PRACTICAL DESIGN TECHNIQUES FOR SENSOR SIGNAL CONDITIONING

APPLICATIONS OF TEMPERATURE SENSORS

- **Monitoring**
  - **Portable Equipment**
  - **CPU Temperature**
  - **Battery Temperature**
  - **Ambient Temperature**

- **Compensation**
  - **Oscillator Drift in Cellular Phones**
  - **Thermocouple Cold-Junction Compensation**

- **Control**
  - **Battery Charging**
  - **Process Control**

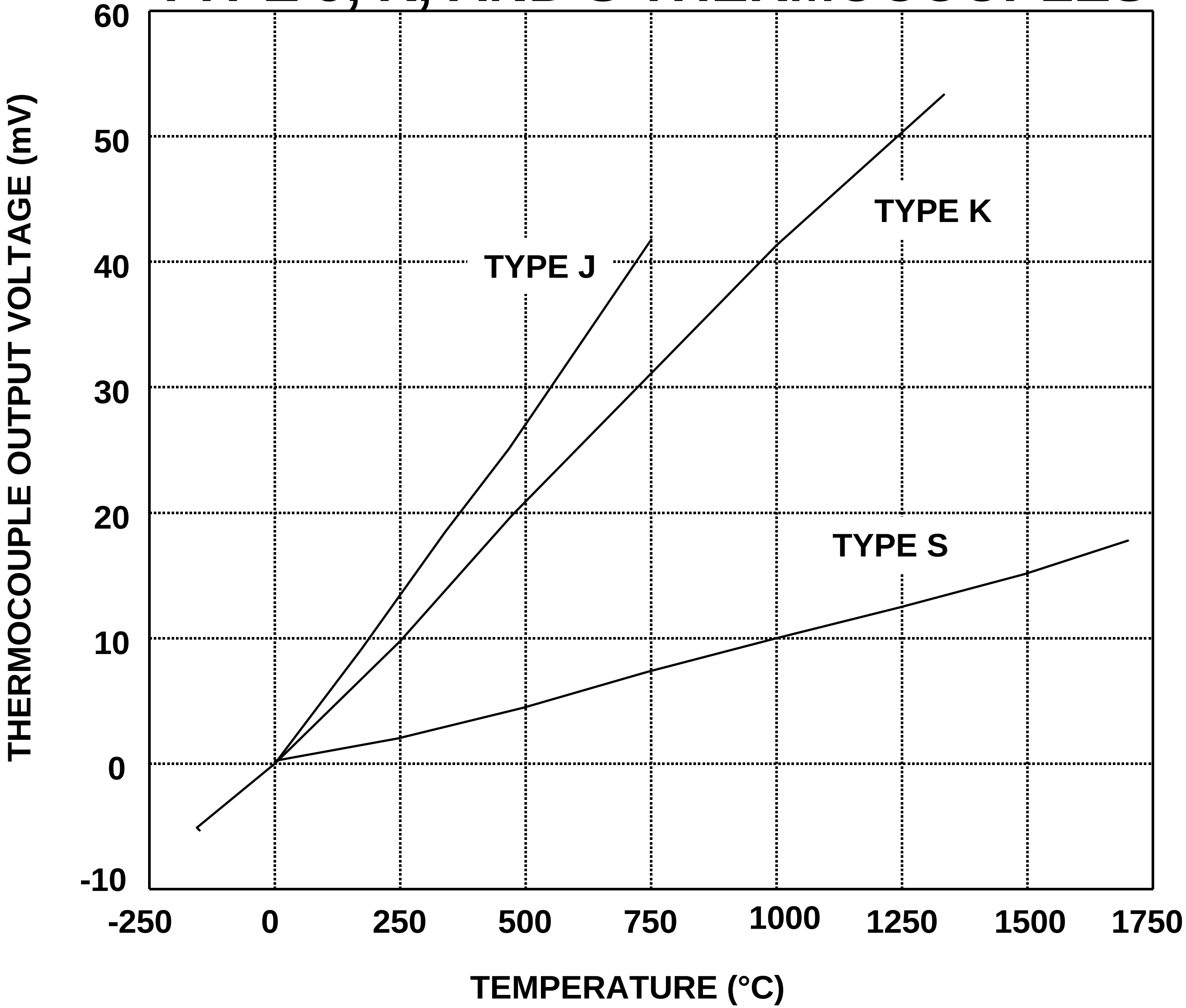
TYPES OF TEMPERATURE SENSORS

THERMOCOUPLE	RTD	THERMISTOR	SEMICONDUCTOR
Widest Range: –184ºC to +2300ºC	Range: –200ºC to +850ºC	Range: 0ºC to +100ºC	Range: –55ºC to +150ºC
High Accuracy and Repeatability	Fair Linearity	Poor Linearity	Linearity: 1ºC Accuracy: 1ºC
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

COMMON THERMOCOUPLES

JUNCTION MATERIALS	TYPICAL USEFUL RANGE (ºC)	NOMINAL SENSITIVITY (μV/ºC)	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



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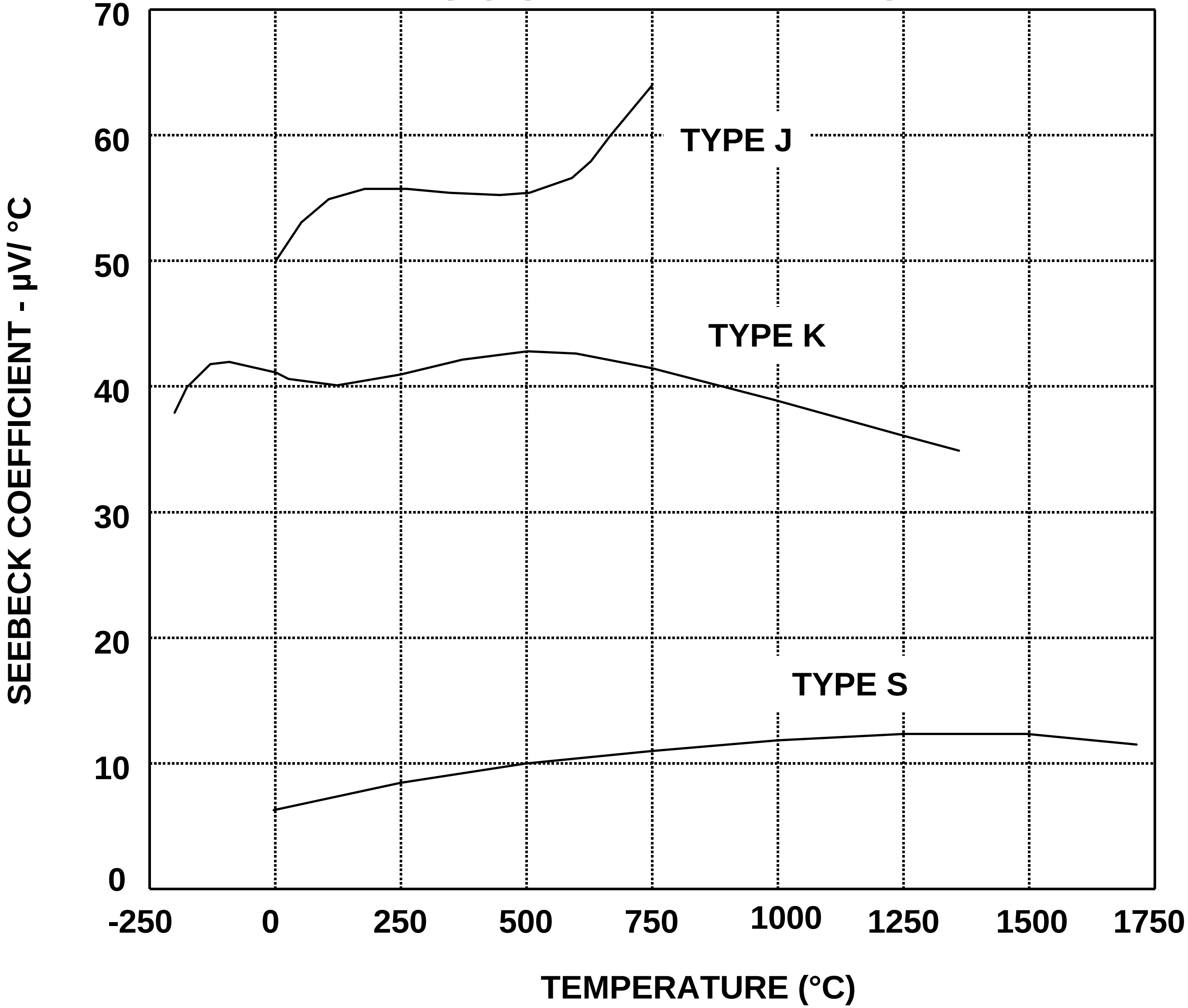
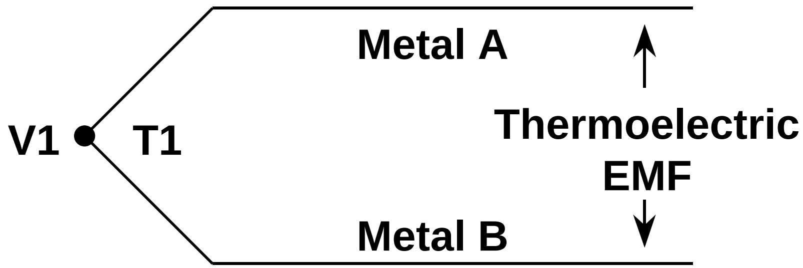
THERMOCOUPLE SEEBECK COEFFICIENT VERSUS TEMPERATURE

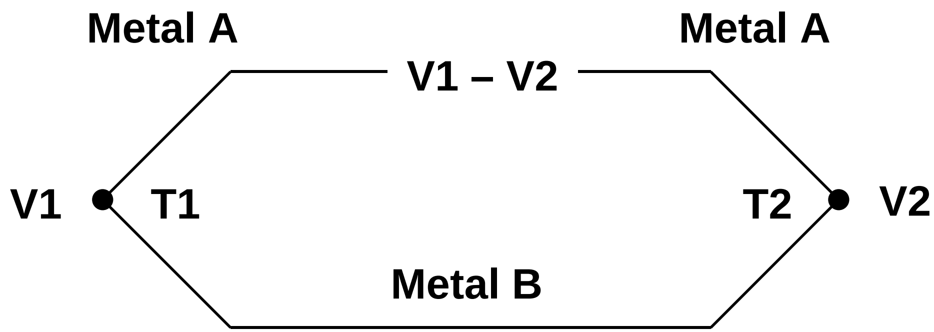


THERMOCOUPLE BASICS

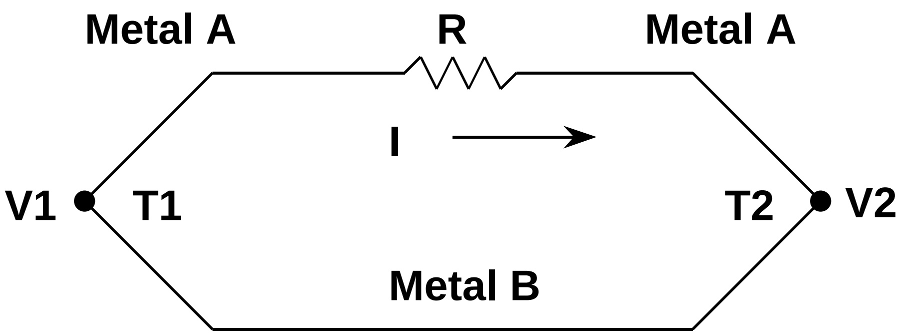
A. THERMOELECTRIC VOLTAGE



C. THERMOCOUPLE MEASUREMENT

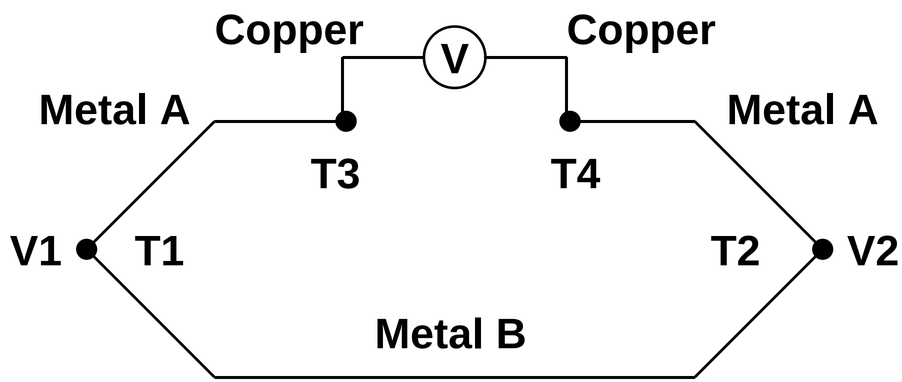


B. THERMOCOUPLE



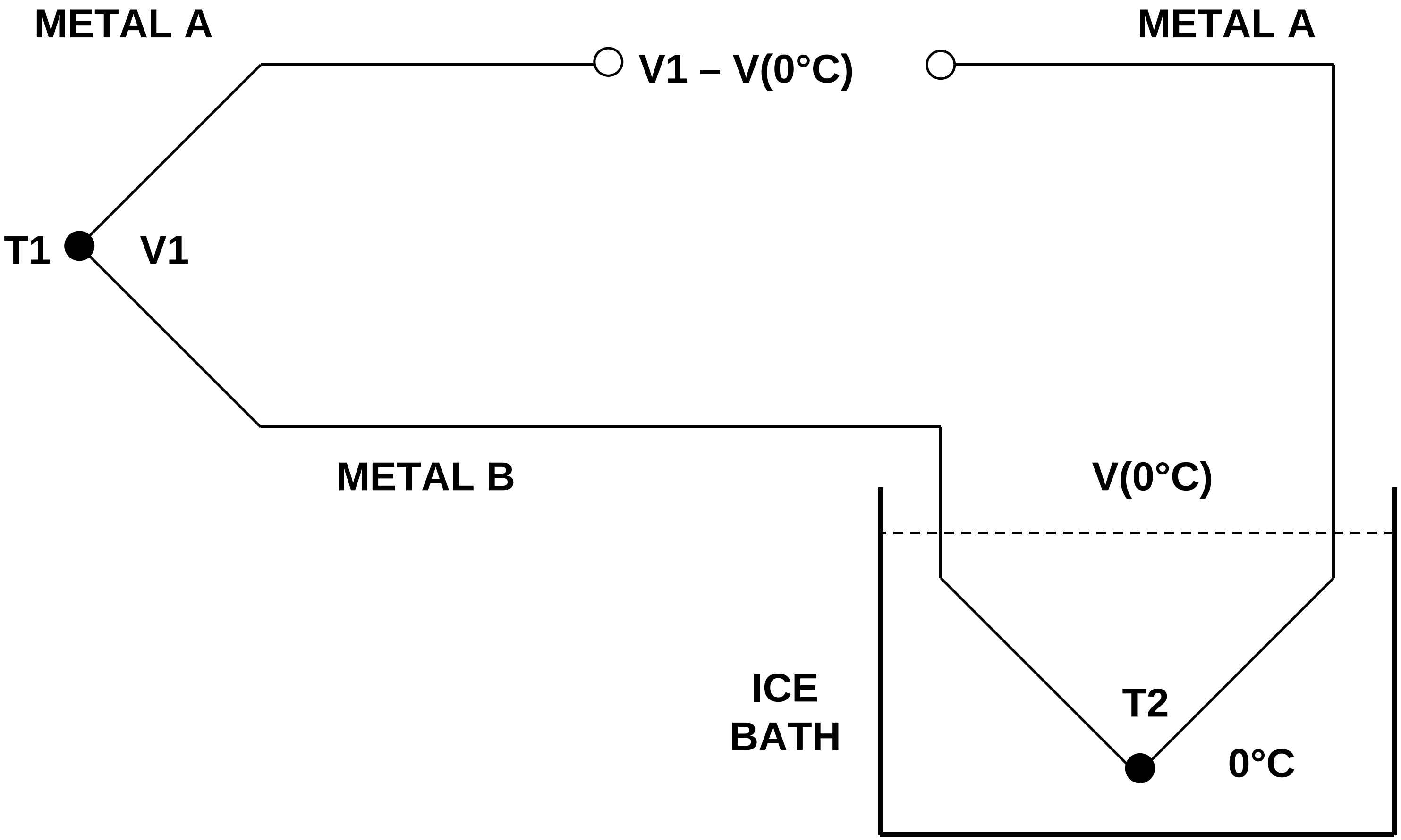
R = Total Circuit Resistance
I = (V1 – V2) / R

D. THERMOCOUPLE MEASUREMENT



V = V1 – V2, If T3 = T4

CLASSICAL COLD-JUNCTION COMPENSATION USING AN ICE-POINT (0°C) REFERENCE JUNCTION



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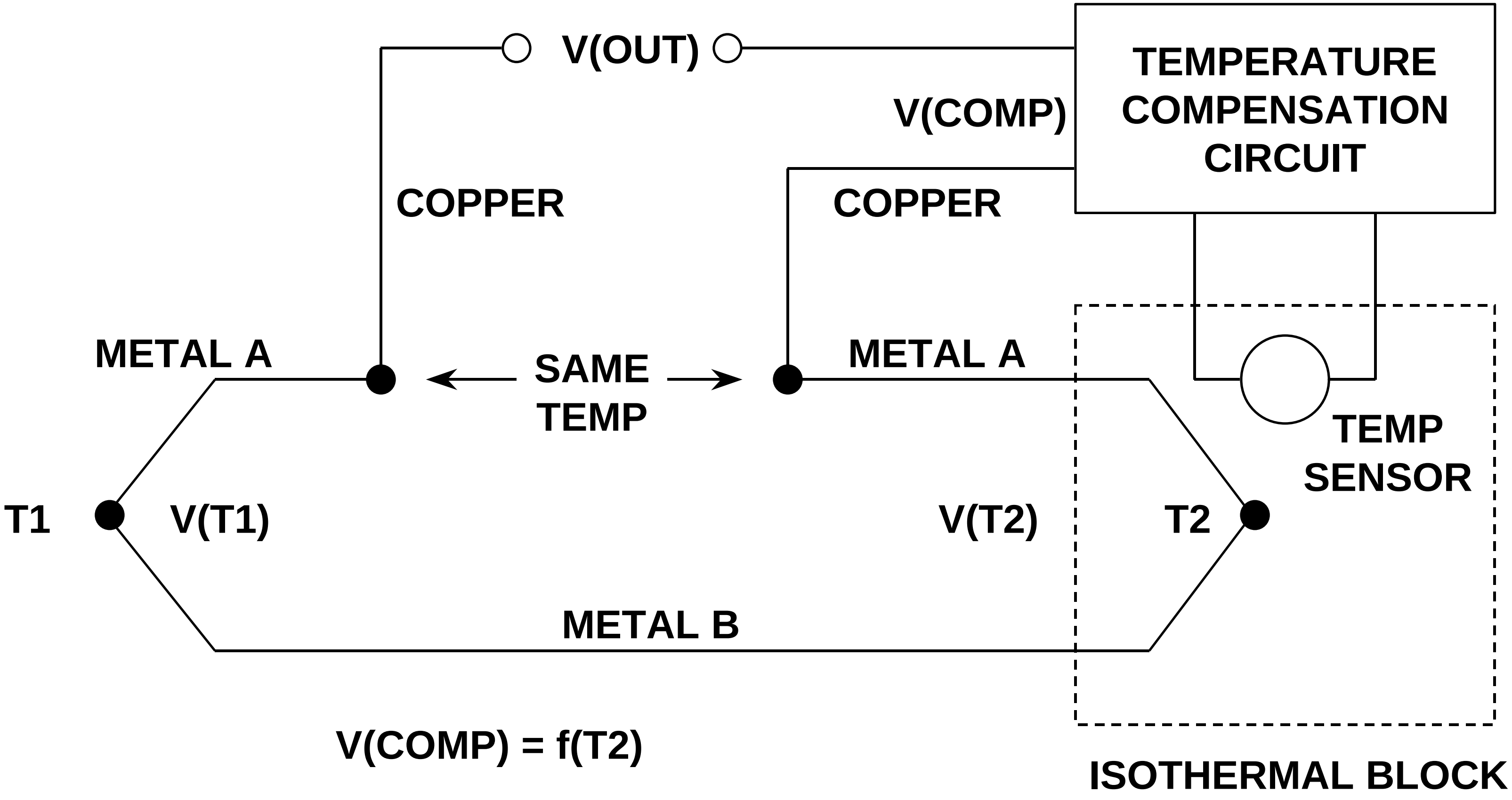
USING A TEMPERATURE SENSOR FOR COLD-JUNCTION COMPENSATION



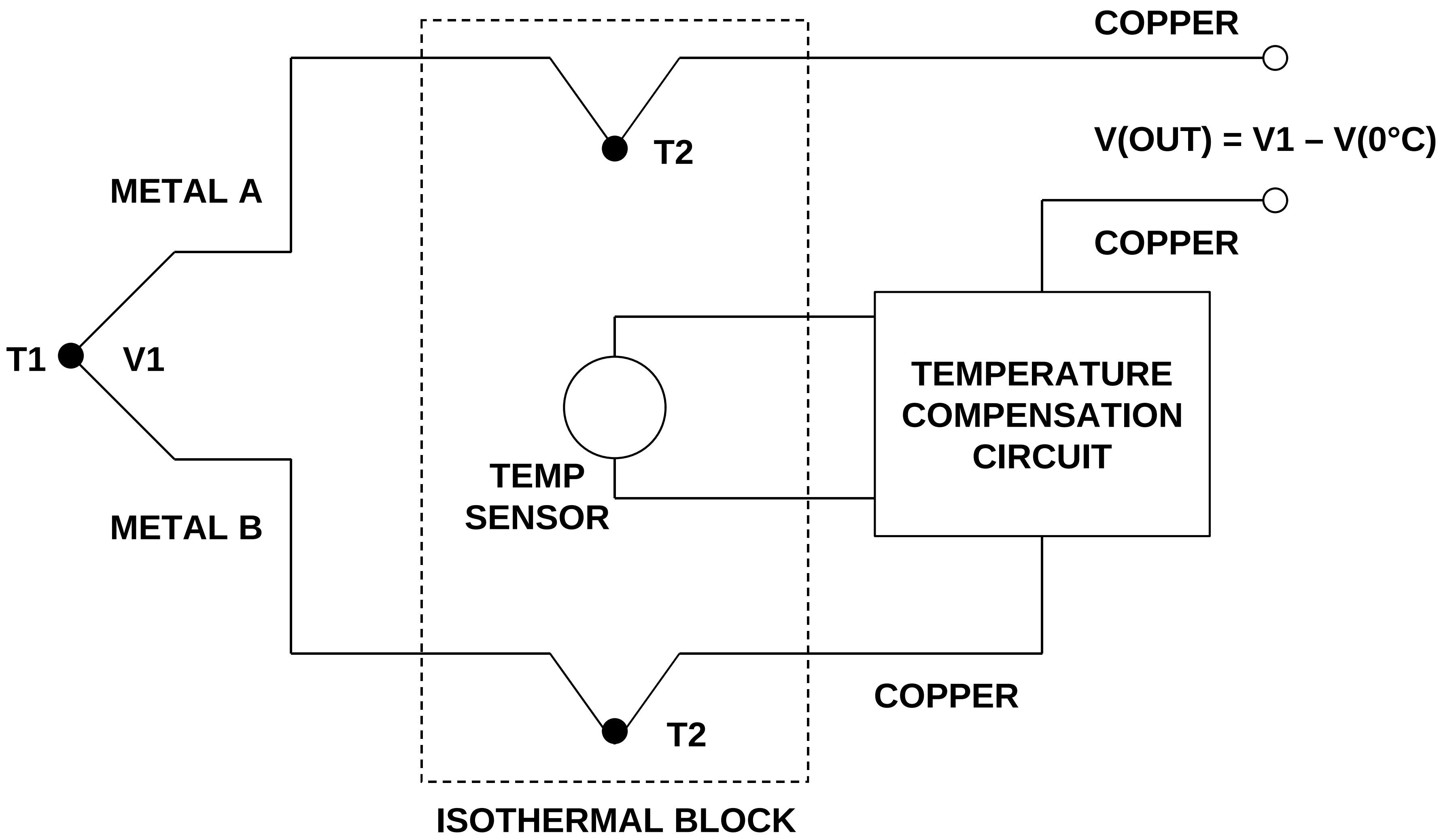
V(COMP) = f(T2)

V(OUT) = V(T1) – V(T2) + V(COMP)

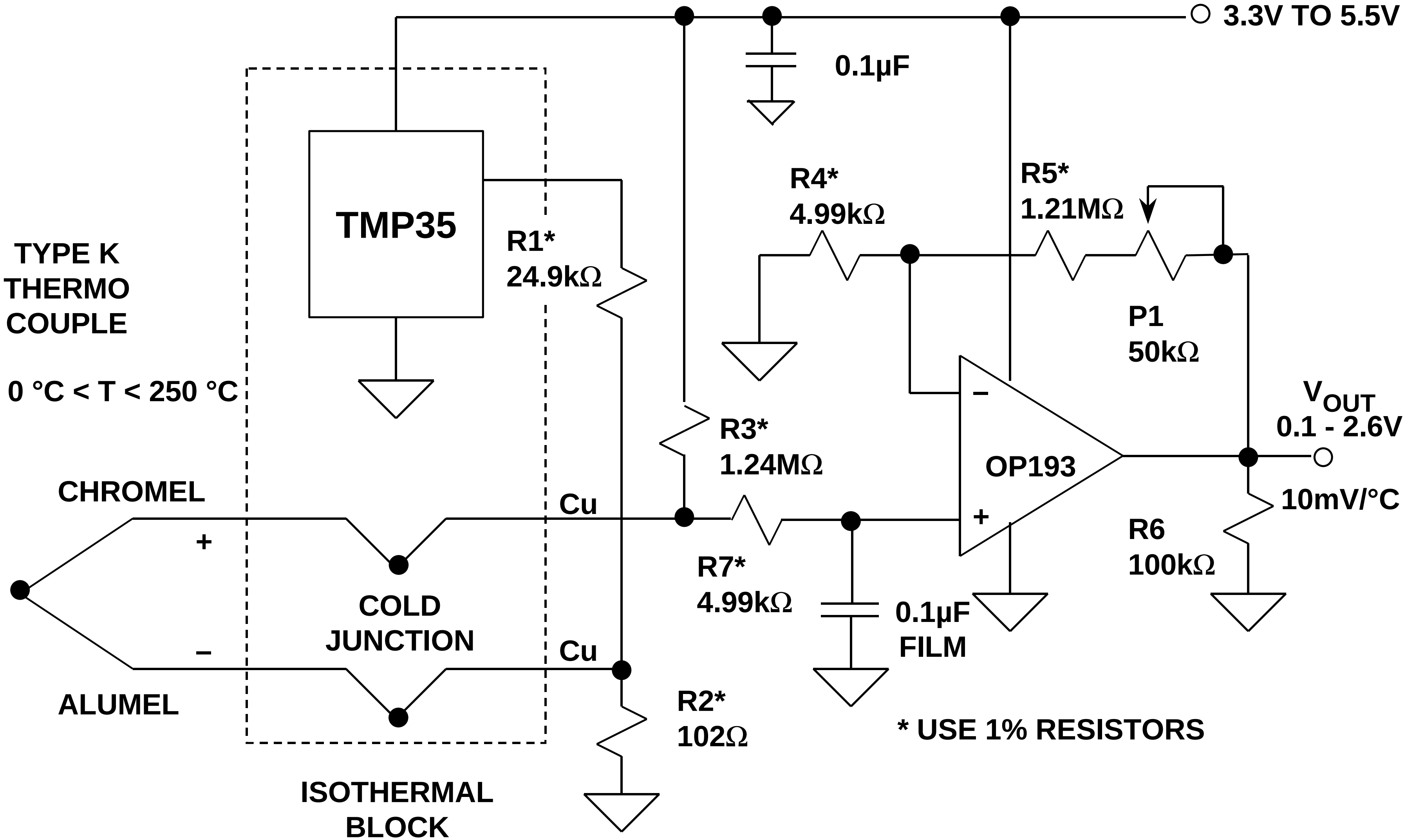
IF V(COMP) = V(T2) – V(0°C), THEN

V(OUT) = V(T1) – V(0°C)

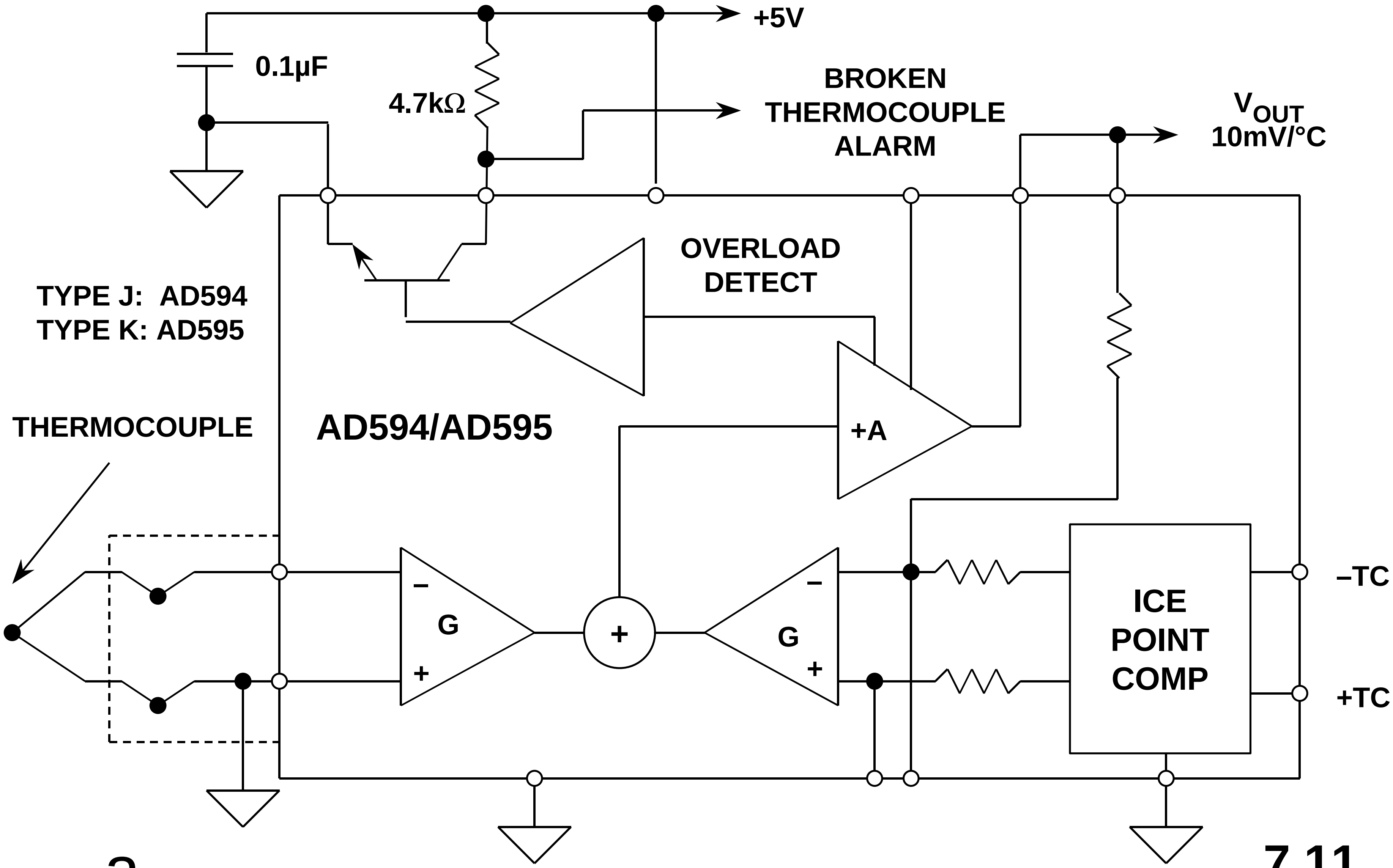
TERMINATING THERMOCOUPLE LEADS DIRECTLY TO AN ISOTHERMAL BLOCK



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



AD594/AD595 MONOLITHIC THERMOCOUPLE AMPLIFIERS WITH COLD-JUNCTION COMPENSATION



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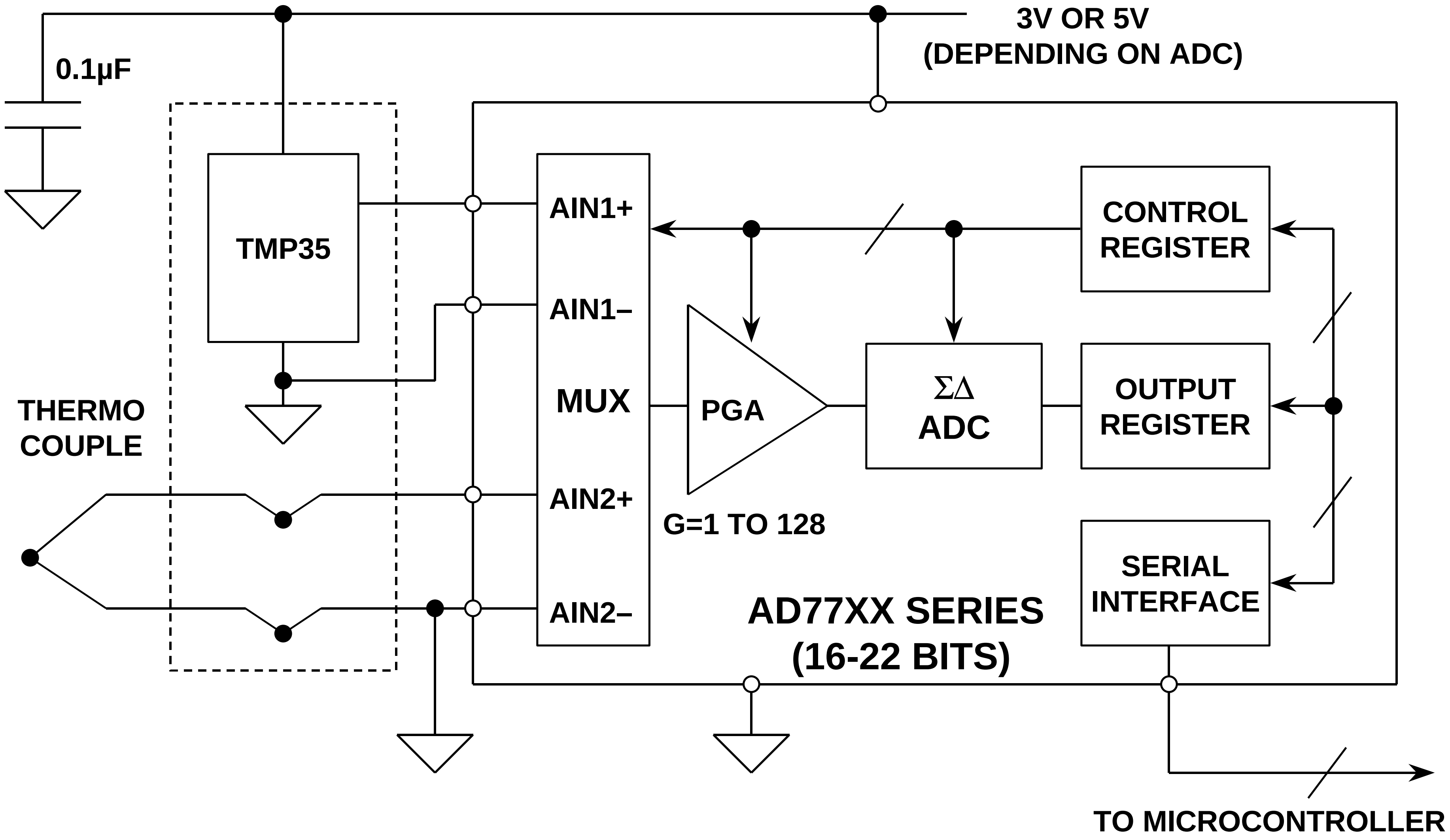
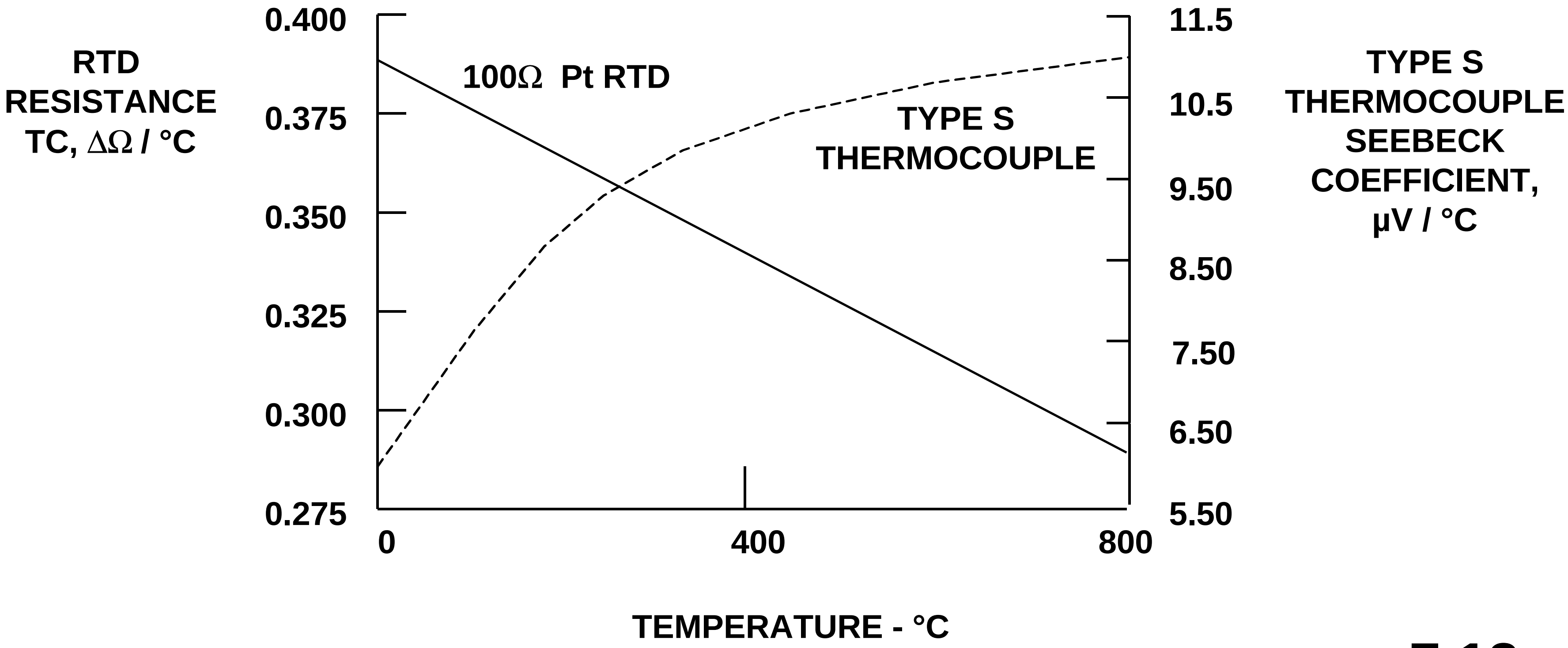
AD77XX ADC USED WITH
TMP35 TEMPERATURE SENSOR FOR CJC

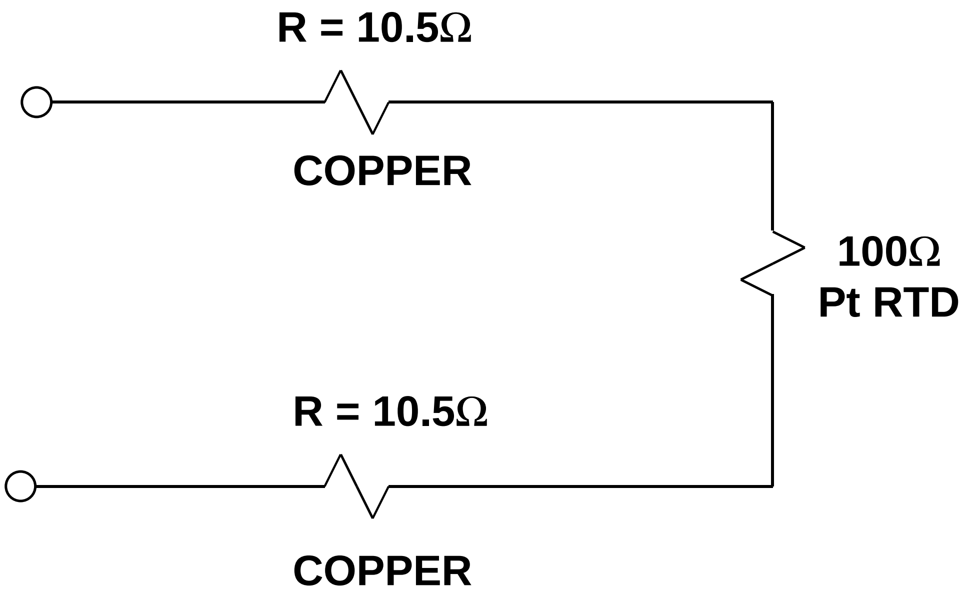


RESISTANCE TEMPERATURE DETECTORs (RTD)

- **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**



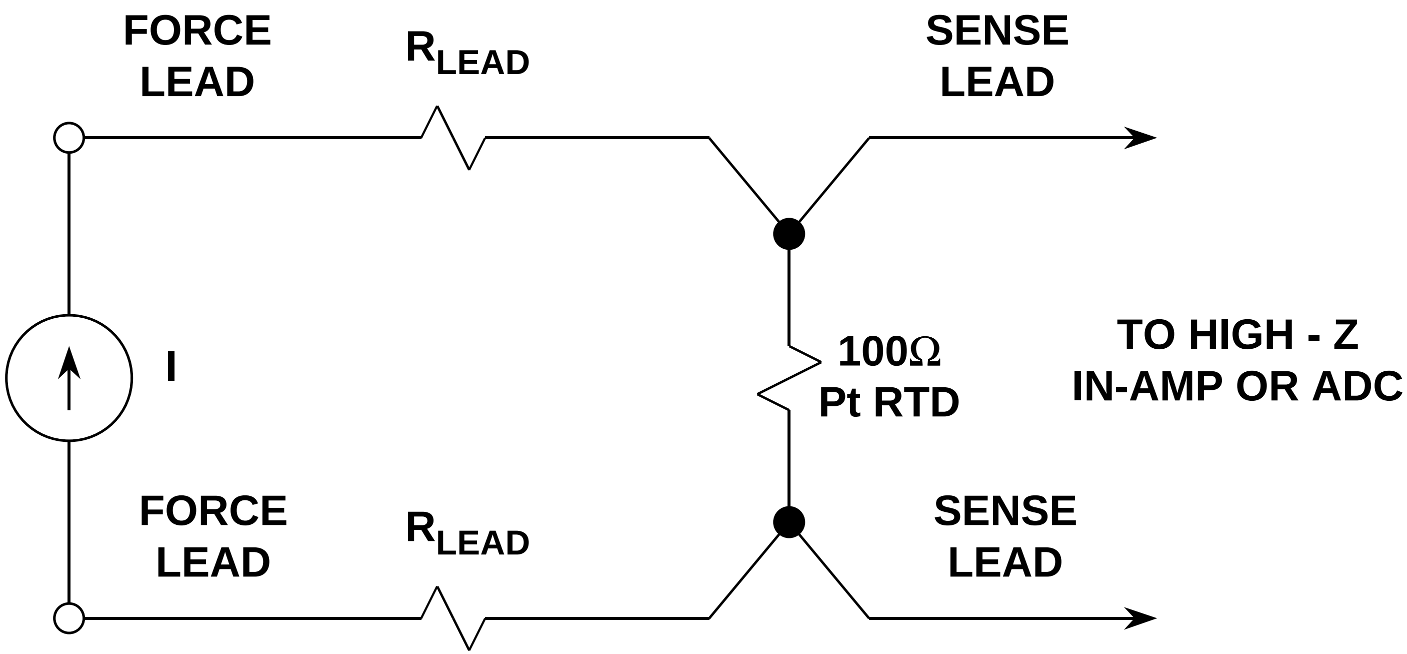
A 100Ω Pt RTD WITH 100 FEET OF 30-GAUGE LEAD WIRES



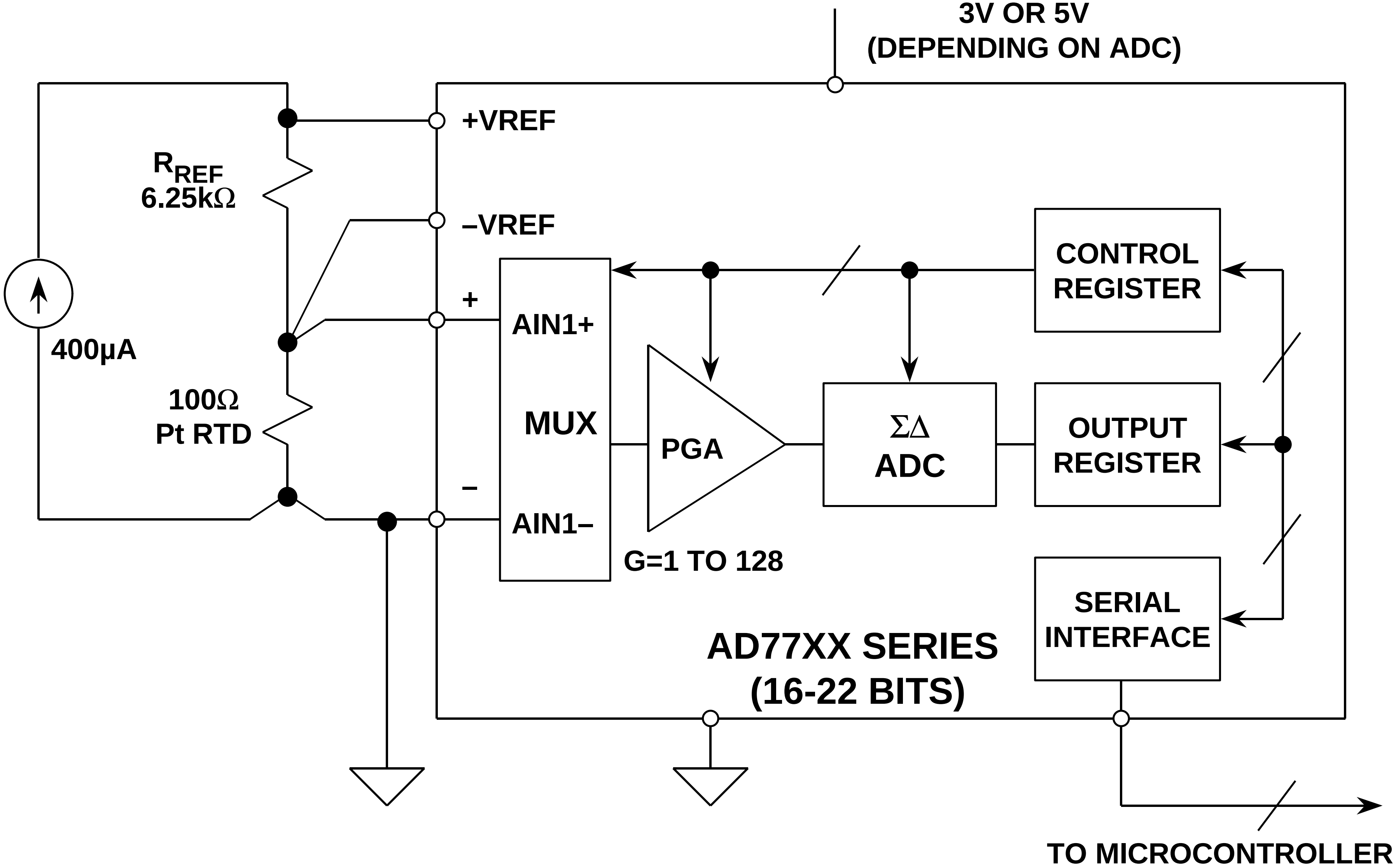
RESISTANCE TC OF COPPER = 0.40%/°C @ 20°C

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

FOUR-WIRE OR KELVIN CONNECTION TO Pt RTD FOR ACCURATE MEASUREMENTS



INTERFACING A Pt RTD TO A HIGH RESOLUTION ADC



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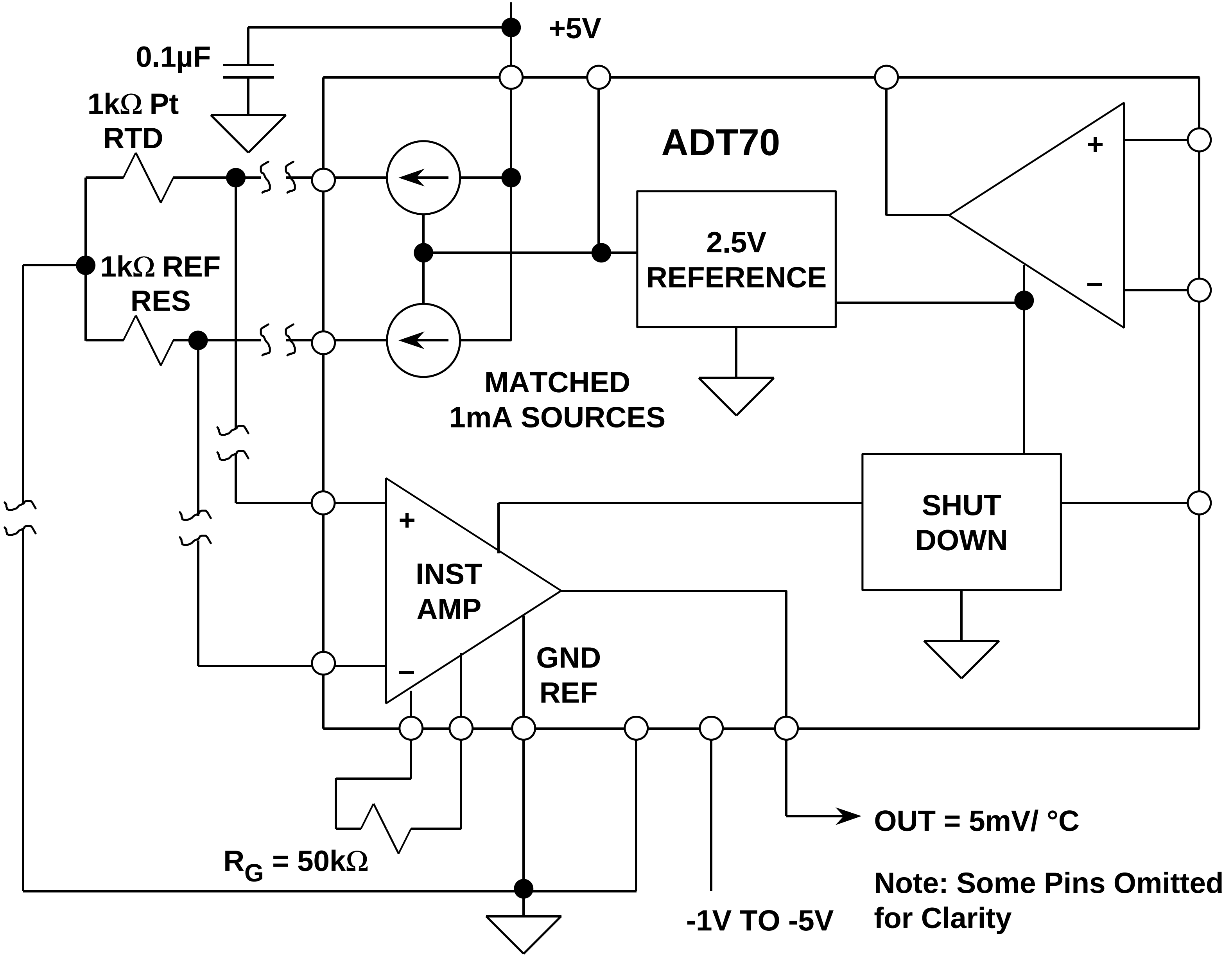
CONDITIONING THE PLATINUM RTD USING THE ADT70



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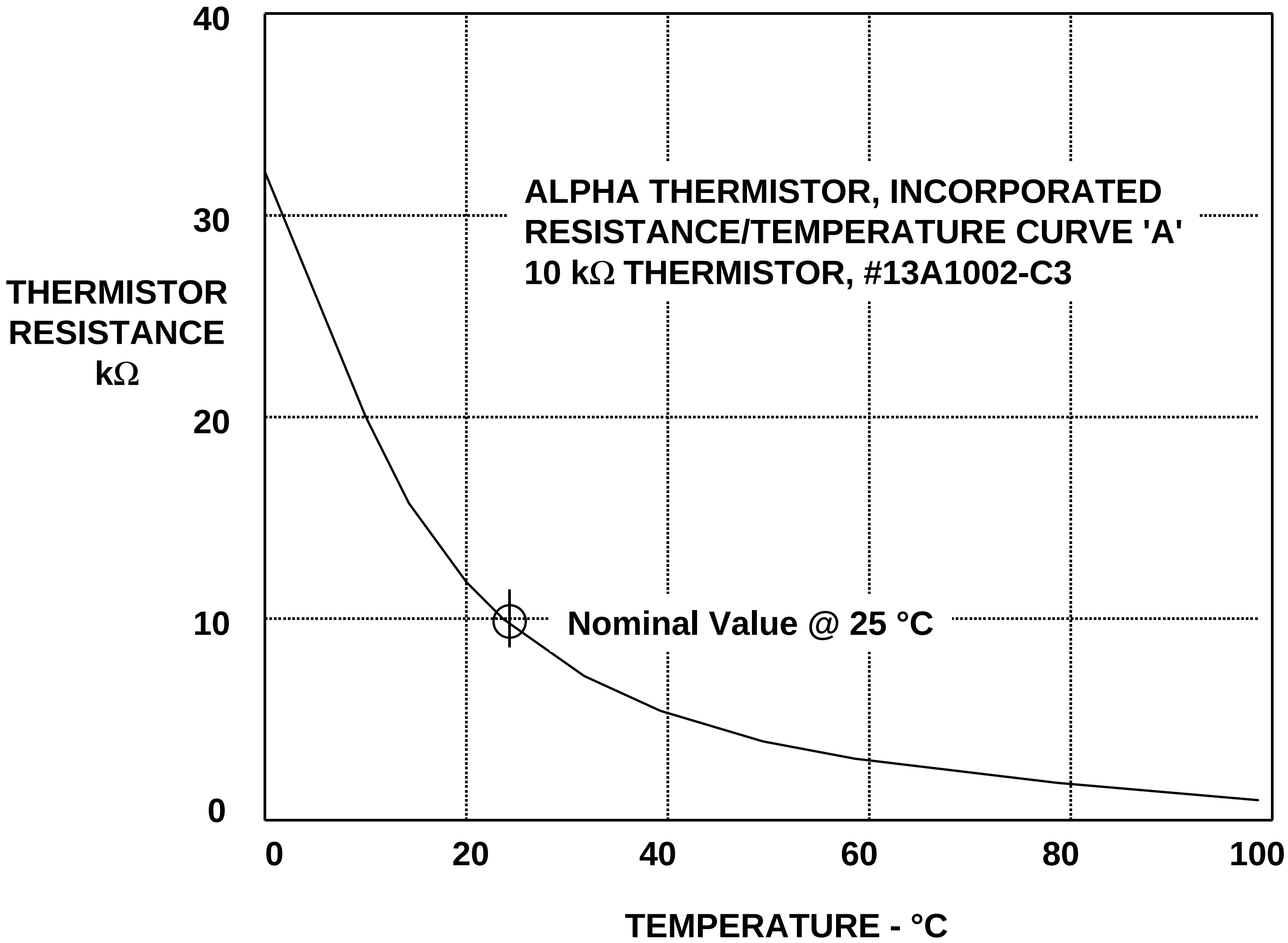
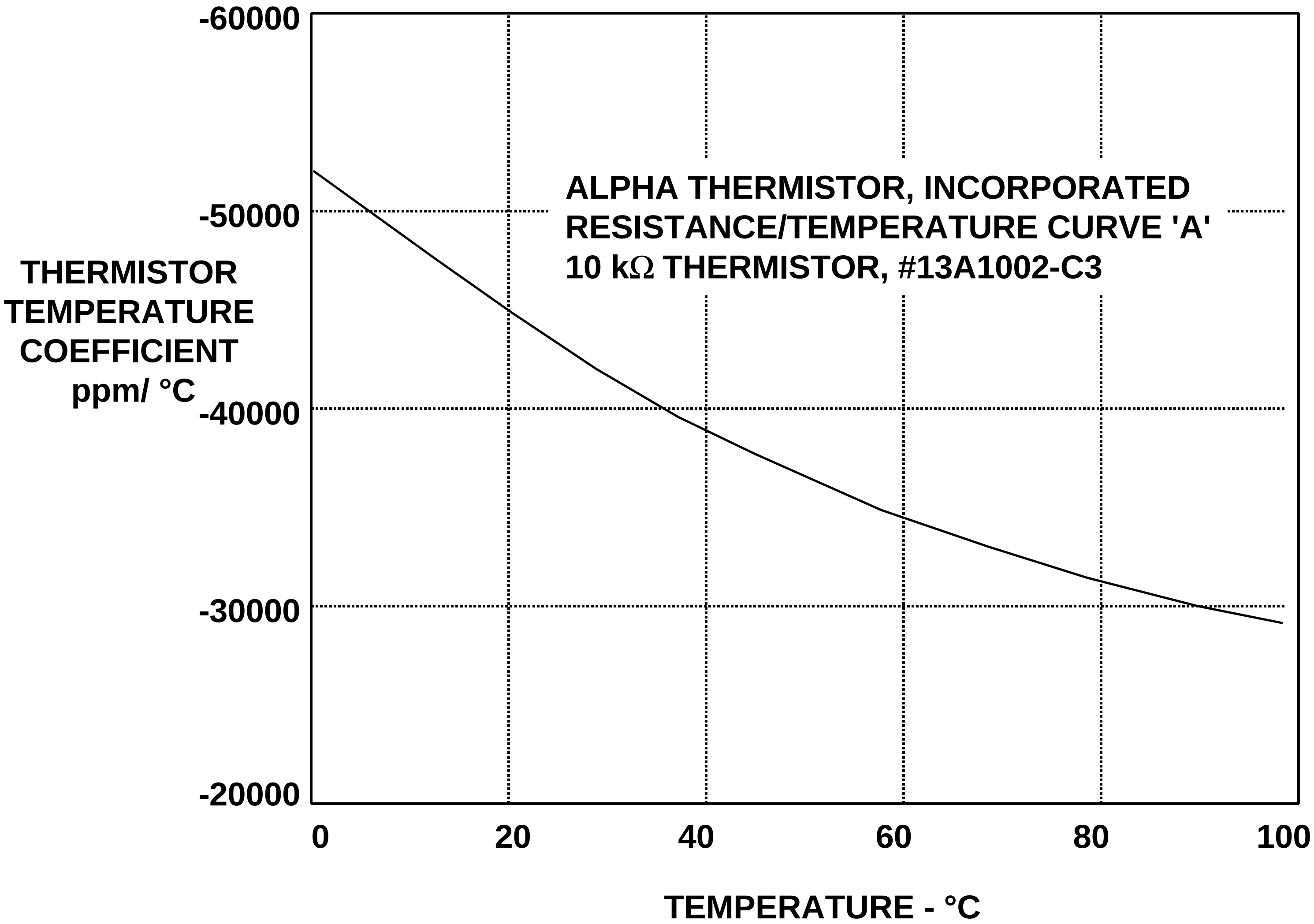
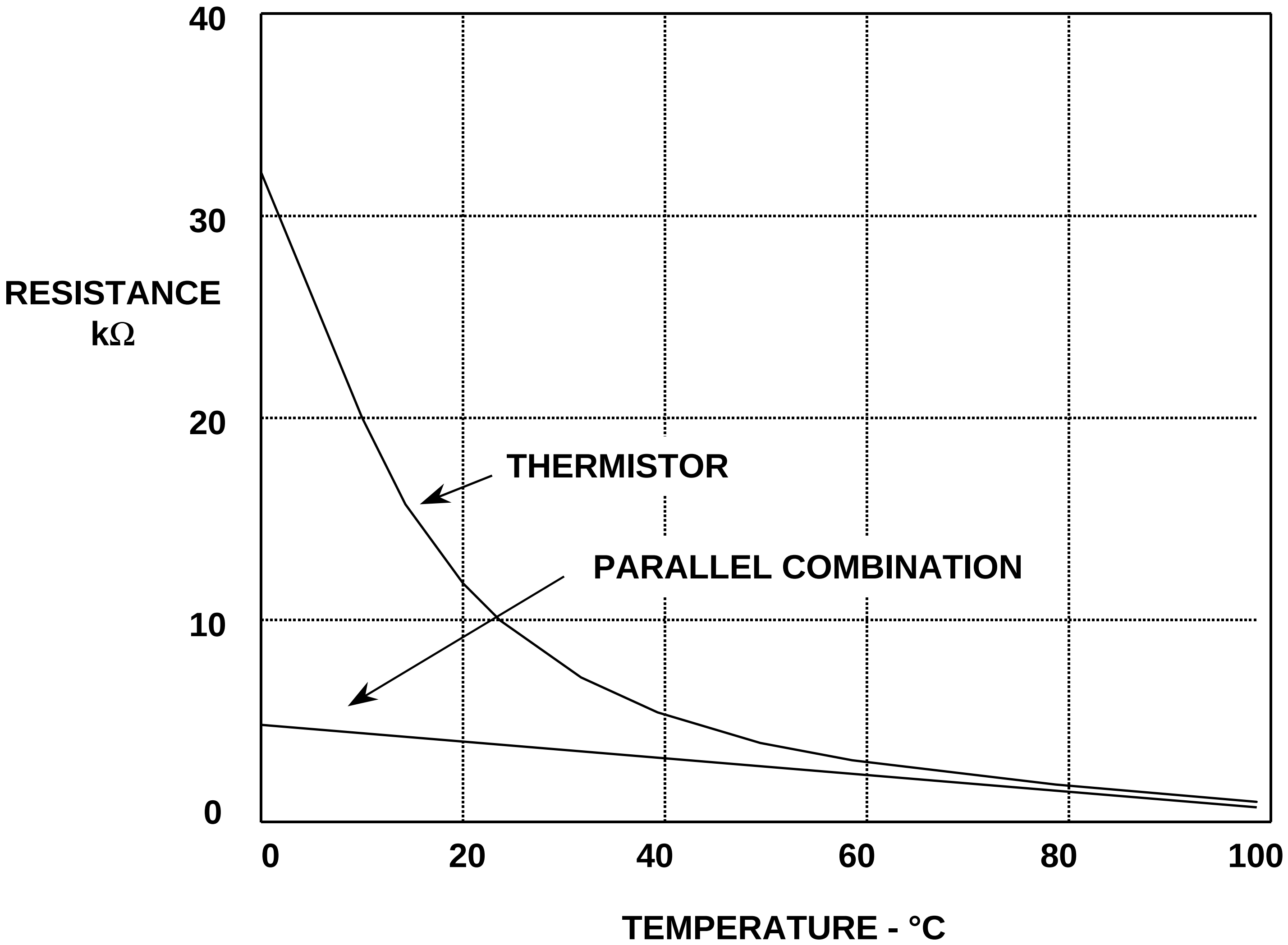
RESISTANCE CHARACTERISTICS OF A 10kΩ NTC THERMISTOR



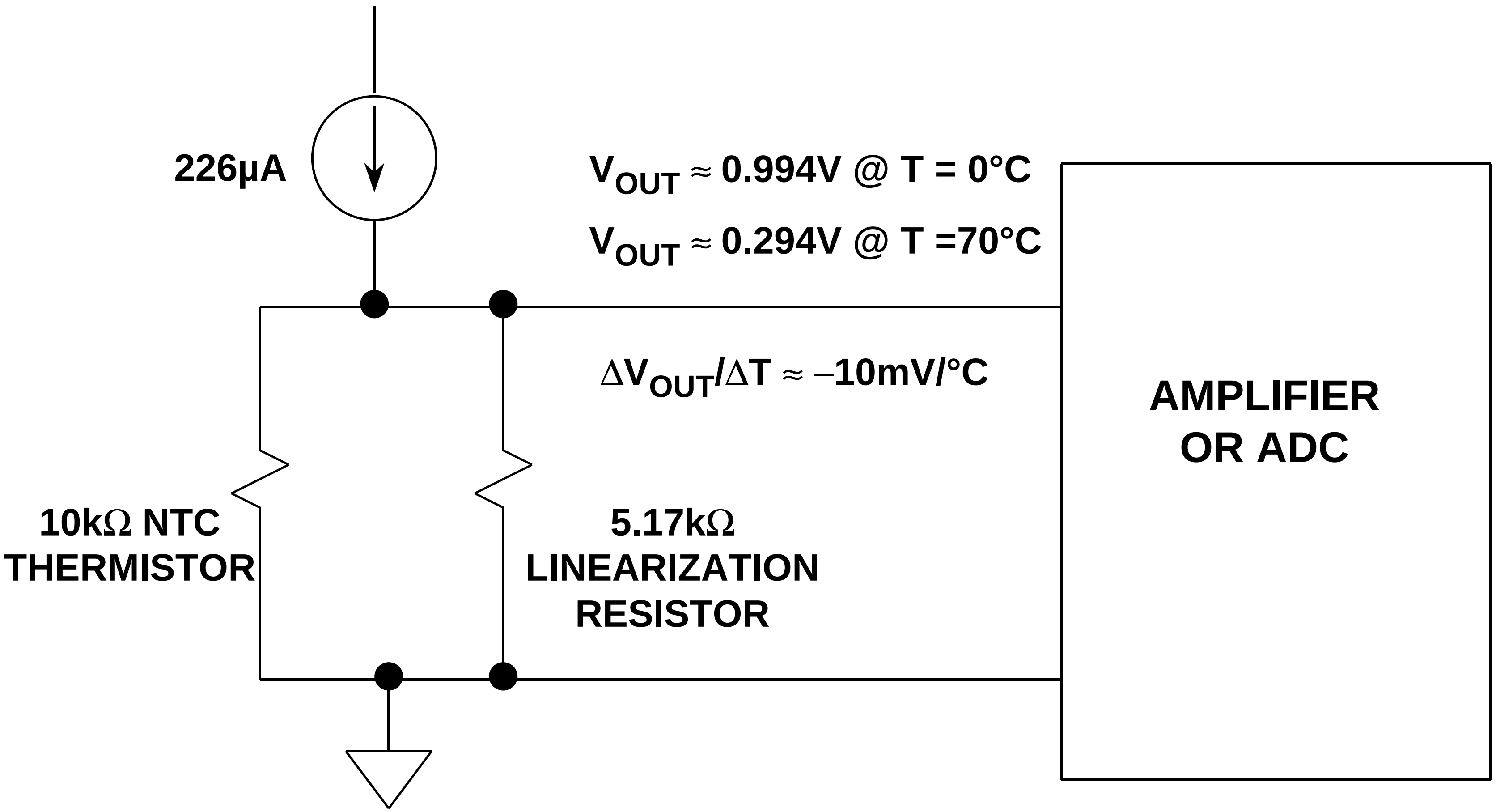
TEMPERATURE COEFFICIENT OF 10kΩ NTC THERMISTOR



LINEARIZATION OF NTC THERMISTOR USING A 5.17kΩ SHUNT RESISTOR

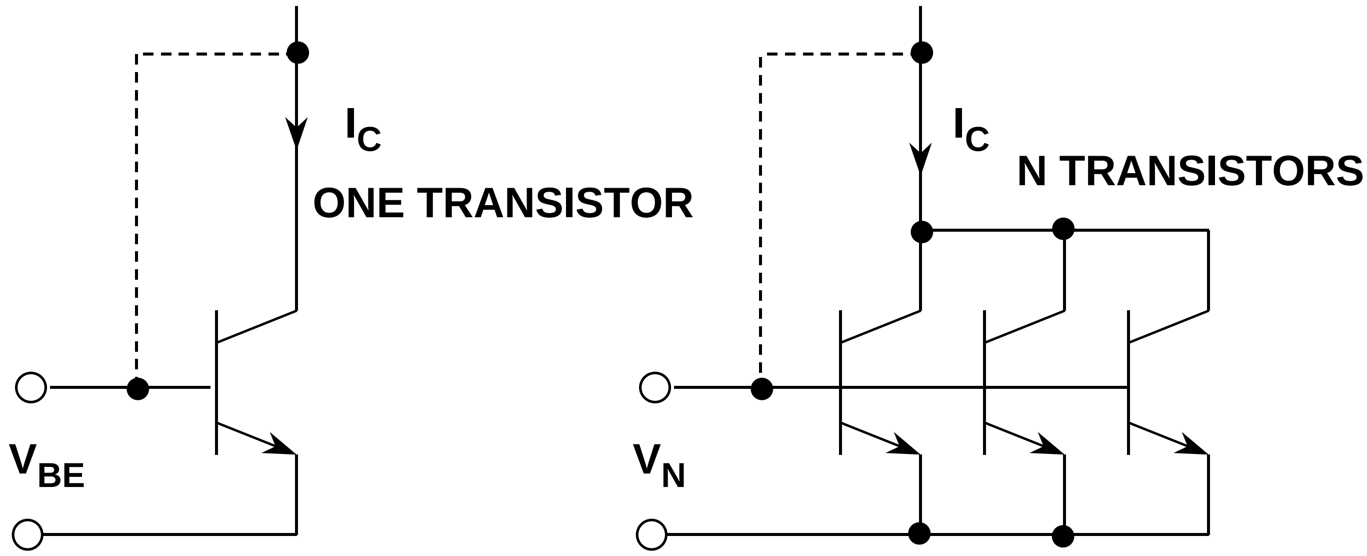


LINEARIZED THERMISTOR AMPLIFIER



LINEARITY ≈ ± 2°C, 0°C TO +70°C

BASIC RELATIONSHIPS FOR SEMICONDUCTOR TEMPERATURE SENSORS



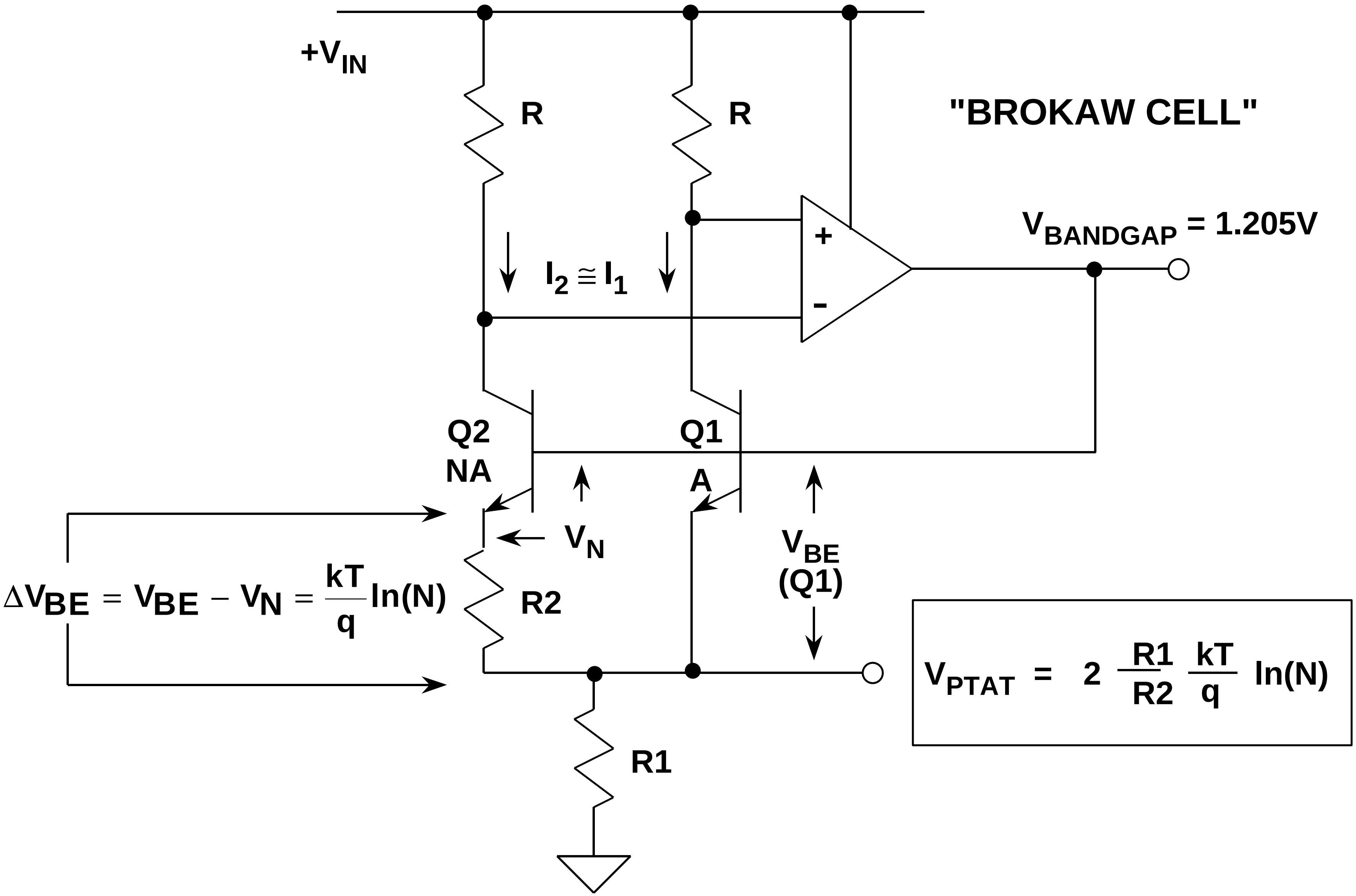
$$V_{BE} = \frac{kT}{q}\ln\left(\frac{I_C}{I_S}\right)$$

$$V_N = \frac{kT}{q}\ln\left(\frac{I_C}{N \cdot I_S}\right)$$

$$\Delta V_{BE} = V_{BE} - V_N = \frac{kT}{q}\ln(N)$$

INDEPENDENT OF I_C, I_S

CLASSIC BANDGAP TEMPERATURE SENSOR



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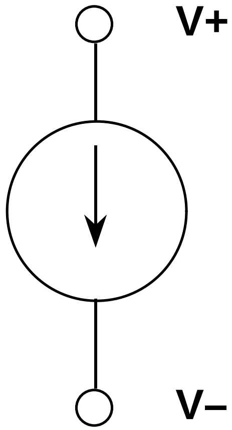
CURRENT OUTPUT SENSORS: AD592, TMP17

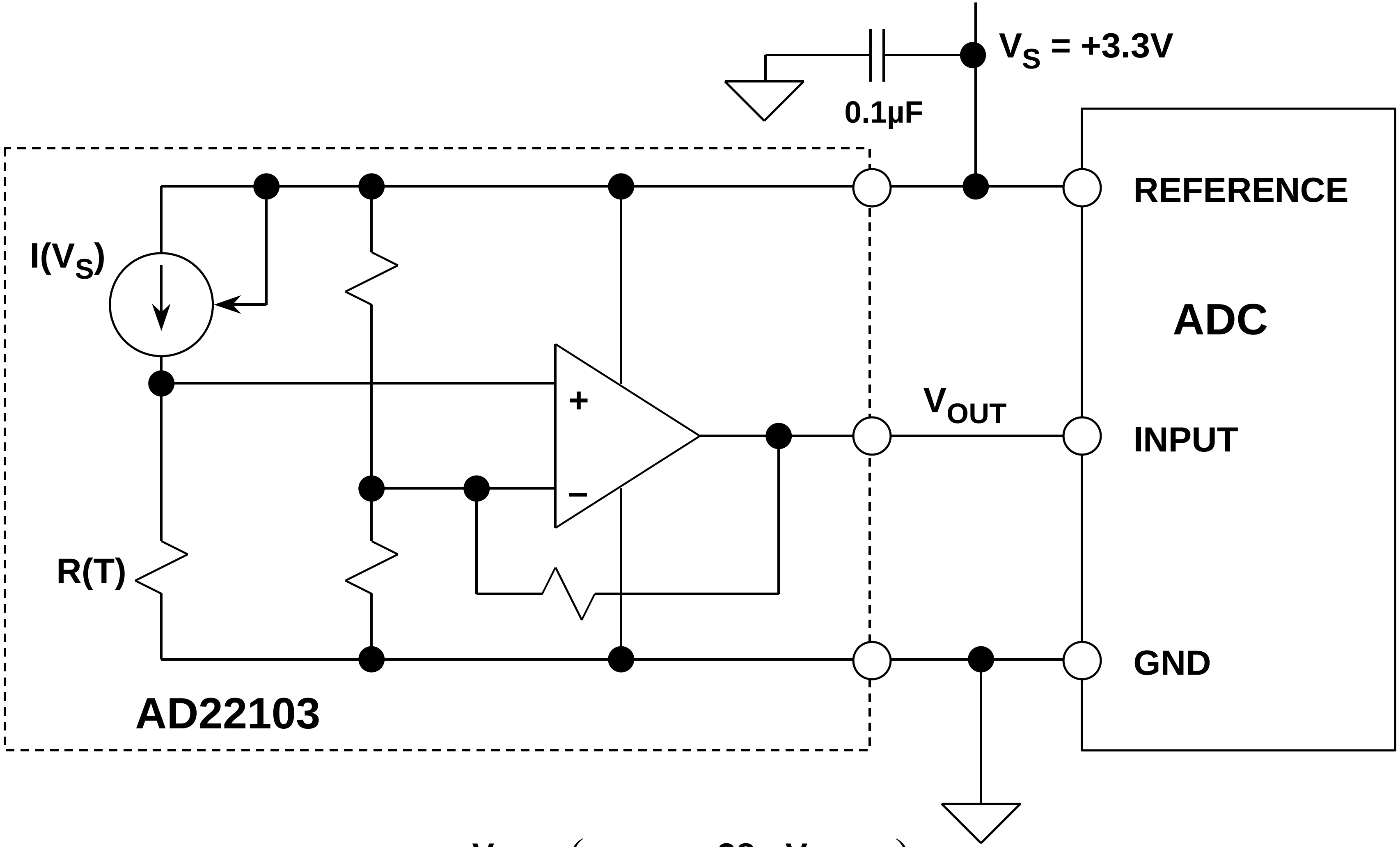


AD592: TO-92 PACKAGE

TMP17: SO-8 PACKAGE

- 1µA/K Scale Factor
- Nominal Output Current @ +25°C: 298.2µA
- Operation from 4V to 30V
- ±0.5°C Max Error @ 25°C, ±1.0°C Error Over Temp, ±0.1°C Typical Nonlinearity (AD592CN)
- ±2.5°C Max Error @ 25°C, ±3.5°C Error Over Temp, ±0.5°C Typical Nonlinearity (TMP17F)
- AD592 Specified from –25°C to +105°C
- TMP17 Specified from –40°C to +105°C

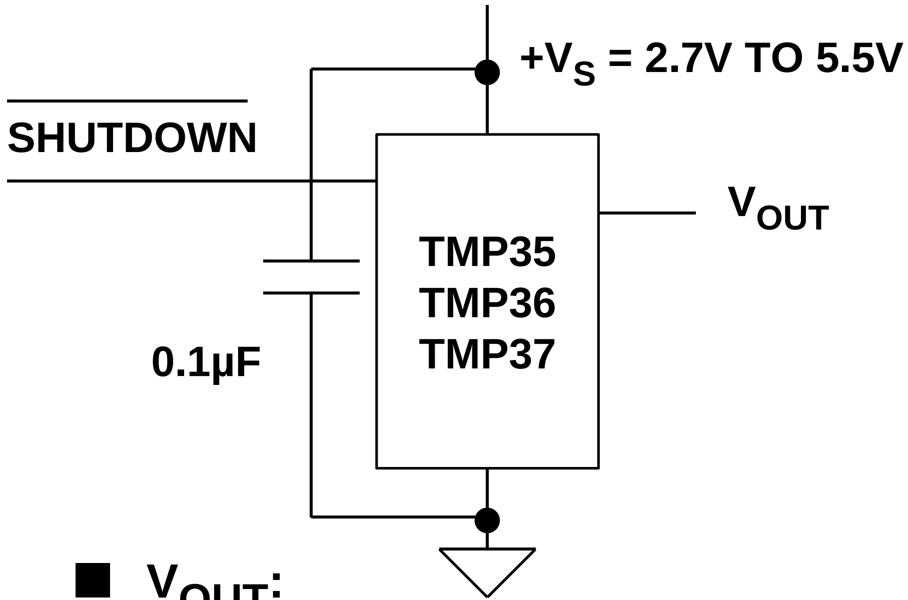
RATIOMETRIC VOLTAGE OUTPUT SENSORS

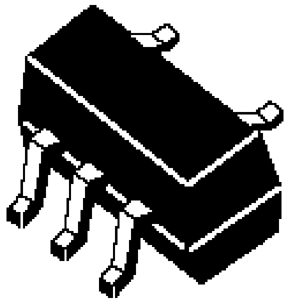


$$V_{OUT} = \frac{V_S}{3.3V} \times \left(0.25V + \frac{28mV}{°C} \times T_A \right)$$

a

ABSOLUTE VOLTAGE OUTPUT SENSORS WITH SHUTDOWN



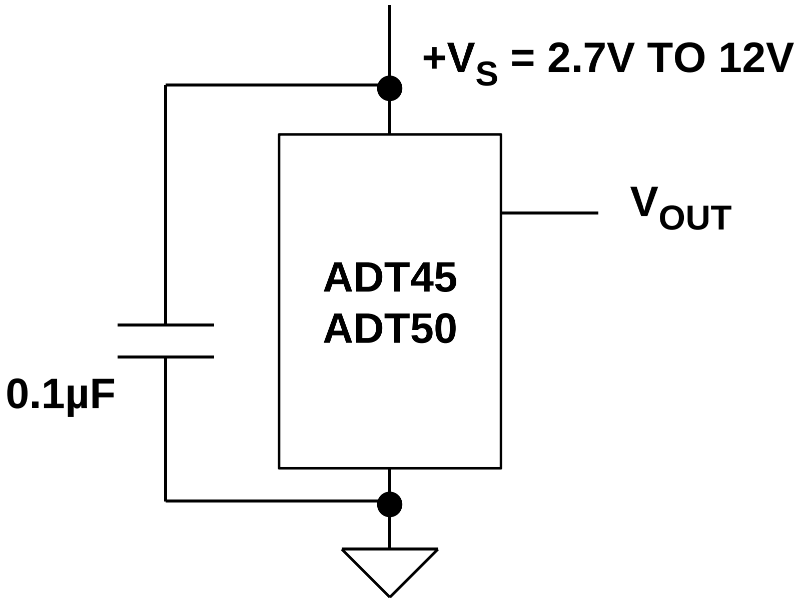


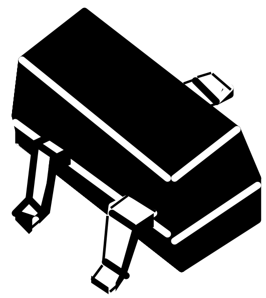
SOT-23-5

ALSO
SO-8
OR TO-92

- V_{OUT}:
  - TMP35, 250mV @ 25°C, 10mV/°C (+10°C to +125°C)
  - TMP36, 750mV @ 25°C, 10mV/°C (–40°C to +125°C)
  - TMP37, 500mV @ 25°C, 20mV/°C (+5°C to +100°C)
- ±2°C Error Over Temp (Typical), ±0.5°C Non-Linearity (Typical)
- Specified –40°C to +125°C
- 50µA Quiescent Current, 0.5µA in Shutdown Mode

ADT45/ADT50 ABSOLUTE VOLTAGE OUTPUT SENSORS

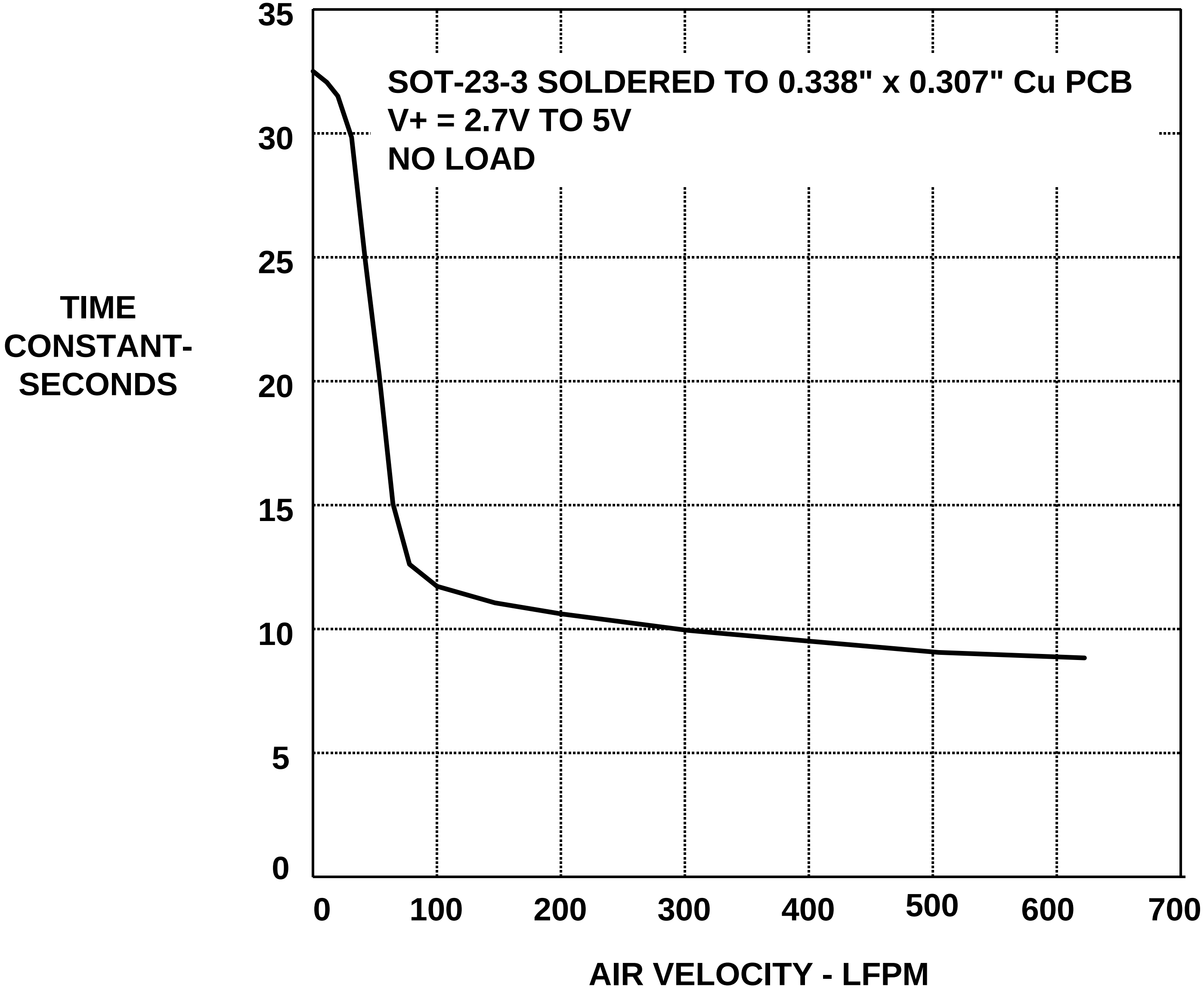




SOT-23

- V_{OUT}:
  - ADT45, 250mV @ 25°C, 10mV/°C Scale Factor
  - ADT50, 750mV @ 25°C, 10mV/°C Scale Factor
- ±2°C Error Over Temp (Typical), ±0.5°C Non-Linearity (Typical)
- Specified –40°C to +125°C
- 60µA Quiescent Current

THERMAL RESPONSE IN FORCED AIR FOR SOT-23-3



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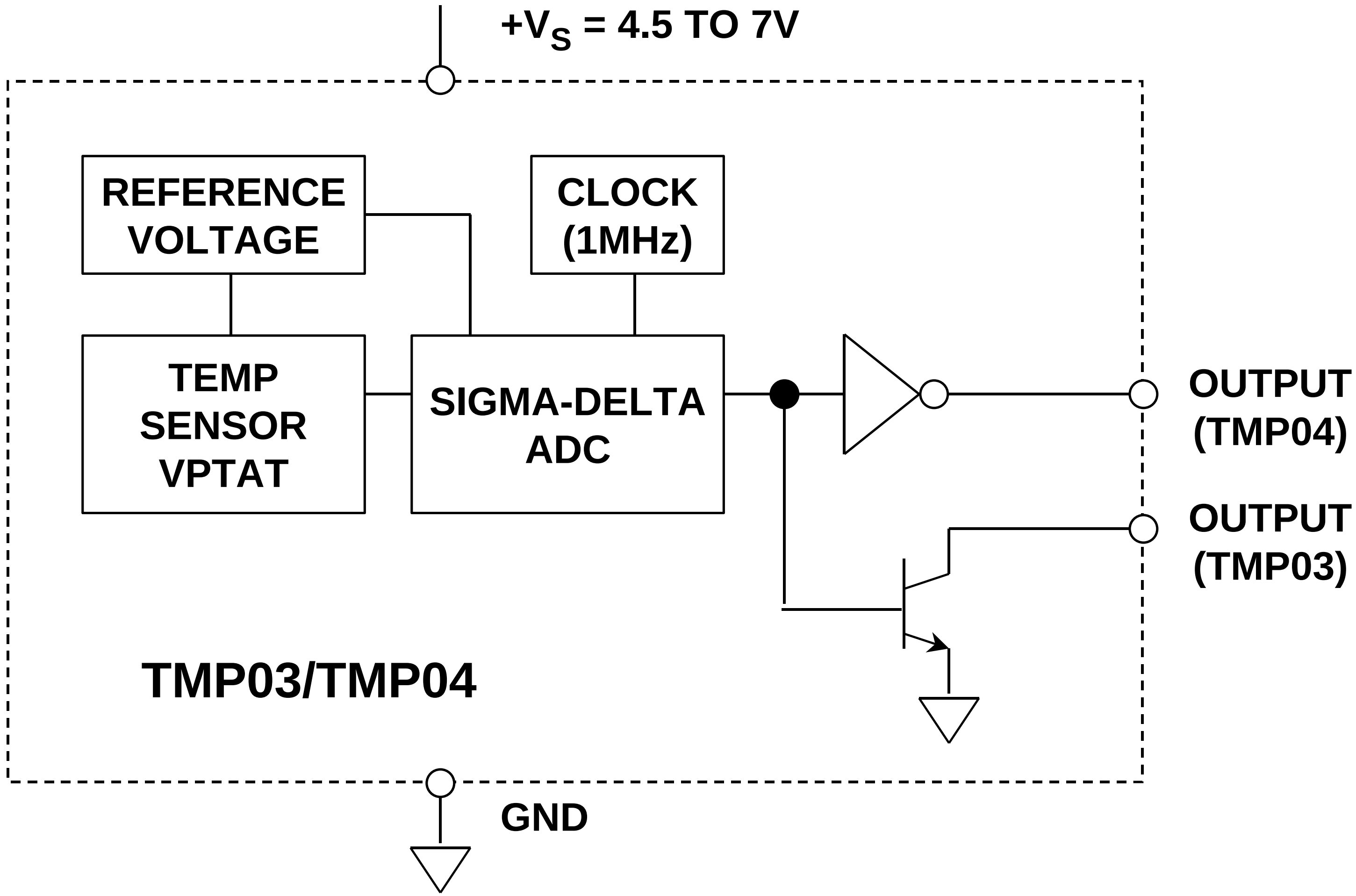
DIGITAL OUTPUT SENSORS: TMP03/04



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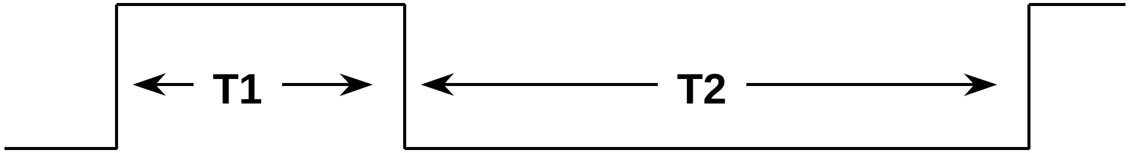
TMP03/TMP04 OUTPUT FORMAT

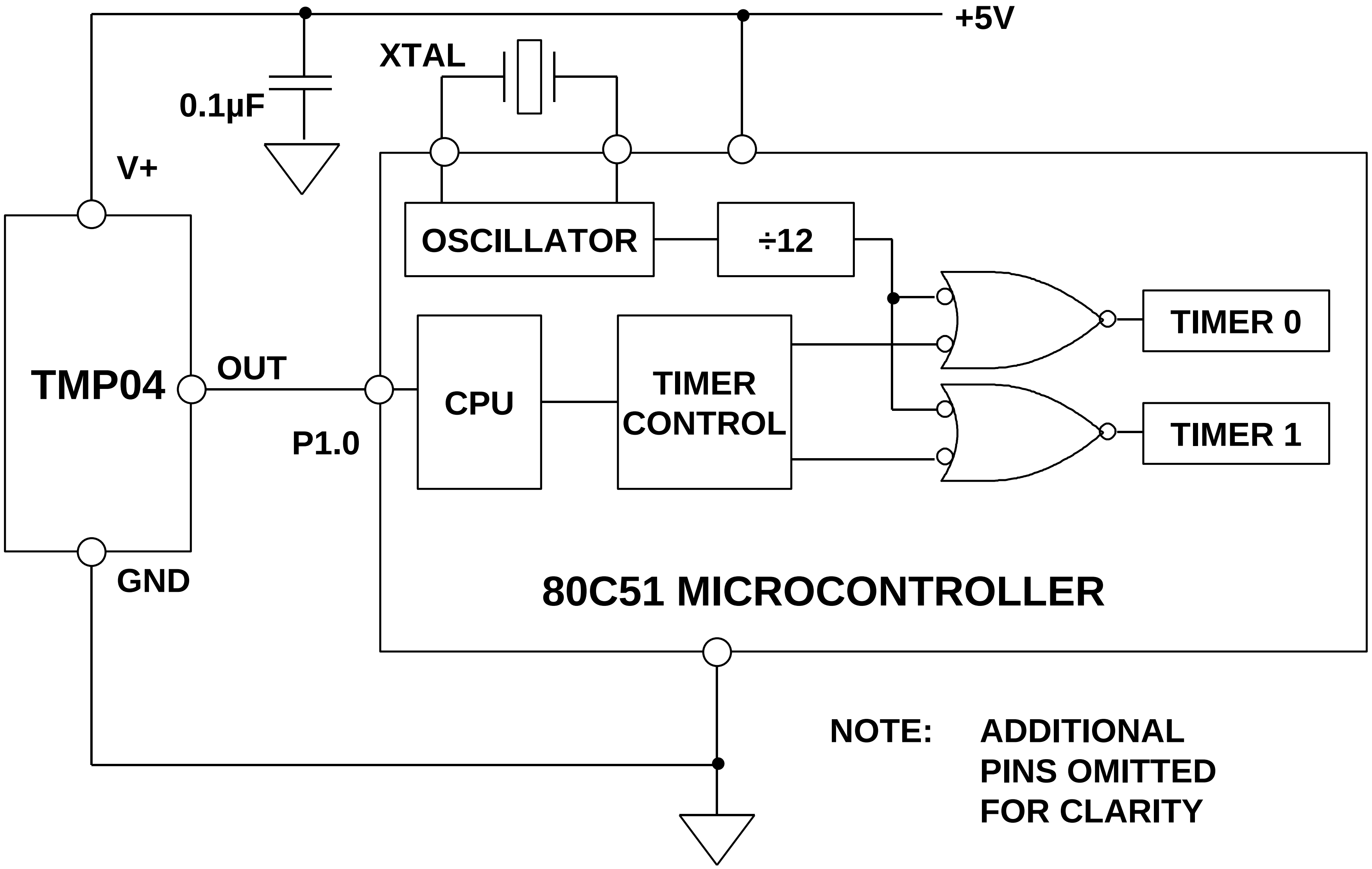


$$\text{TEMPERATURE } (^\circ\text{C}) = 235 - \left(\frac{400 \times \text{T1}}{\text{T2}}\right)$$

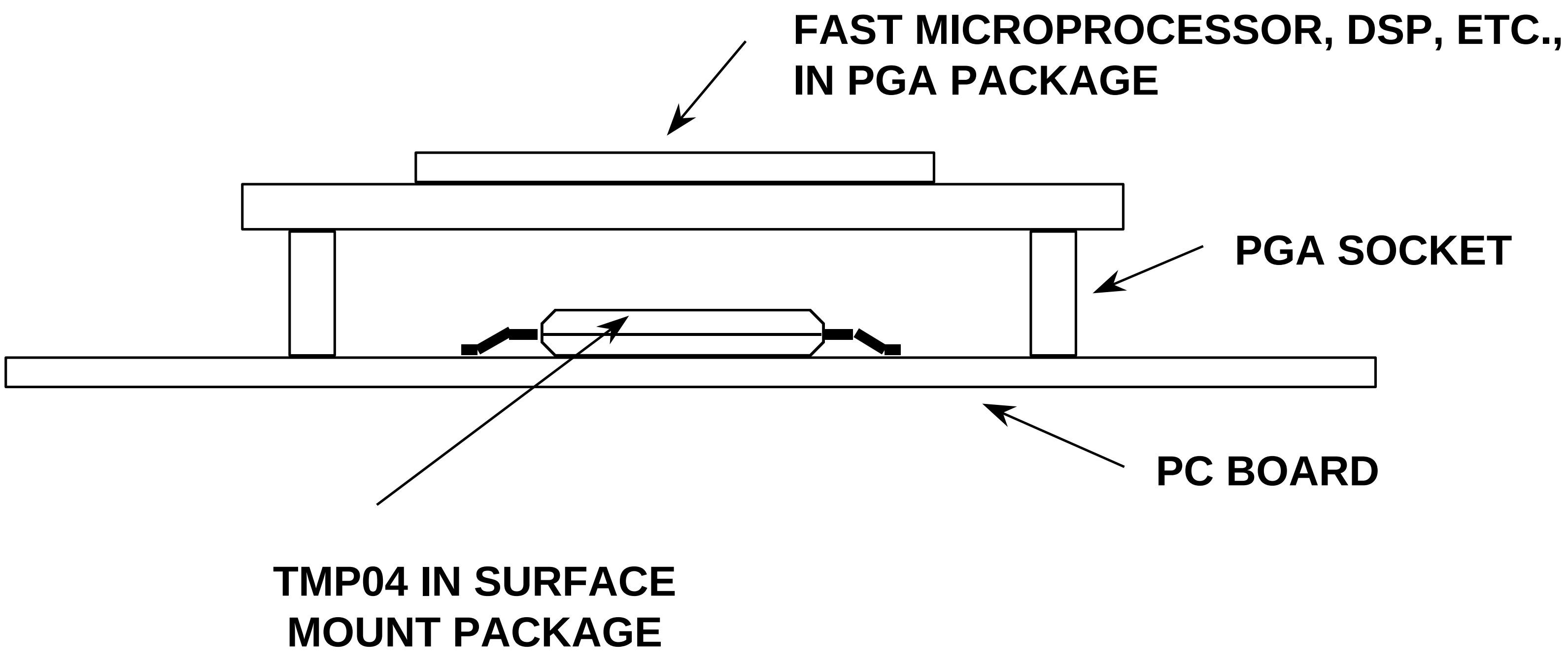
$$\text{TEMPERATURE } (^\circ\text{F}) = 455 - \left(\frac{720 \times \text{T1}}{\text{T2}}\right)$$

- **T1 Nominal Pulse Width = 10ms**
- **±1.5°C Error Over Temp, ±0.5°C Non-Linearity (Typical)**
- **Specified –40°C to +100°C**
- **Nominal T1/T2 @ 0°C = 60%**
- **Nominal Frequency @ +25°C = 35Hz**
- **6.5mW Power Consumption @ 5V**
- **TO-92, SO-8, or TSSOP Packages**

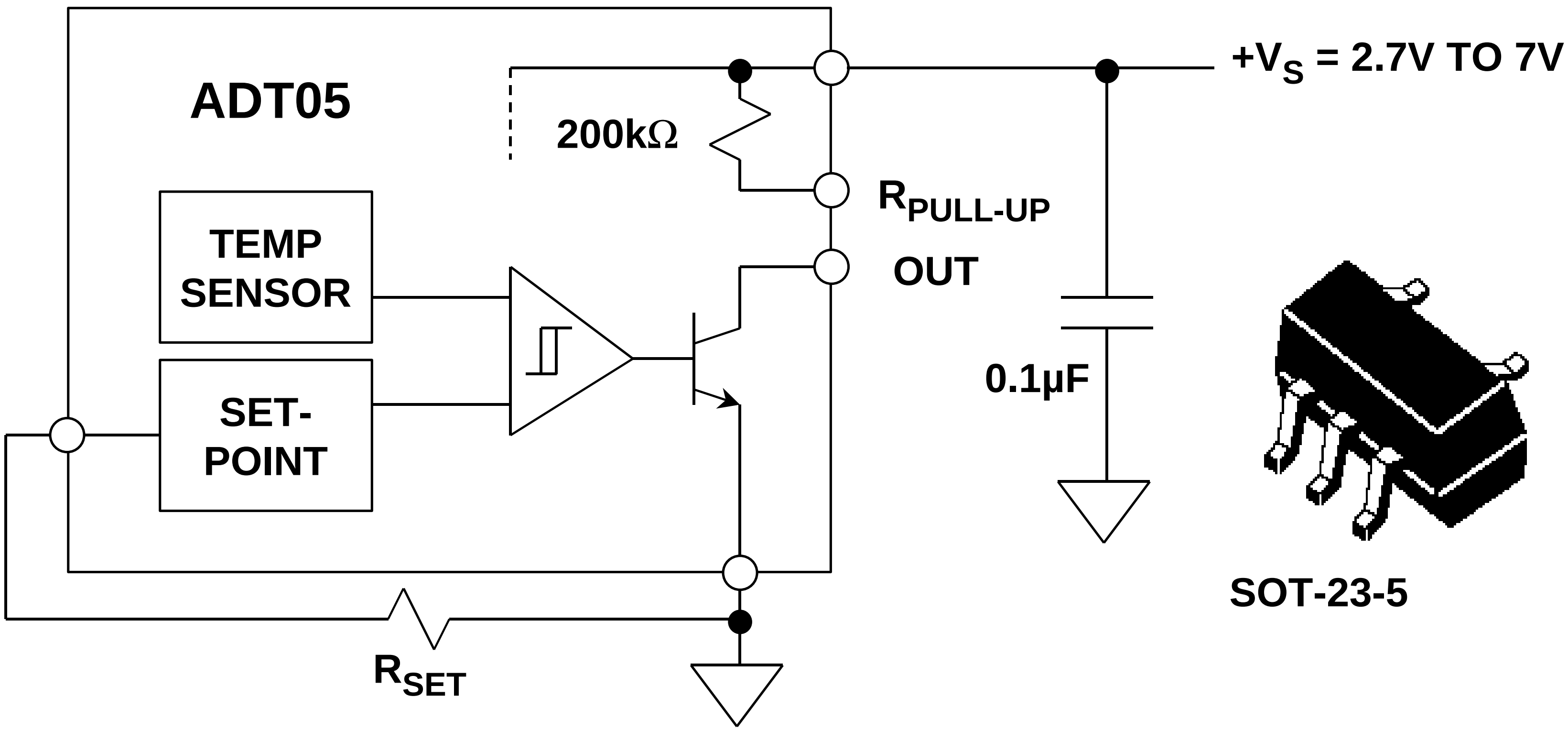
INTERFACING TMP04 TO A MICROCONTROLLER



MONITORING HIGH POWER MICROPROCESSOR OR DSP WITH TMP04

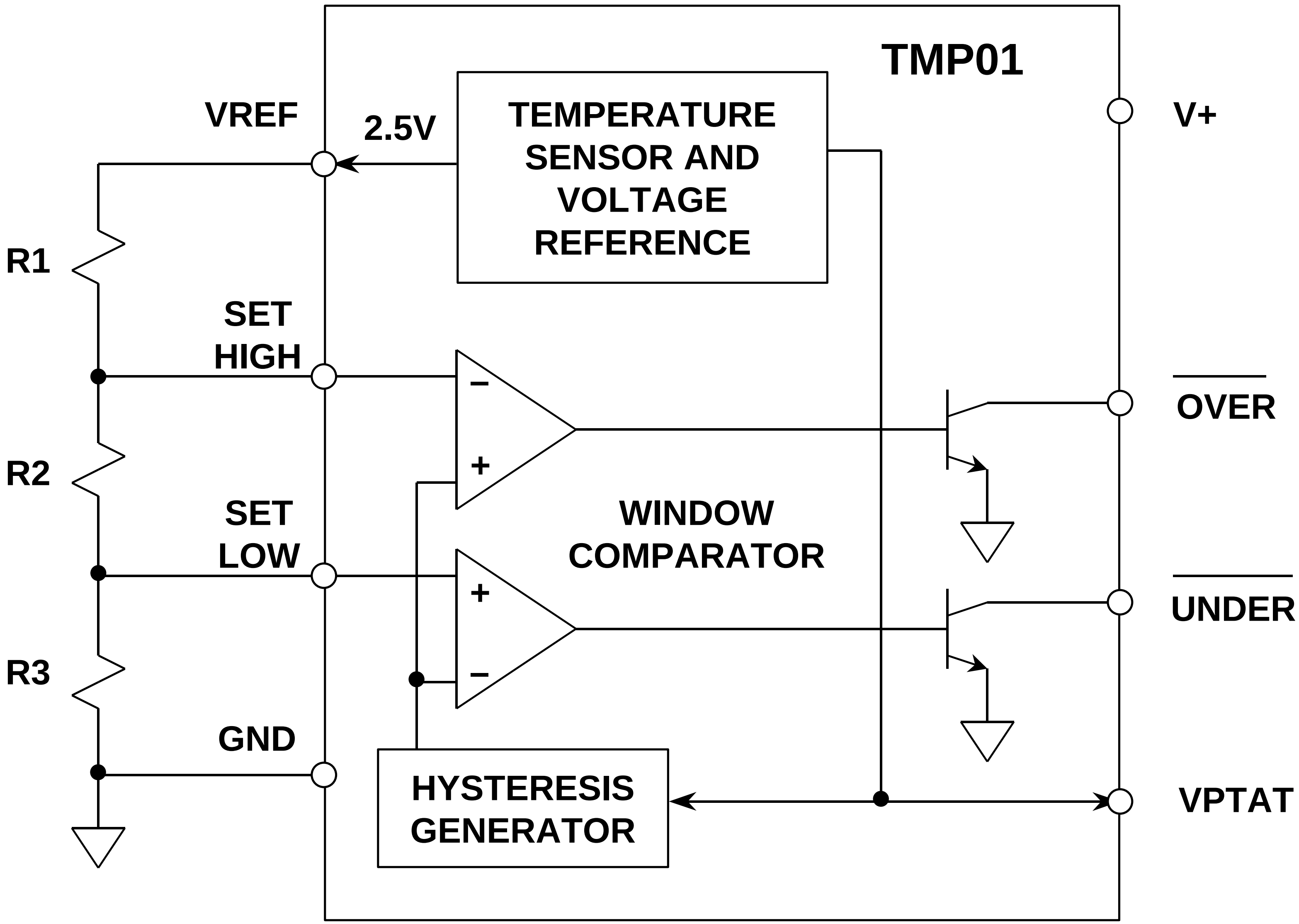


ADT05 THERMOSTATIC SWITCH



- ±2°C Setpoint Accuracy
- 4°C Preset Hysteresis
- Specified Operating Range: –40°C to + 150°C
- Power Dissipation: 200µW @ 3.3V

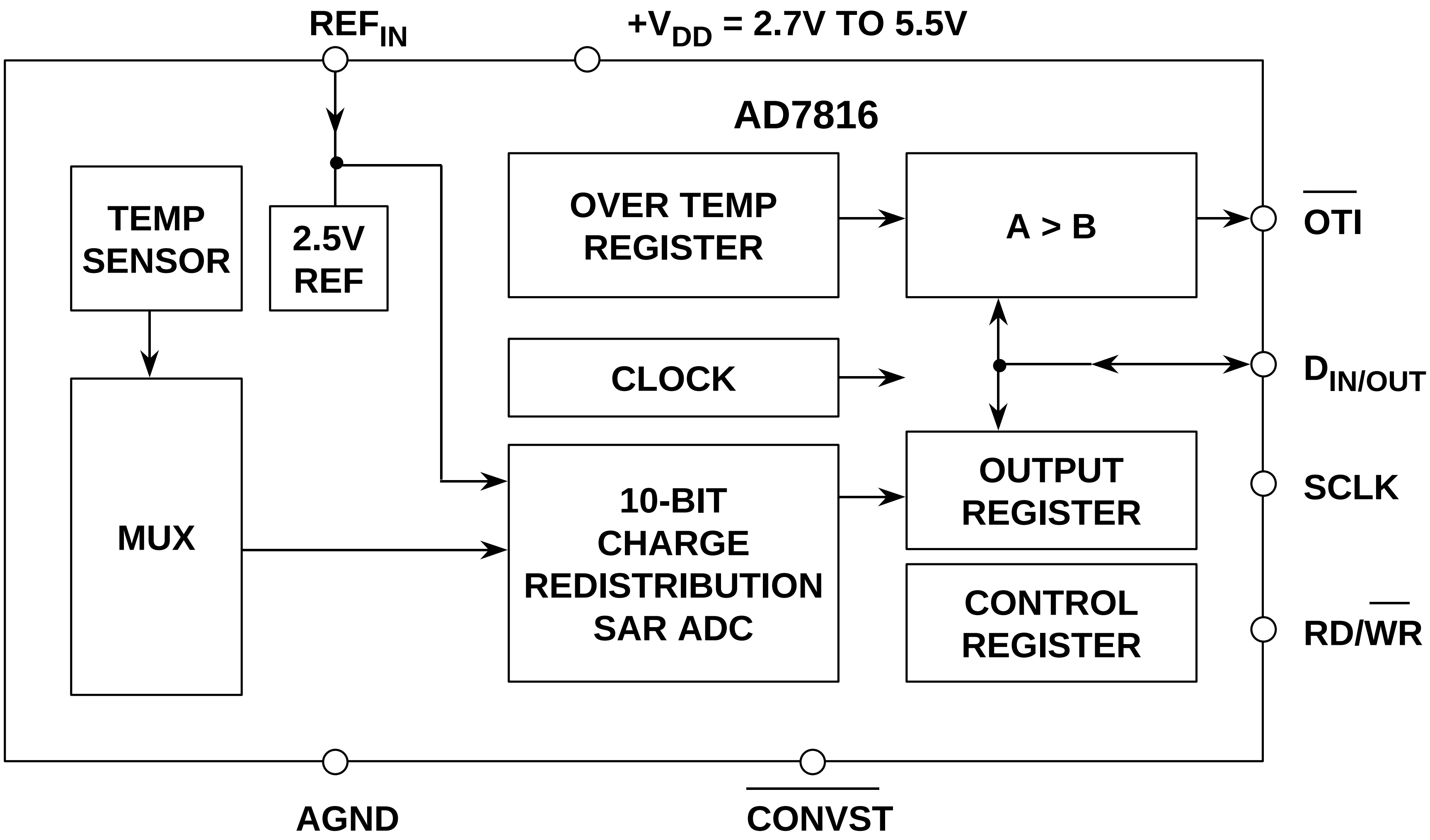
TMP01 PROGRAMMABLE SETPOINT CONTROLLER



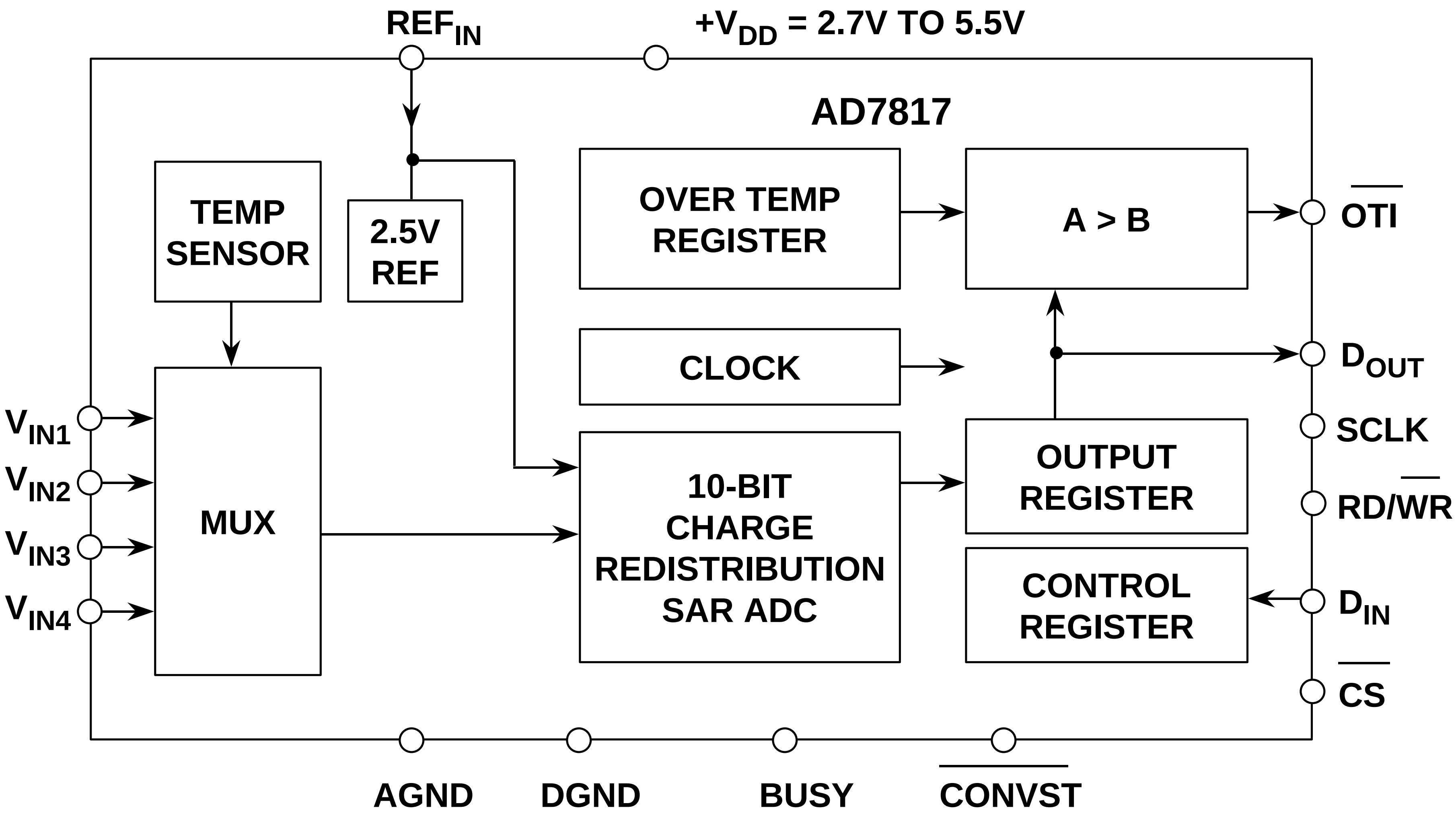
TMP01 SETPOINT CONTROLLER KEY FEATURES

- V_C: 4.5 to 13.2V
- Temperature Output: VPTAT, +5mV/K
- Nominal 1.49V Output @ 25°C
- ±1°C Typical Accuracy Over Temperature
- Specified Operating Range: –55°C to + 125°C
- Resistor-Programmable Hysteresis
- Resistor-Programmable Setpoints
- Precision 2.5V ±8mV Reference
- 400µA Quiescent Current, 1µA in Shutdown
- Packages: 8-Pin Dip, 8-Pin SOIC, 8-Pin TO-99
- Other Setpoint Controllers:
  - Dual Setpoint Controllers: ADT21/ADT22 (3V Versions of TMP01 with Internal Hysteresis)
  - Quad Setpoint Controller: ADT14

AD7816 10-BIT DIGITAL TEMPERATURE SENSOR WITH SERIAL INTERFACE



AD7817 10-BIT MUXED INPUT ADC WITH TEMP SENSOR



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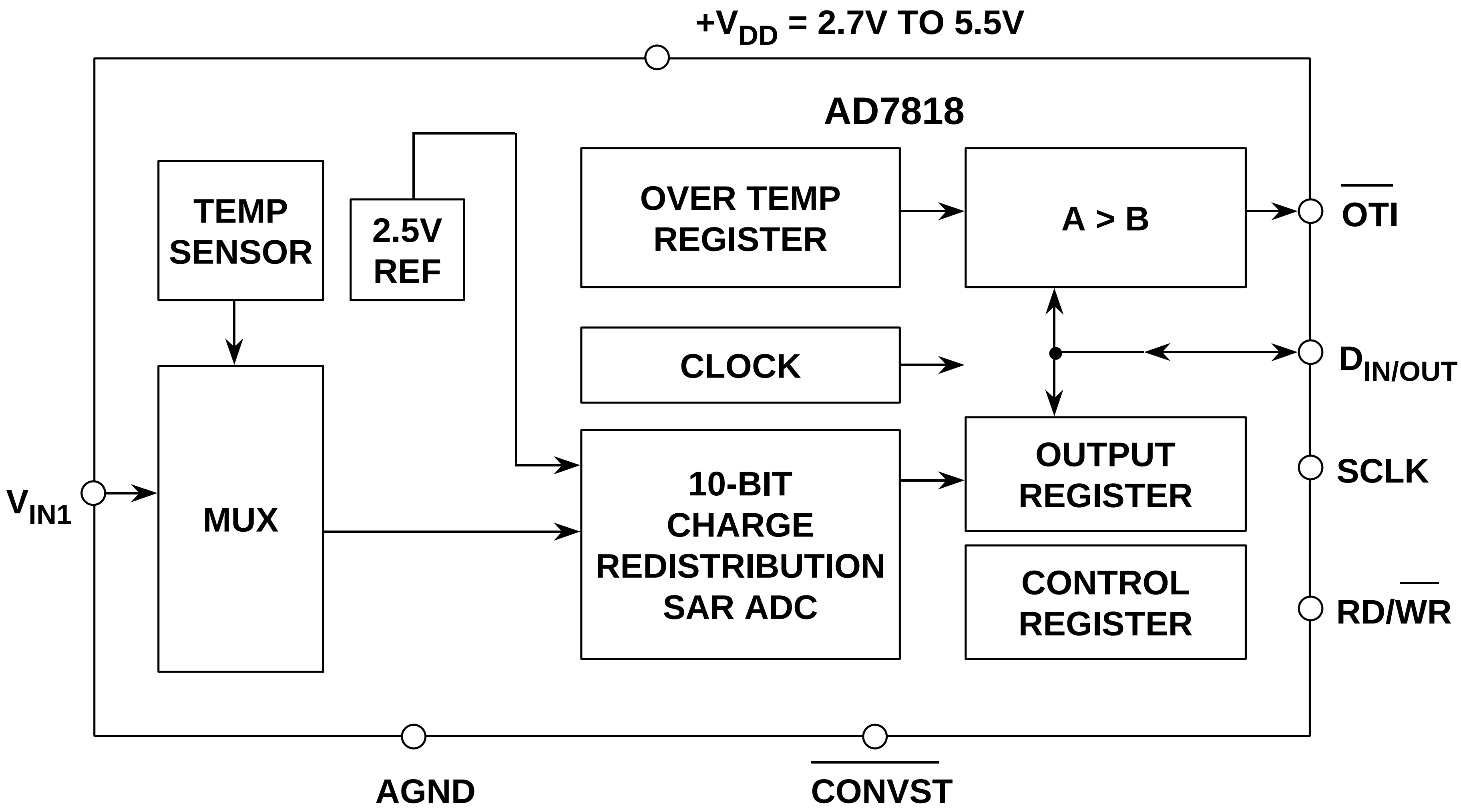
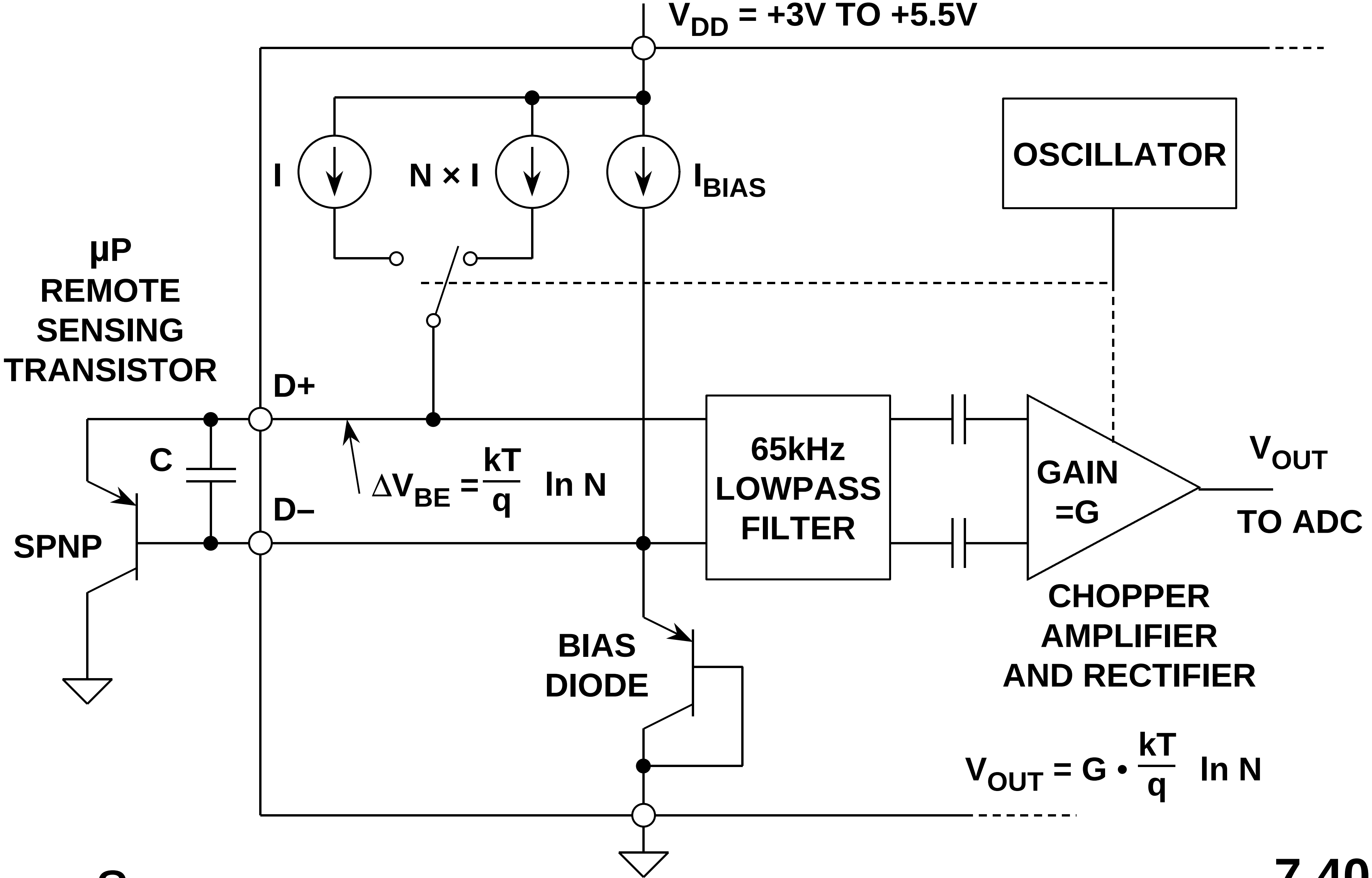
AD7818 SINGLE INPUT 10-BIT ADC WITH TEMP SENSOR



AD7816/7817/7818 - SERIES TEMP SENSOR 10-BIT ADCs WITH SERIAL INTERFACE

- 10-Bit ADC with 9µs Conversion Time
- Flexible Serial Interface (Intel 8051, Motorola SPI™ and QSPI™, National MICROWIRE™)
- On-Chip Temperature Sensor: –55°C to +125°C
- Temperature Accuracy: ± 2°C from –40°C to +85°C
- On-Chip Voltage Reference: 2.5V ±1%
- +2.7V to +5.5V Power Supply
- 4µW Power Dissipation at 10Hz Sampling Rate
- Auto Power Down after Conversion
- Over-Temp Interrupt Output
- Four Single-Ended Analog Input Channels: AD7817
- One Single-Ended Analog Input Channel: AD7818
- AD7416/7417/7418: Similar, but have I^2C Compatible Interface

ADM1021 MICROPROCESSOR TEMPERATURE MONITOR INPUT SIGNAL CONDITIONING CIRCUITS



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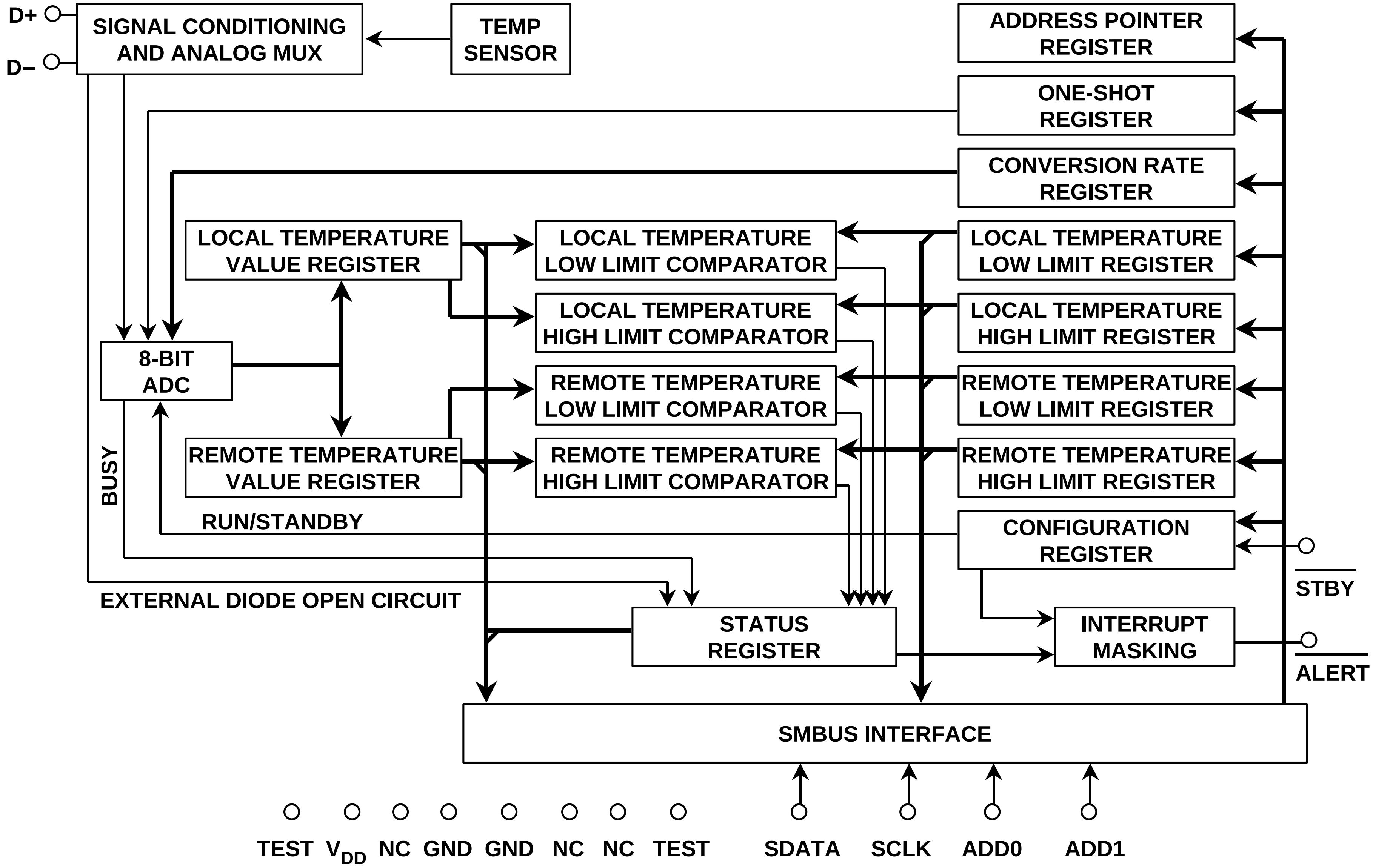
ADM1021 SIMPLIFIED BLOCK DIAGRAM



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ADM1021 KEY SPECIFICATIONS

- On-Chip and Remote Temperature Sensing
- 1°C Accuracy for On-Chip Sensor
- 3°C Accuracy for Remote Sensor
- Programmable Over / Under Temperature Limits
- 2-Wire SMBus Serial Interface
- 70µA Max Operating Current
- 3µA Standby Current
- +3V to +5.5V Supplies
- 16-Pin QSOP Package