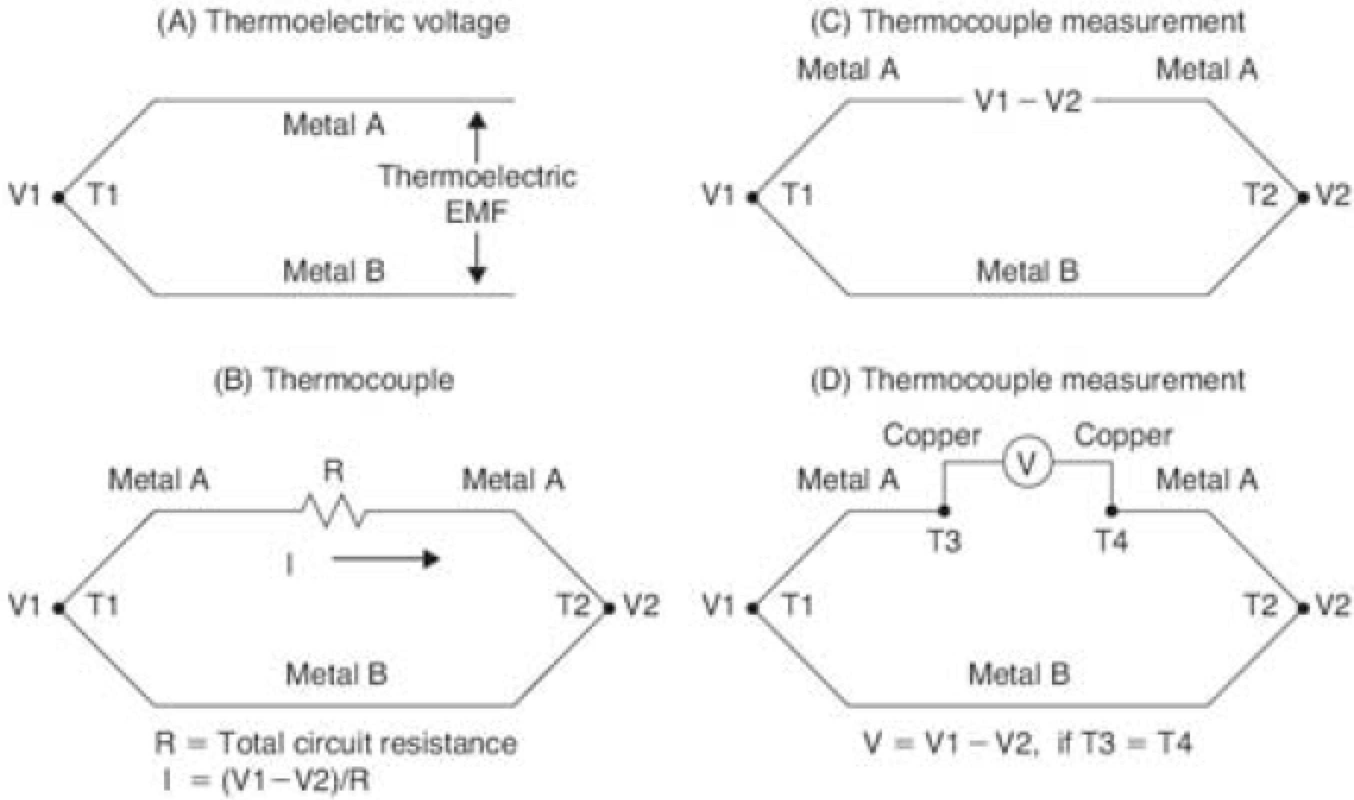


Figure 3-33: Thermocouple basics

Temperature measurements

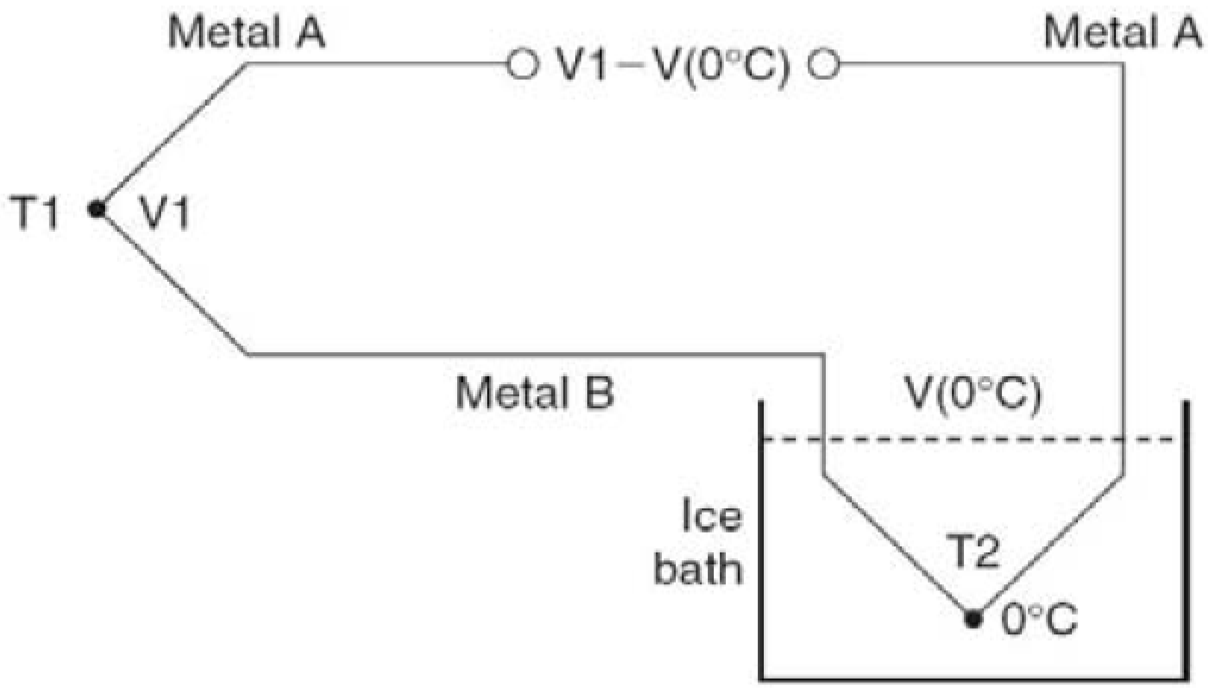


Figure 3-34: Classic cold-junction compensation using an ice-point (0°C) reference junction

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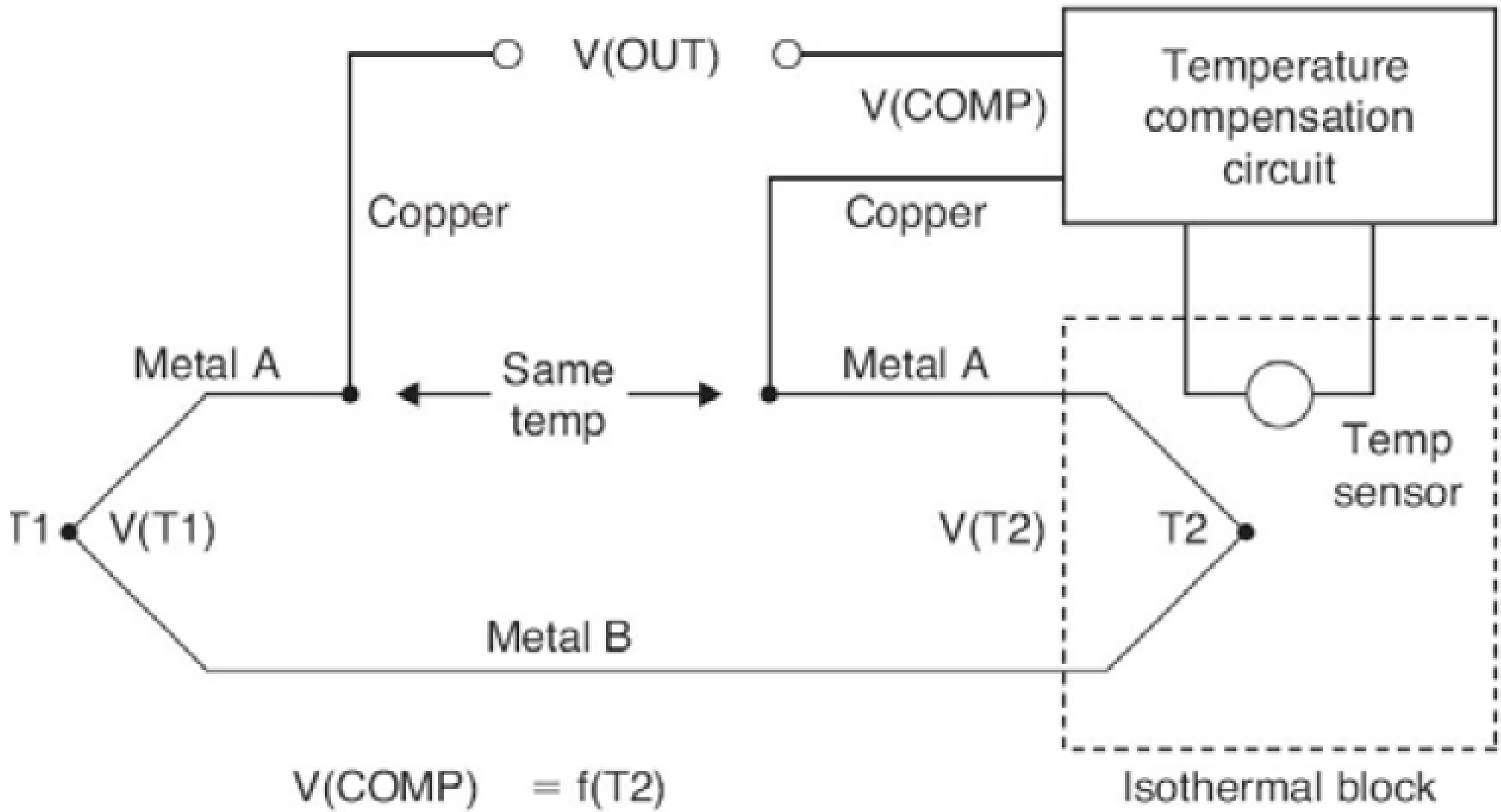
Temperature measurements
Cold-Junction compensation V1



USING A TEMPERATURE SENSOR FOR COLD-JUNCTION COMPENSATION (TMP35)

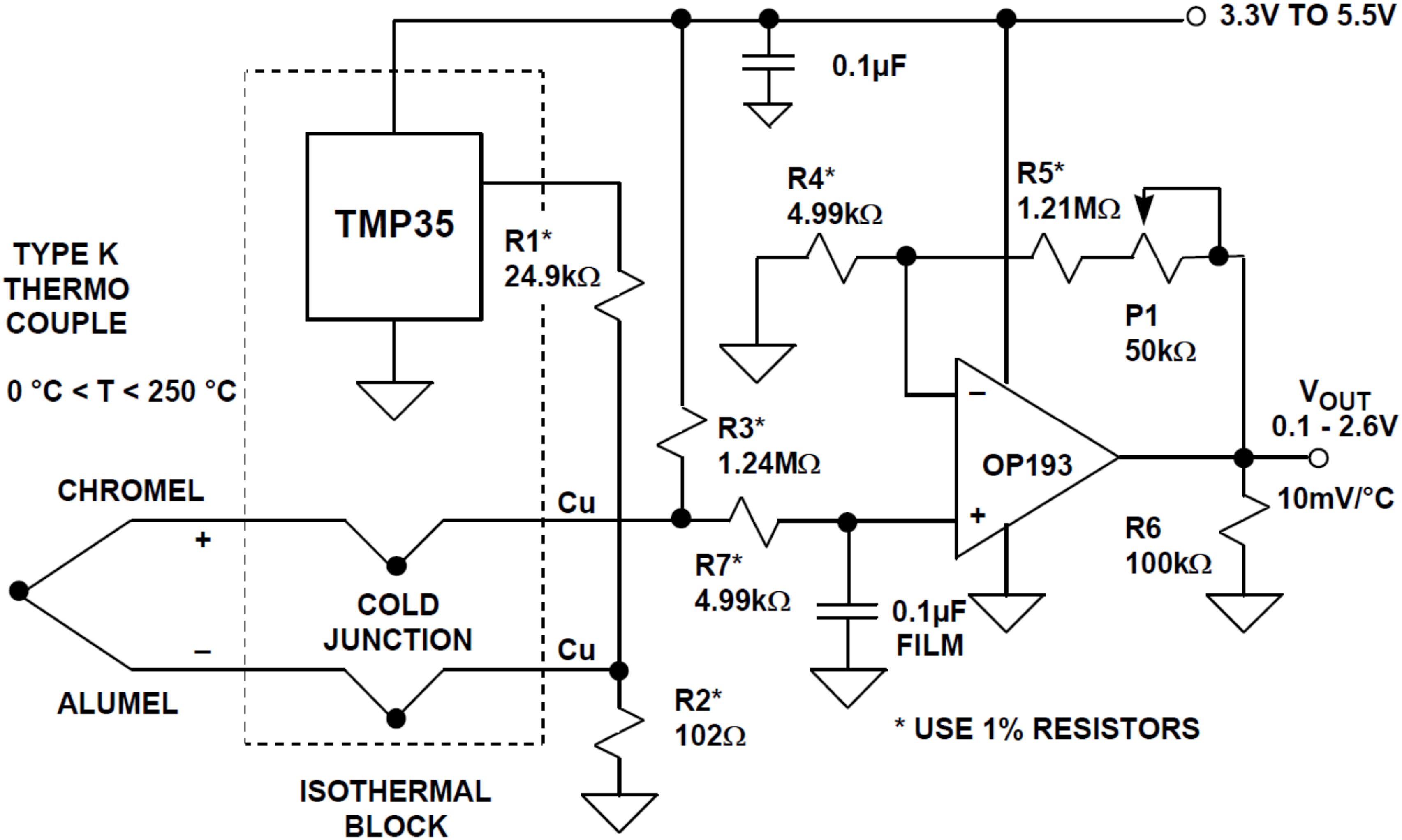
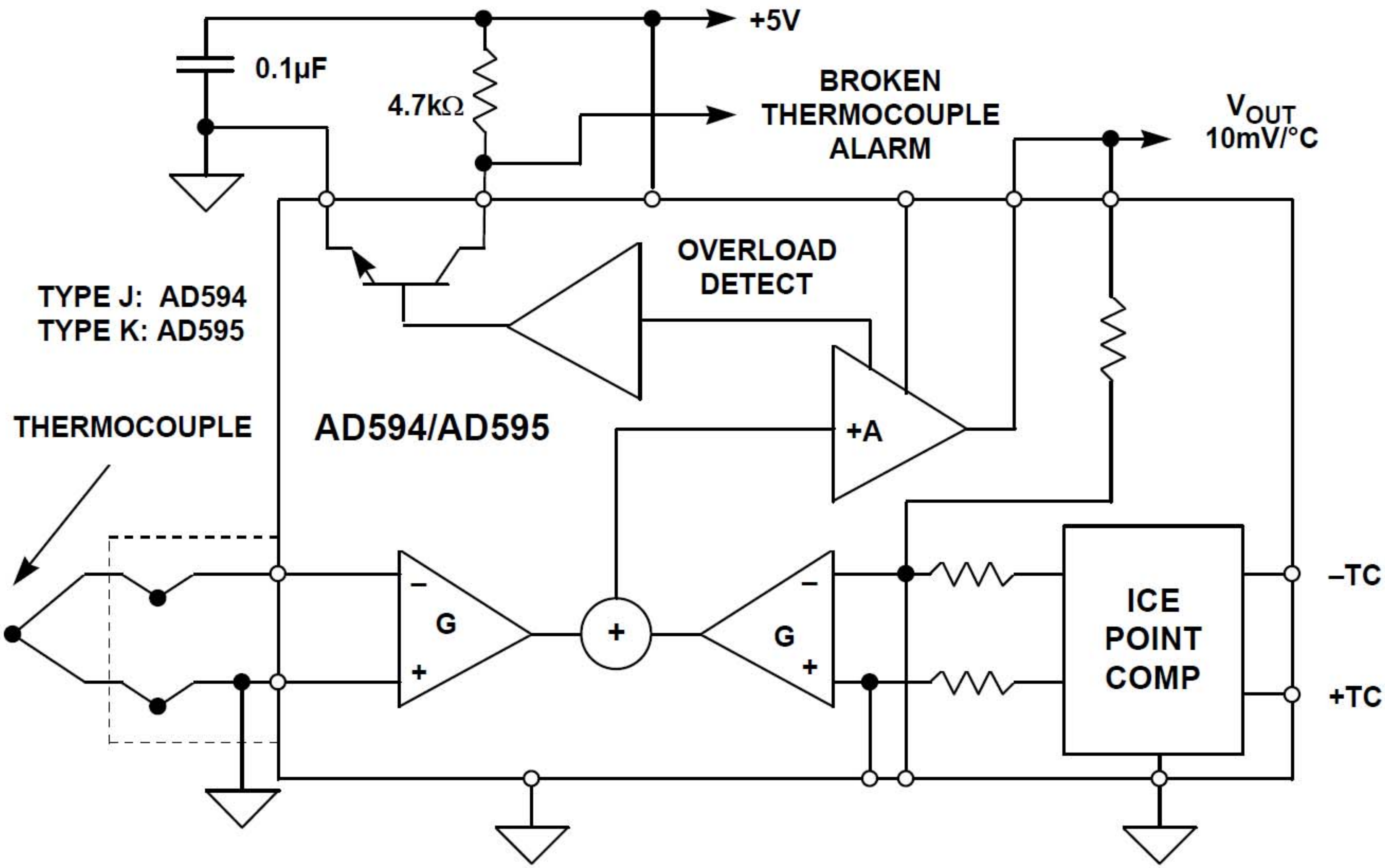


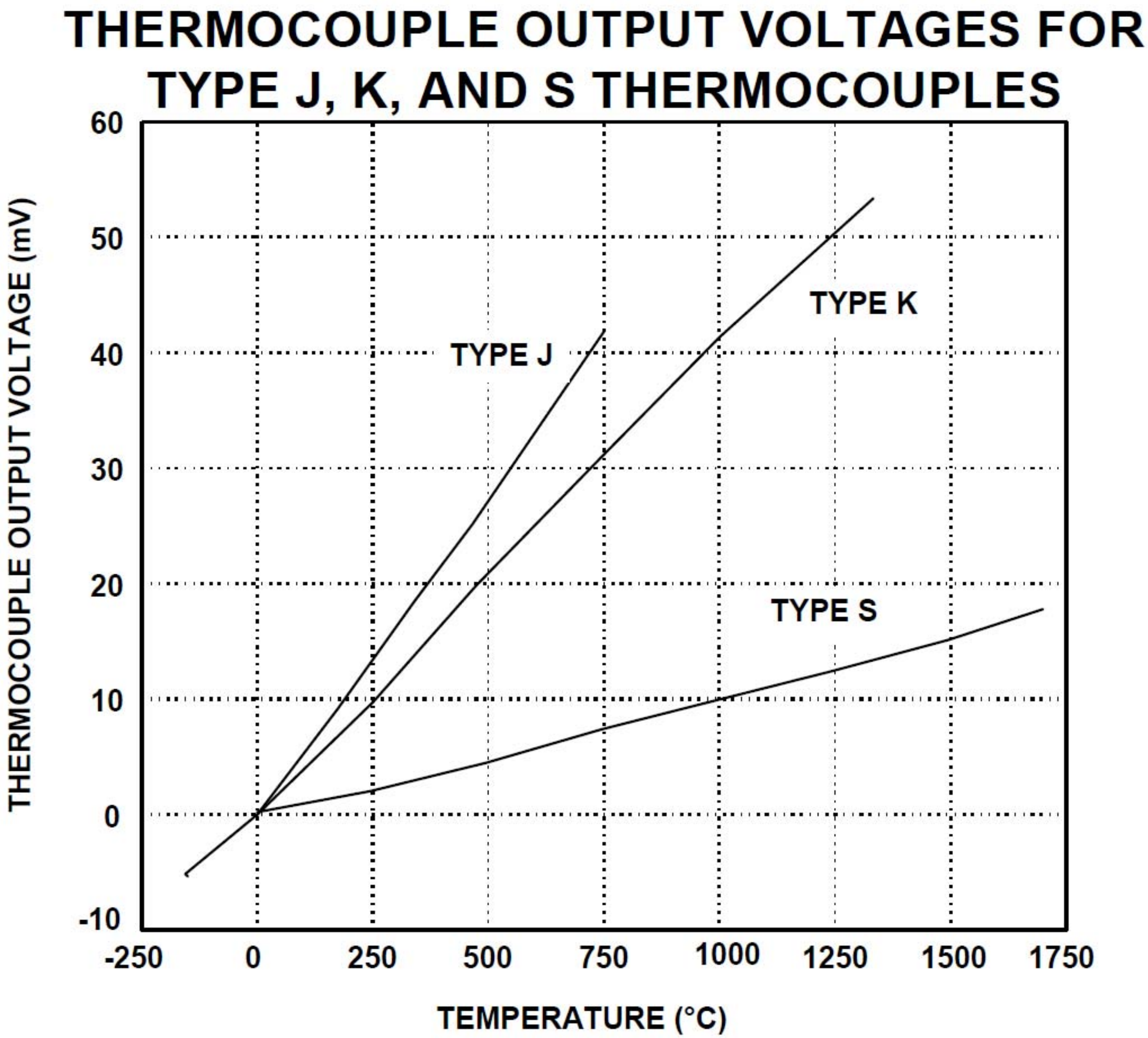
Figure 7.10

AD594/AD595 MONOLITHIC THERMOCOUPLE AMPLIFIERS WITH COLD-JUNCTION COMPENSATION



COMMON THERMOCOUPLES

JUNCTION MATERIALS	TYPICAL USEFUL RANGE (°C)	NOMINAL SENSITIVITY (μV/°C)	ANSI DESIGNATION
Platinum (6%)/ Rhodium-Platinum (30%)/Rhodium	38 to 1800	7.7	B
Tungsten (5%)/Rhenium - Tungsten (26%)/Rhenium	0 to 2300	16	C
Chromel - Constantan	0 to 982	76	E
Iron - Constantan	0 to 760	55	J
Chromel - Alumel	–184 to 1260	39	K
Platinum (13%)/Rhodium-Platinum	0 to 1593	11.7	R
Platinum (10%)/Rhodium-Platinum	0 to 1538	10.4	S
Copper-Constantan	–184 to 400	45	T



THERMOCOUPLE OUTPUT VOLTAGES FOR
TYPE J, K, AND S THERMOCOUPLES
THERMOCOUPLE OUTPUT VOLTAGE (mV)
60
50
40
30
20
10
0
-10
-250
0
250
500
750
1000
1250
1500
1750
TEMPERATURE (°C)
TYPE J
TYPE K
TYPE S

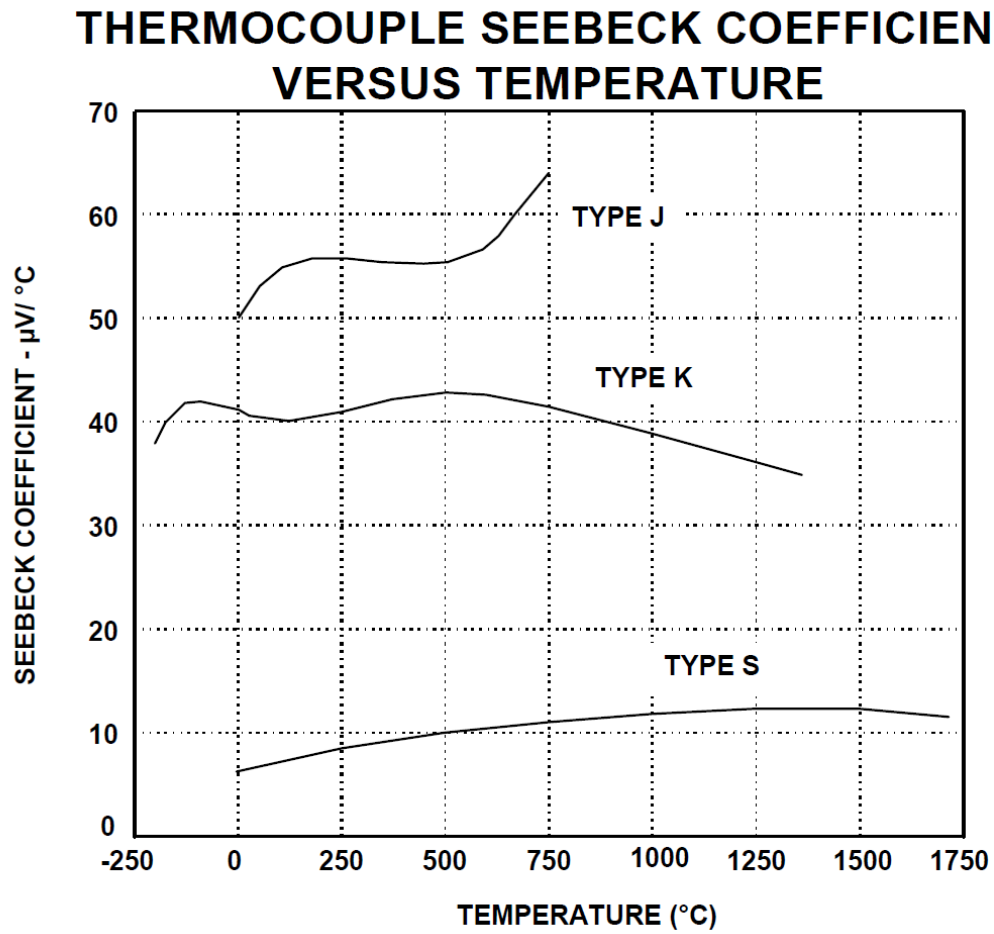


Figure 7.5

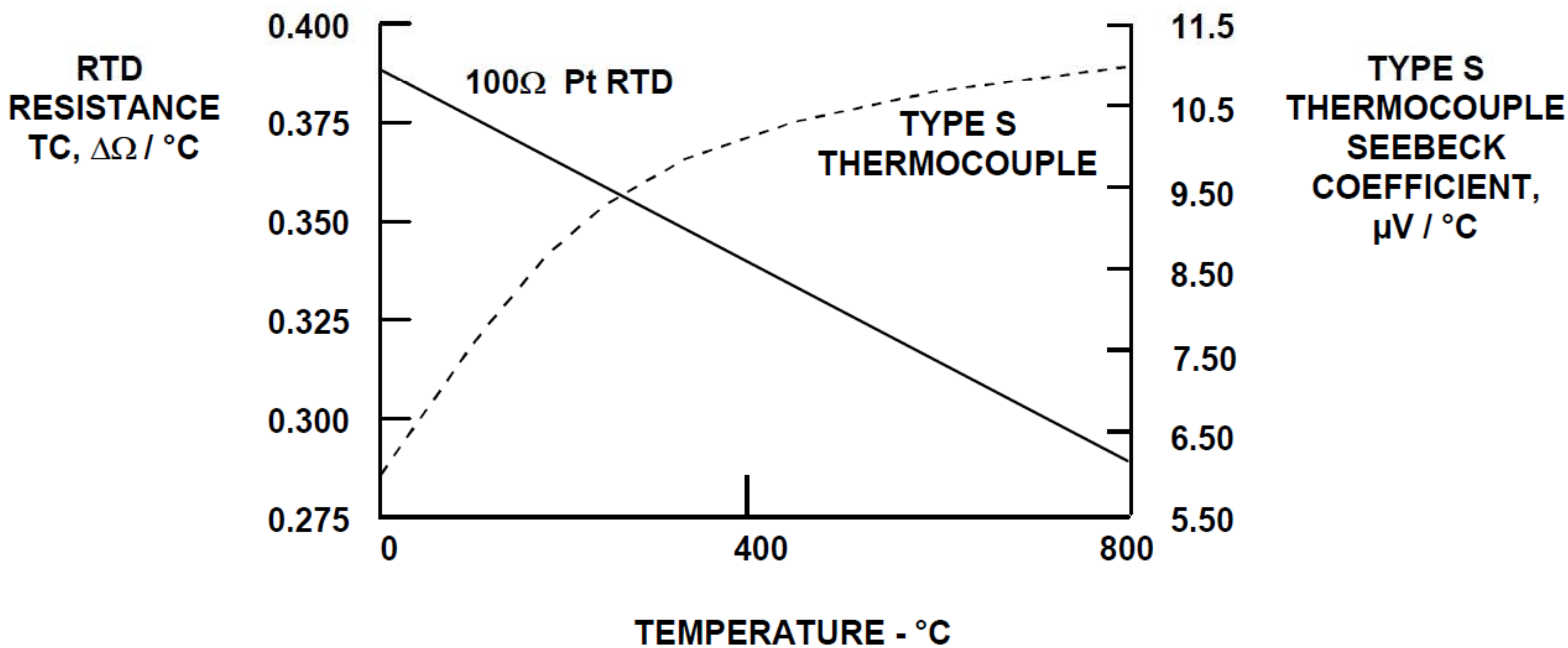
Figure 7.5 shows how the Seebeck coefficient (the *change* of output voltage with *change* of sensor junction temperature - i.e., the first derivative of output with respect to temperature) varies with sensor junction temperature (we are still considering the case where the reference junction is maintained at 0°C).

Temperature measurements Resistance Temperature Detectors

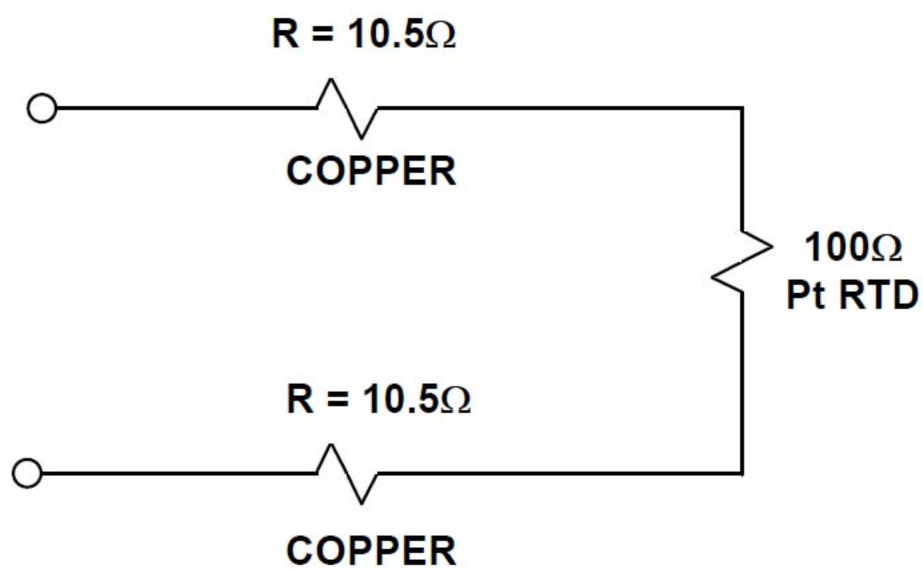
- The resistance changes with temperature
- Typically built of Pt wire
- More accurate than thermocouples
- More linear than thermocouples

RESISTANCE TEMPERATURE DETECTORs (RTD)

- Platinum (Pt) the Most Common
- 100Ω, 1000Ω Standard Values
- Typical TC = 0.385% / °C,
  0.385Ω / °C for 100Ω Pt RTD
- Good Linearity - Better than Thermocouple, Easily Compensated



A 100Ω Pt RTD WITH 100 FEET OF 30-GAUGE LEAD WIRES



RESISTANCE TC OF COPPER = 0.40%/°C @ 20°C

RESISTANCE TC OF Pt RTD = 0.385%/ °C @ 20°C

Figure 7.14

Circuitry for Resistive Transducer

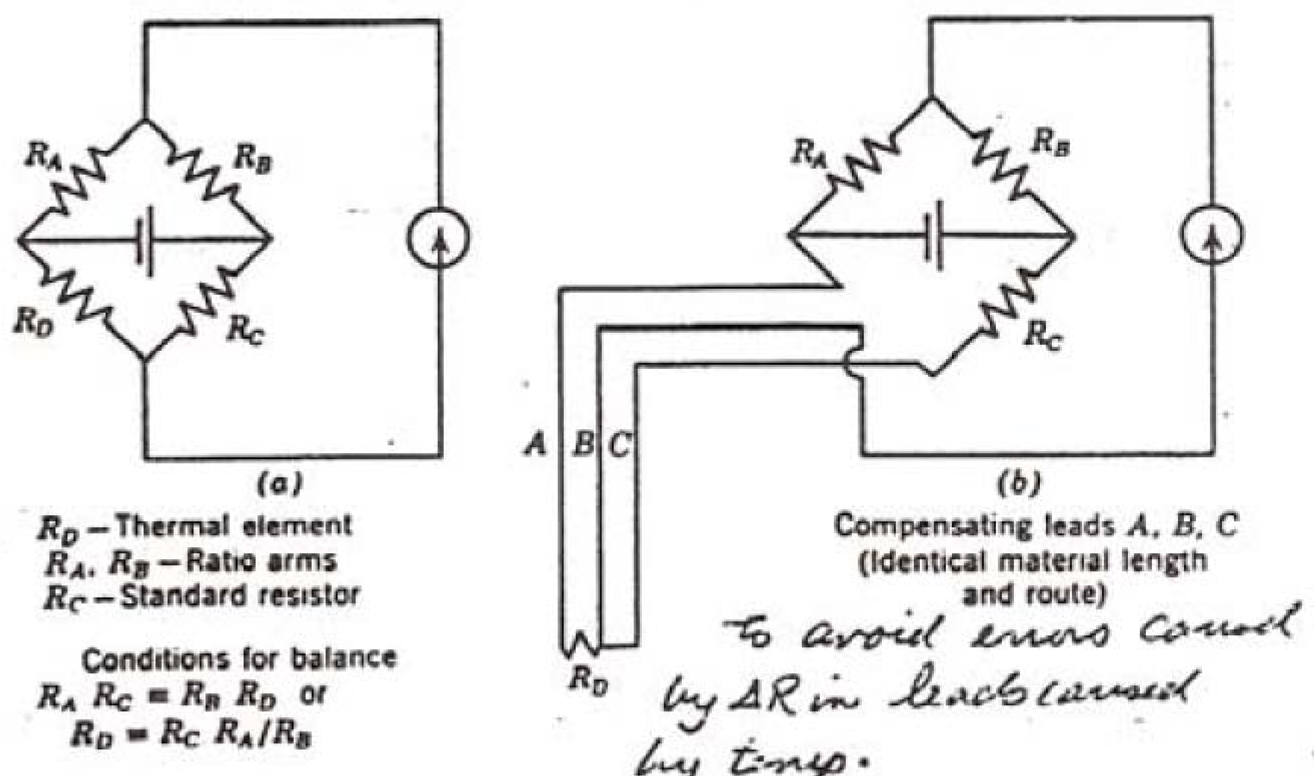
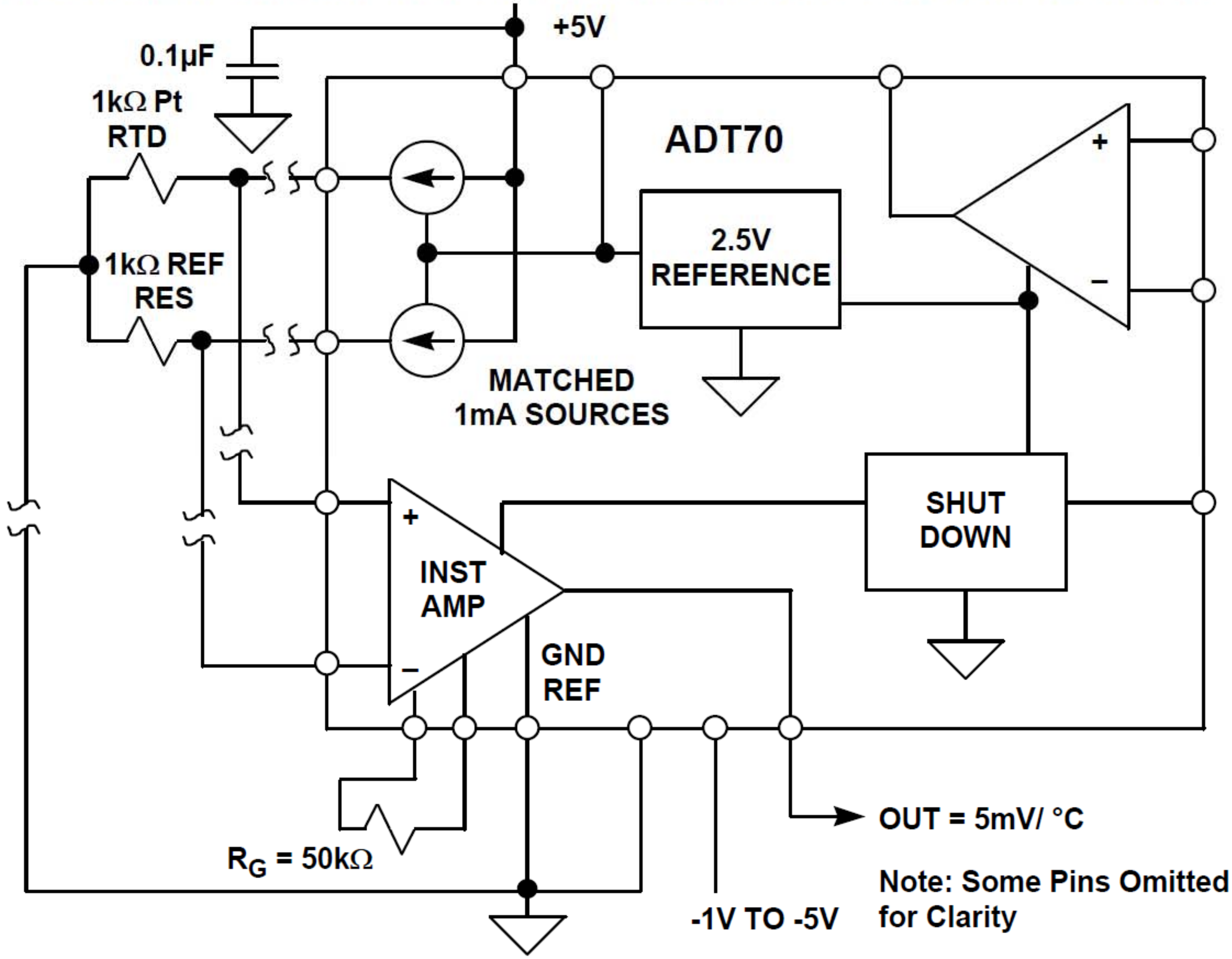


Figure 2-1. Circuits for Wheatstone bridge (a) and compensated bridge (b).

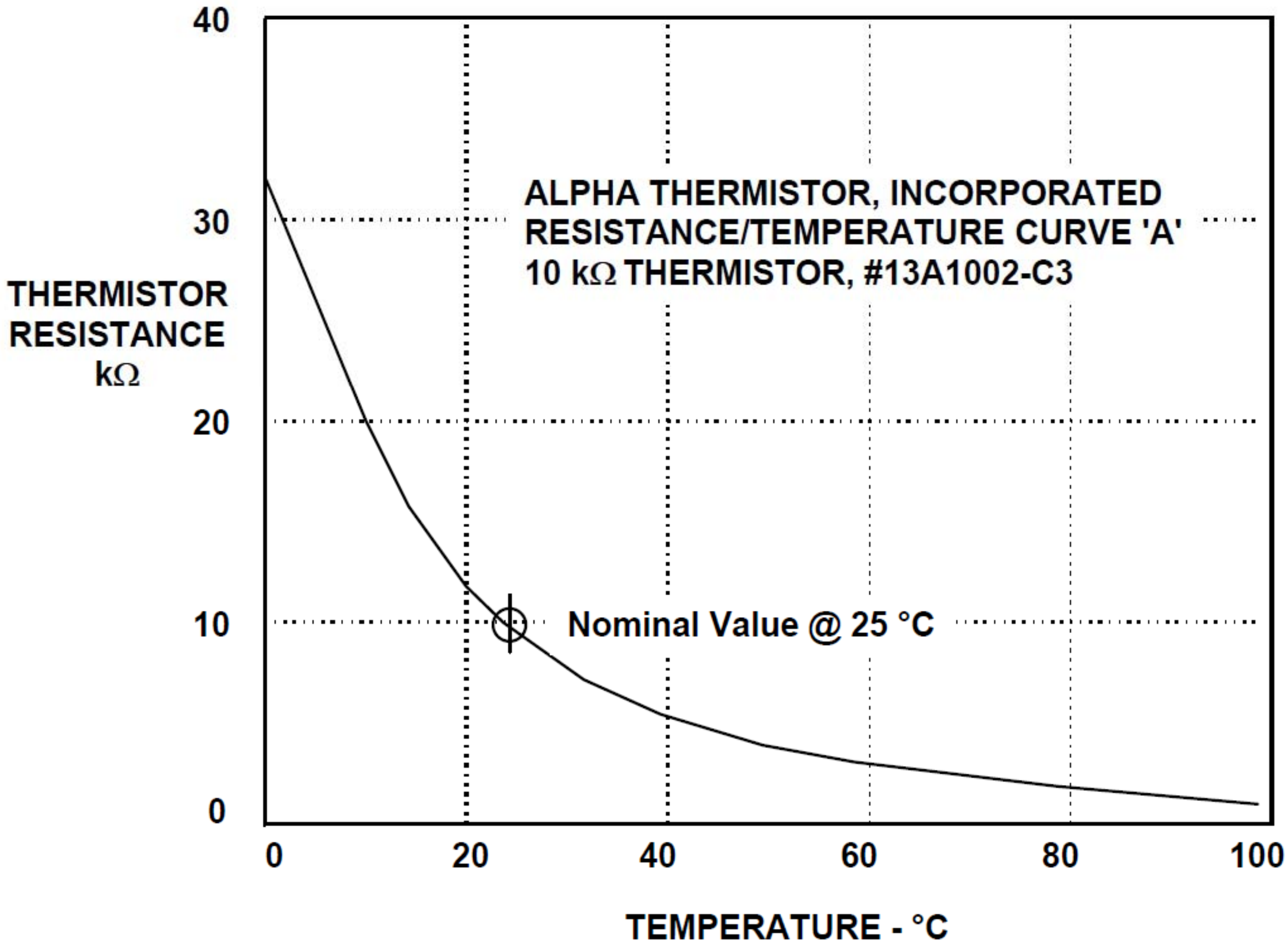
CONDITIONING THE PLATINUM RTD USING THE ADT70



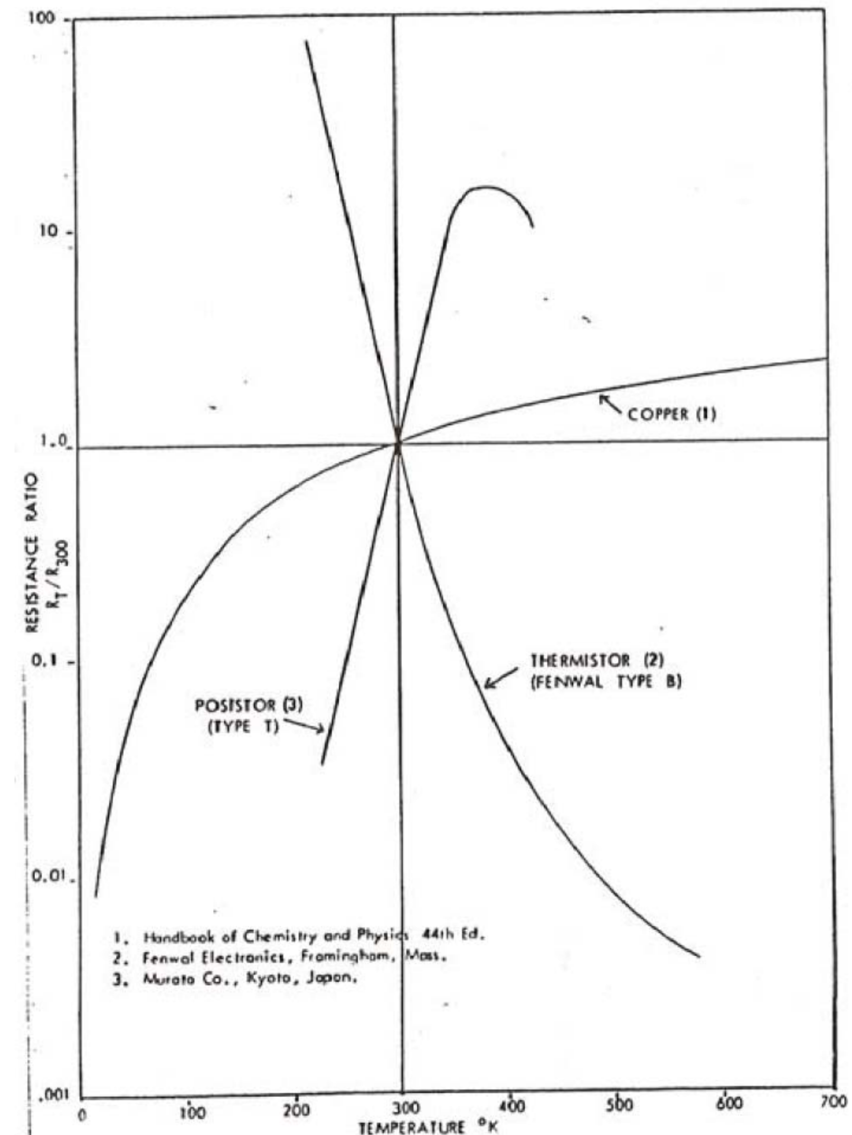
Thermistor Sensors

- Temperature sensitive resistor similar to metals above
- Solid semiconductor material
- Negative (NTC) or positive temperature coefficient – NTC most common
- Highly nonlinear but most sensitive
- Don’t need to worry about lead compensation
- Excellent for biomedical applications

RESISTANCE CHARACTERISTICS OF A 10kΩ NTC THERMISTOR

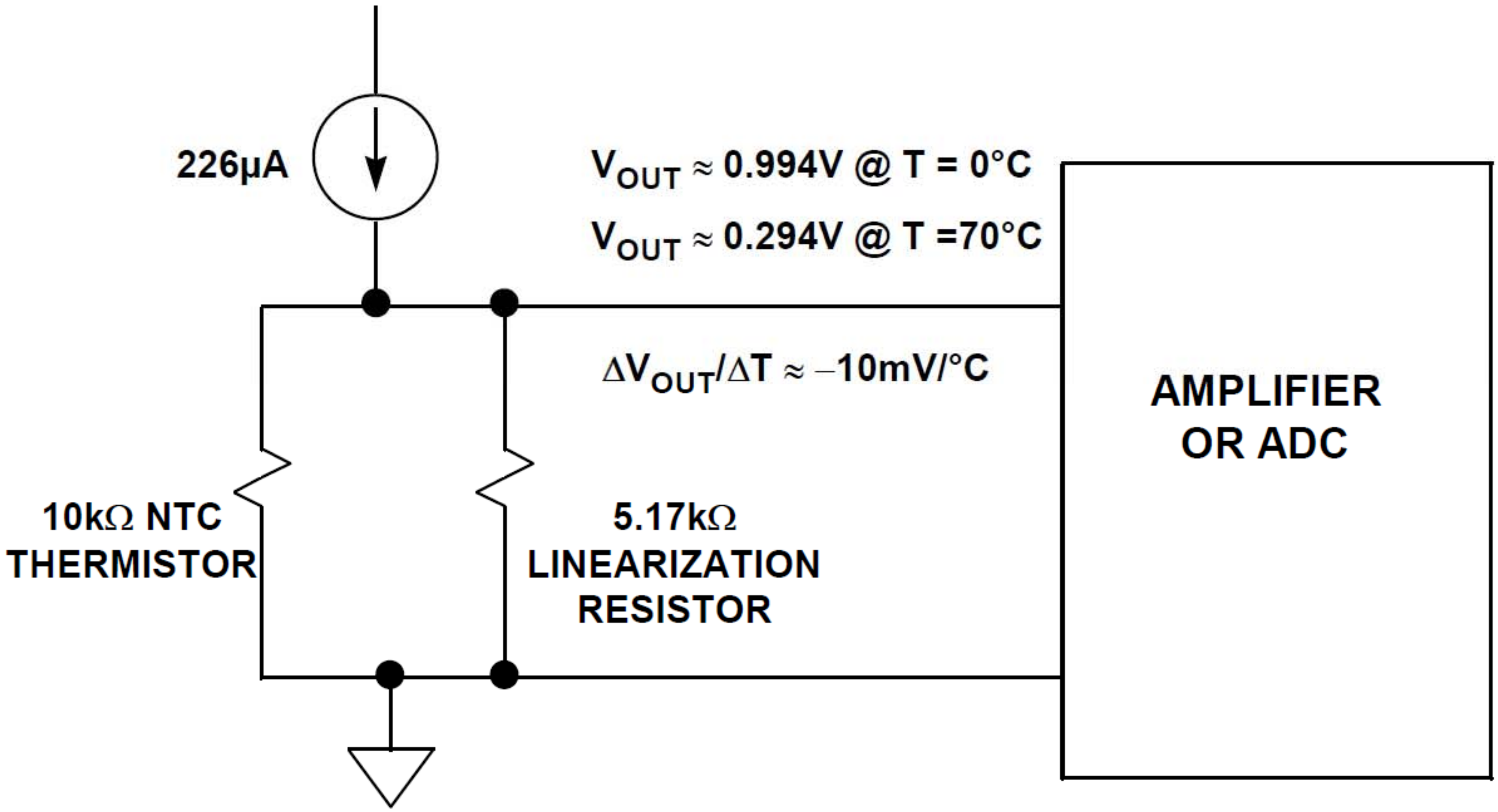


Resistive Transducers Characteristics



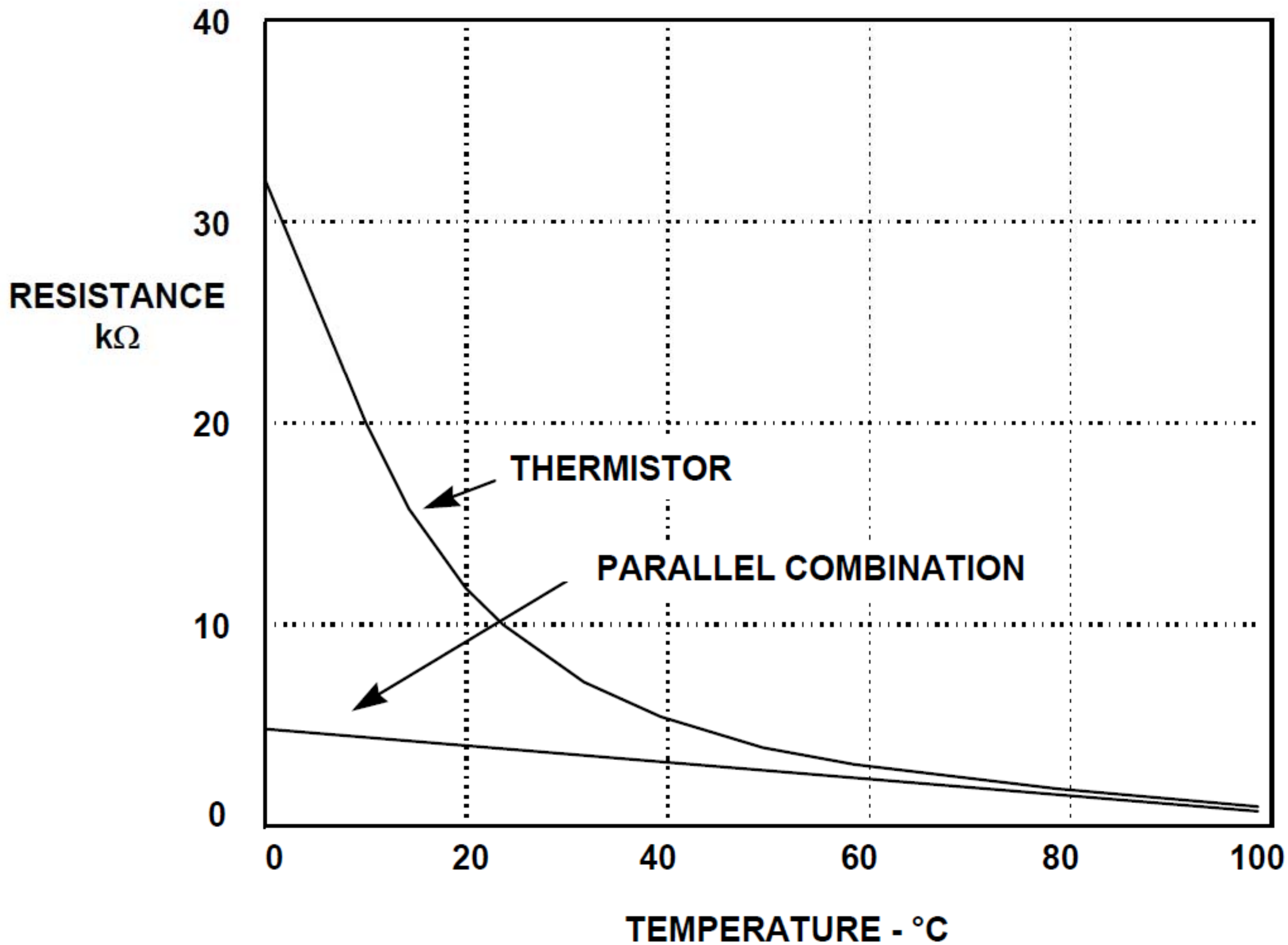
igure 2-2. Resistance temperature characteristics of copper, a typical thermistor, and a osistor.

LINEARIZED THERMISTOR AMPLIFIER



LINEARITY ≈ ± 2°C, 0°C TO +70°C

LINEARIZATION OF NTC THERMISTOR USING A 5.17kΩ SHUNT RESISTOR



Temperature Measurements

- Temperature is an important parameter for any living organism.
- Sensor selection function
  - Desired temperature range
  - Desired sensitivity
  - Desired response time