Chipsmall Limited consists of a professional team with an average of over 10 year of expertise in the distribution of electronic components. Based in Hongkong, we have already established firm and mutual-benefit business relationships with customers from,Europe,America and south Asia,supplying obsolete and hard-to-find components to meet their specific needs.

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MCP9600

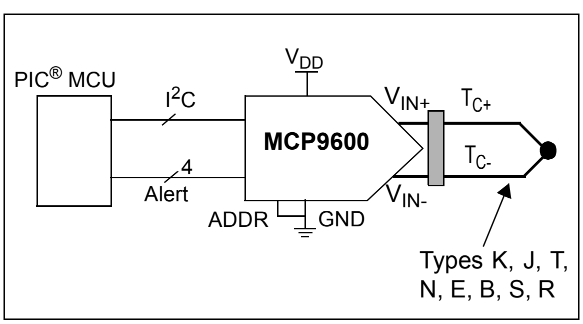
Thermocouple EMF to Temperature Converter, ±1.5 °C Maximum Accuracy

Features

- Thermocouple Electromotive Force (EMF) to °C Converter
  - Integrated Cold-Junction Compensation
- Supported Types (designated by NIST ITS-90):
  - Type K, J, T, N, S, E, B and R
- ±1.5°C (Max.) Hot-Junction Accuracy
- Measurement Resolution:
  - Hot- and Cold-Junctions: 0.0625°C (typical)
- Four Programmable Temperature Alert Outputs
  - Monitor Hot- or Cold-Junction Temperatures
  - Detect Rising or Falling Temperatures
  - Up to 255°C of Programmable Hysteresis
- Programmable Digital Filter for Temperature
- Low Power:
  - Shutdown Mode
  - Burst Mode: 1 to 128 Temperature Samples
- 2-Wire Interface: I^2C Compatible, 100 kHz
  - Supports Eight Devices per I^2C bus
- Operating Voltage Range: 2.7V to 5.5V
- Operating Current: 300 µA (typical)
- Shutdown Current: 2 µA (typical)
- Package: 20-lead MQFN

Typical Applications

- Petrochemical Thermal Management
- Hand-Held Measurement Equipment
- Industrial Equipment Thermal Management
- Ovens
- Industrial Engine Thermal Monitor
- Temperature Detection Racks



Description

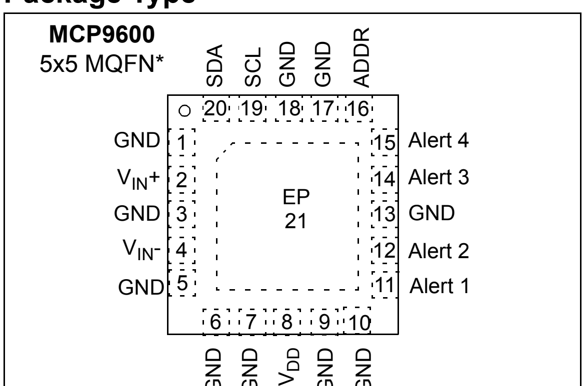
Microchip Technology Inc.'s MCP9600 converts thermocouple EMF to degree Celsius with integrated Cold-Junction compensation. This device corrects the thermocouple nonlinear error characteristics of eight thermocouple types and outputs ±1.5°C accurate temperature data for the selected thermocouple. The correction coefficients are derived from the National Institute of Standards and Technology (NIST) ITS-90 Thermocouple Database.

The MCP9600 digital temperature sensor comes with user-programmable registers which provide design flexibility for various temperature sensing applications. The registers allow user-selectable settings such as Low-Power modes for battery-powered applications, adjustable digital filter for fast transient temperatures and four individually programmable temperature alert outputs which can be used to detect multiple temperature zones.

The temperature alert limits have multiple user programmable configurations such as alert polarity as either an active-low or active-high push-pull output, and output function as comparator mode (useful for thermostat-type operation) or interrupt mode for microprocessor-based systems. In addition, the alerts can detect either a rising or a falling temperature with up to 255°C hysteresis.

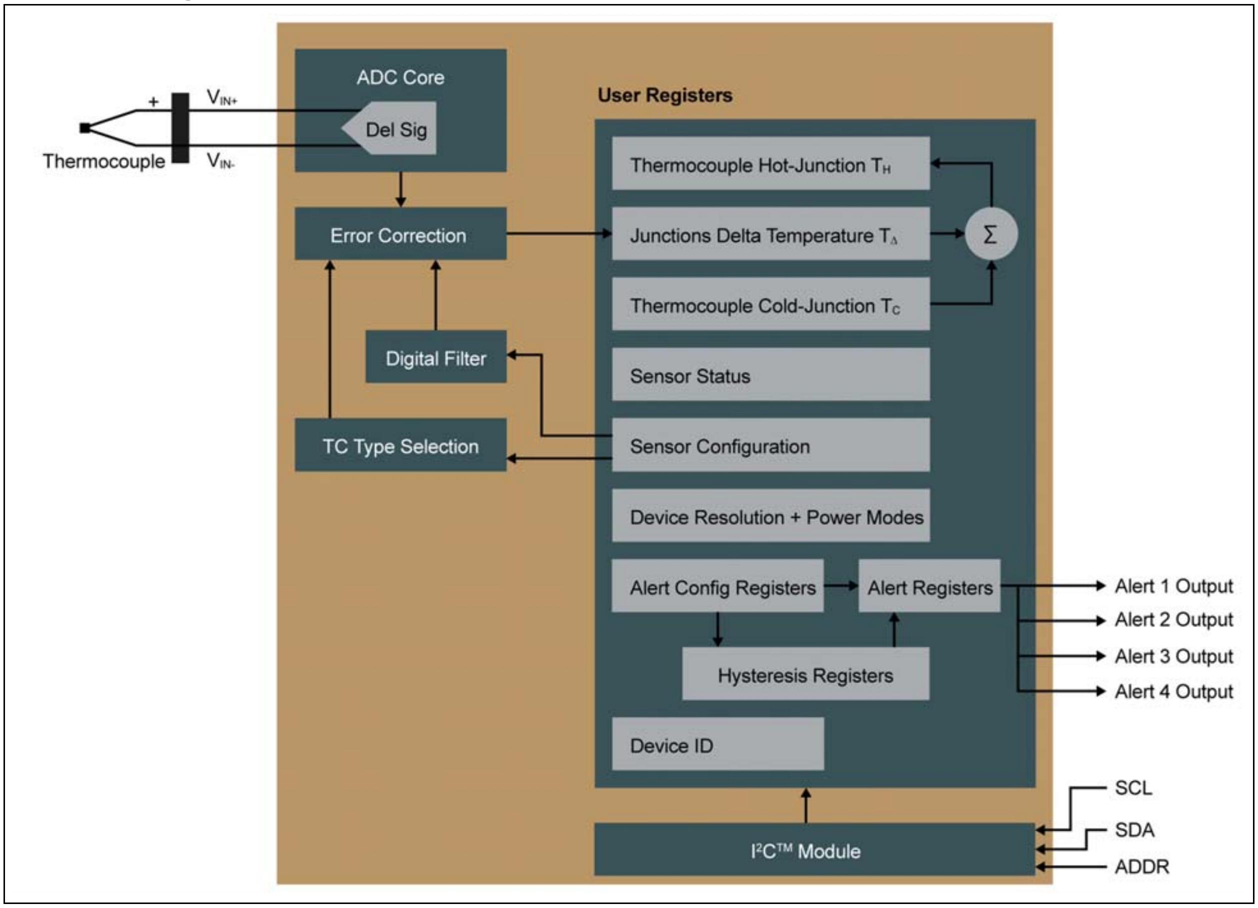
This sensor uses an industry standard 2-Wire, I^2C compatible serial interface and supports up to eight devices per bus by setting the device address using the ADDR pin.

Package Type

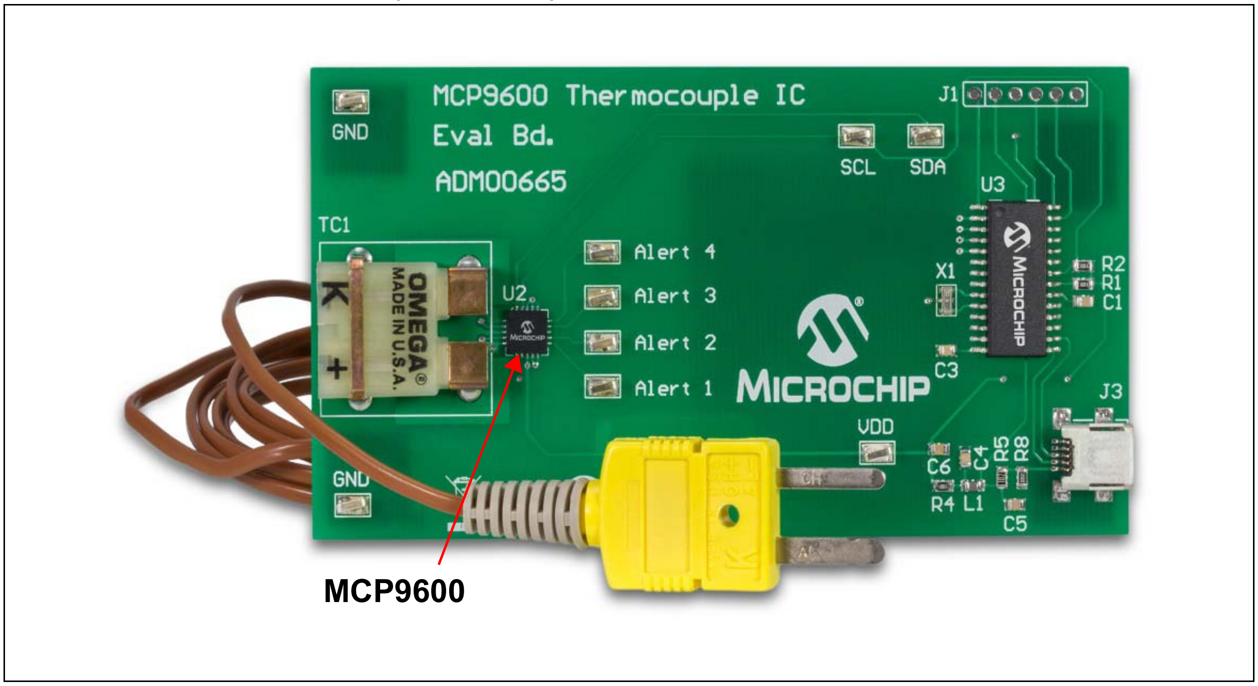


* Includes Exposed Thermal Pad (EP); see Table 3-1.

MCP9600 Registers



MCP9600 Evaluation Board (ADM00665)



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V_{DD} 6.0V
Voltage at all Input/Output Pins .... GND – 0.3V to 6.0V
Storage Temperature .... -65°C to +150°C
Ambient Temperature with Power Applied .... -40°C to +125°C
Junction Temperature (T_J) .... +150°C
ESD Protection on all Pins (HBM:MM) .... (4 kV:300V)
Latch-up Current at each Pin .... ±100 mA

† Notice: Stresses above those listed under "Maximum ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

DC CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, T_A = -40°C to +125°C (where: T_A = T_C, defined as Device Ambient Temperature).

Parameters	Sym.	Min.	Typ.	Max.	Unit	Conditions
Thermocouple Sensor Measurement Accuracy						
T_H Hot-Junction Accuracy (V_{DD} = 3.3V) $T_H = T_C + T_\Delta$	T_{H_ACY}	-1.5	±0.5	+1.5	°C	T_A = 0°C to +85°C,
		-3.0	±1	+3.0	°C	T_A = -40°C to +125°C
T_C Cold-Junction Accuracy (V_{DD} = 3.3V)	T_{C_ACY}	-1.0	±0.5	+1.0	°C	T_A = 0°C to +85°C
		-2.0	±1	+2.0	°C	T_A = -40°C to +125°C
T_Δ Junctions Temperature Delta Accuracy						
Type K: T_Δ = -200°C to +1372°C V_{EMF} range: -5.907 mV to 54.886 mV	T_{Δ_ACY}	-0.5	±0.25	+0.5	°C	T_A = 0°C to +85°C, V_{DD} = 3.3V (**Note 1**)
Type J: T_Δ = -150°C to +1200°C V_{EMF} range: -3.336 mV to 47.476 mV						
Type T: T_Δ = -200°C to +400°C V_{EMF} range: -5.603 mV to 20.81 mV						
Type N: T_Δ = -150°C to +1300°C V_{EMF} range: -3.336 mV to 47.476 mV						
Type E: T_Δ = -200°C to +1000°C V_{EMF} range: -8.825 mV to 76.298 mV						
Type S: T_Δ = 250°C to +1664°C V_{EMF} range: -1.875 mV to 17.529 mV						T_A = 0°C to +85°C, V_{DD} = 3.3V (**Note 1, 2**)
Type B: T_Δ = 1000°C to +1800°C V_{EMF} range: -4.834 mV to 13.591 mV						
Type R: T_Δ = 250°C to +1664°C V_{EMF} range: -1.923 mV to 19.732 mV						

Note 1: The T_{Δ_ACY} temperature accuracy specification is defined as the device accuracy to the NIST ITS-90 Thermocouple EMF to Degree Celsius conversion Database. T_Δ is also defined as the temperature difference between the Hot and Cold Junctions or temperatures from the NIST ITS-90 database.

2: The device measures temperature below the specified range, however the sensitivity to changes in temperature reduces exponentially. Type R and S measure down to -50°C, or -0.226mV_{EMF} and -0.235mV_{EMF}, respectively. Type B measures down to 500°C or 1.242mV_{EMF} (see Figures 2-7, 2-8, 2-14 and Figures 2-10, 2-11 and 2-17).

3: Exceeding the V_{IN_CM} input range may cause leakage current through the ESD protection diodes at the thermocouple input pins. This parameter is characterized but not production tested.

DC CHARACTERISTICS

Parameters	Sym.	Min.	Typ.	Max.	Unit	Conditions
Electrical Specifications: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, T_A = -40°C to +125°C (where: T_A = T_C, defined as Device Ambient Temperature).						
Sensor Characteristics						
T_C and T_H Temperature Resolution	T_{RES}	—	±0.0625	—	°C	With max. Resolution
Sampling Rate (T_A = +25°C)	t_{CONV}	—	320	—	ms	18-bit Resolution
		—	80	—	ms	16-bit Resolution
		—	20	—	ms	14-bit Resolution
		—	5	—	ms	12-bit Resolution
Temperature Calculation Time	t_{CALC}	—	12	—	ms	T_A = +25°C
Thermocouple Input						
Offset Error	V_{OERR}	—	±2	—	µV	
Offset Error Drift	V_{OERR_DRF}	—	50	—	nV/°C	
Full-Scale Gain Error	G_{ERR}	—	—	±0.04	%FS	T_A = 0°C to +85°C
Full-Scale Gain Error Drift	G_{ERR_DRF}	—	±0.01	—	%FS	
Full-Scale Integral Nonlinearity	INL	—	10	—	ppm	
Voltage Resolution	V_{RES}	—	2	—	µV	18-bit Resolution
Differential Mode Range	V_{IN_DF}	-250	—	+250	mV	ADC input range
Differential Mode Impedance	Z_{IN_DF}	—	300	—	kΩ	
Common-Mode Range	V_{IN_CM}	V_{DD}-0.3	—	V_{DD}+0.3	V	(**Note 3**)
Common-Mode Impedance	Z_{IN_CM}	—	25	—	MΩ	
Common-Mode Rejection Ratio	CMRR	—	105	—	dB	
Power Supply Rejection Ratio	PSRR	—	60	—	dB	
Line Regulation	V_{Line_R}	—	0.2	—	°C/V	
Alert 1, 2, 3, 4 Outputs						
Low-Level Voltage	V_{OL}	—	—	0.4	V	I_{OL}= 3 mA
High-Level Voltage	V_{OH}	V_{DD}-0.5	—	—	V	I_{OH}= 3 mA
Operating Voltage and Current						
Operating Voltage	V_{DD}	2.7	—	5.5	V	
I^2C Inactive Current	I_{DD}	—	0.3	0.5	mA	V_{DD}=3.3V, T_A = 85°C
I^2C Active Current or during t_{CALC}		—	1.5	2.5	mA	
Shutdown Current	I_{SHDN}	—	2	5	µA	I^2C Inactive
Power On Reset (POR) Thresholds	V_{POR}	1.0	2.1	2.6	V	Rising/Falling V_{DD}
Thermal Response						
5x5 mm MQFN Package (Cold-Junction)	t_{RSP}	—	3	—	s	Time to 63%, +25°C (Air) to +125°C (oil bath), 2x2 inch PCB

Note 1: The T_{Δ_ACY} temperature accuracy specification is defined as the device accuracy to the NIST ITS-90 Thermocouple EMF to Degree Celsius conversion Database. T_Δ is also defined as the temperature difference between the Hot and Cold Junctions or temperatures from the NIST ITS-90 database.

2: The device measures temperature below the specified range, however the sensitivity to changes in temperature reduces exponentially. Type R and S measure down to -50°C, or -0.226mV_{EMF} and -0.235mV_{EMF}, respectively. Type B measures down to 500°C or 1.242mV_{EMF} (see Figures 2-7, 2-8, 2-14 and Figures 2-10, 2-11 and 2-17).

3: Exceeding the V_{IN_CM} input range may cause leakage current through the ESD protection diodes at the thermocouple input pins. This parameter is characterized but not production tested.

INPUT/OUTPUT PIN DC CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, T_A = -40°C to +125°C (where: T_A = T_C, defined as Device Ambient Temperature).

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Serial Input/Output and I²C Slave Address Input (ADDR)						
Input (SCL, SDA)						
High-Level Voltage	V_{IH}	$0.7V_{DD}$	—	—	V	
Low-Level Voltage	V_{IL}	—	—	$0.3V_{DD}$	V	
Input Current	I_{LEAK}	—	—	±2	µA	
Output (SDA)						
Low-Level Voltage	V_{OL}	—	—	0.4	V	I_{OL}= 3 mA
High-Level Current (leakage)	I_{OH}	—	—	1	µA	V_{OH} = V_{DD}
Low-Level Current	I_{OL}	6	—	—	mA	V_{OL} = 0.6V
Capacitance	C_{IN}	—	5	—	pF	
I²C Slave Address Selection Levels (Note 1)						
Command Byte <1100 000x>	V_{ADDR}	GND	—	—	V	Address = 0
Command Byte <1100 001x>		V_{ADDR_L} (Note 2)	V_{ADDR_TYP} (Note 2)	V_{ADDR_H} (Note 2)		Address = 1
Command Byte <1100 010x>						Address = 2
Command Byte <1100 011x>						Address = 3
Command Byte <1100 100x>						Address = 4
Command Byte <1100 101x>						Address = 5
Command Byte <1100 110x>						Address = 6
Command Byte <1100 111x>		—	—	V_{DD}		Address = 7
SDA and SCLK Inputs						
Hysteresis	V_{HYST}	—	$0.05V_{DD}$	—	V	V_{DD} > 2V
Spike Suppression	T_{SP}	—	50	—	ns	

Note 1: The ADDR pin can be tied to V_{DD} or V_{SS}. For additional slave addresses, resistive divider network can be used to set voltage levels that are rationed to V_{DD}. The device supports up to 8 levels (see **Section 6.3.1 "I2C Addressing"** for recommended resistor values).

2: V_{ADDR_TYP} = Address*V_{DD}/8 + V_{DD}/16,
V_{ADDR_L} = V_{ADDR_TYP} - V_{DD}/32, and
V_{ADDR_H} = V_{ADDR_TYP} + V_{DD}/32 (where: Address = 1, 2, 3, 4, 5, 6).

TEMPERATURE CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground.

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Specified Temperature Range	T_A	-40	—	+125	°C	Note 1
Operating Temperature Range	T_A	-40	—	+125	°C	
Storage Temperature Range	T_A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, MQFN	θ_{JA}	—	38.8	—	°C/W	

Note 1: Operation in this range must not cause T_J to exceed the Maximum Junction Temperature (+150°C).

SENSOR SERIAL INTERFACE TIMING SPECIFICATIONS

Electrical Specifications: Unless otherwise indicated, GND = Ground, T_A = -40°C to +125°C, V_{DD} = 2.7V to 5.5V and C_L = 80 pF (Note 1).				
Parameters	**Sym.**	**Min.**	**Max.**	**Units**
2-Wire I²C Interface				
Serial Port Frequency	f_{SCL}	10	100	kHz
Low Clock (Note 2)	t_{LOW}	4700	—	ns
High Clock	t_{HIGH}	4000	—	ns
Rise Time (Note 3)	t_R	—	1000	ns
Fall Time (Note 3)	t_F	20	300	ns
Data in Setup Time (Note 2)	$t_{SU:DAT}$	250	—	ns
Data in Hold Time	$t_{HD:DAT}$	0	—	ns
Start Condition Setup Time	$t_{SU:STA}$	4700	—	ns
Start Condition Hold Time	$t_{HD:STA}$	4000	—	ns
Stop Condition Setup Time	$t_{SU:STO}$	4000	—	ns
Bus Idle/Free	t_{B-FREE}	10	—	µs
Bus Capacitive Load	C_b	—	400	pf
Clock Stretching	$t_{STRETCH}$	60	—	µs

Note 1: All values referred to $V_{IL\ MAX}$ and $V_{IH\ MIN}$ levels.

2: This device can be used in a Standard-mode I²C-bus system, but the requirement $t_{SU:DAT} \geq 250$ ns must be met.

3: Characterized, but not production tested.

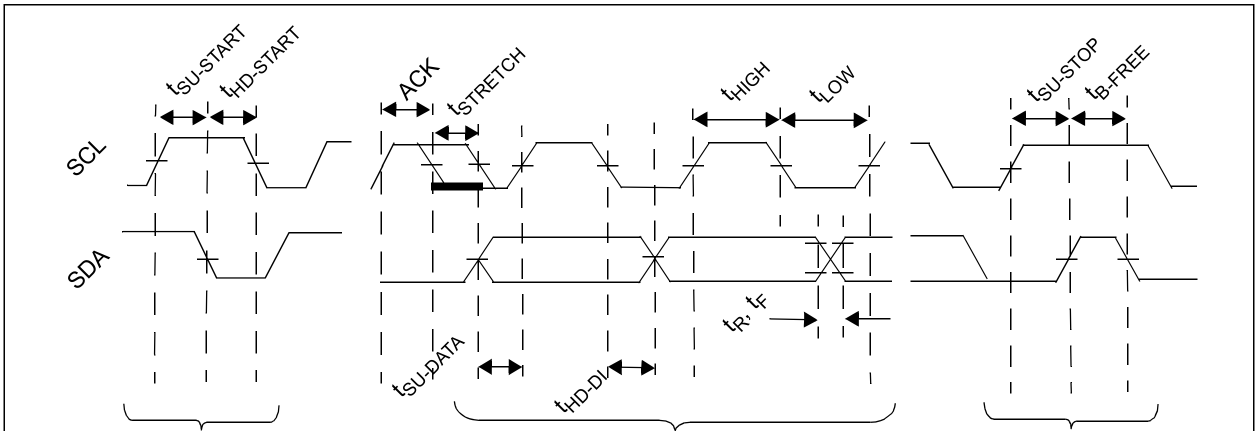


FIGURE 1-1: *Timing Diagram.*

2.0 TYPICAL PERFORMANCE CURVES

Note:	The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, SDA/SCL pulled-up to V_{DD} and T_A = -40°C to +125°C.

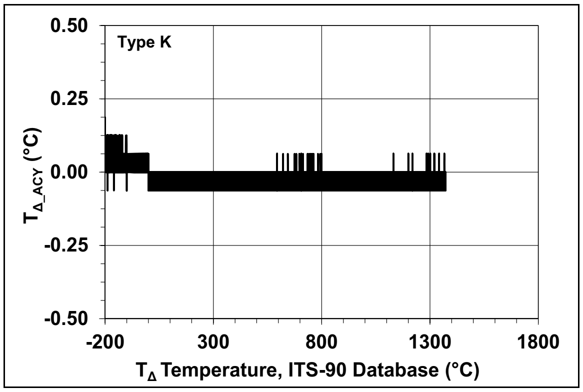


FIGURE 2-1: *Typical Temperature Accuracy from NIST ITS-90 Database, Type K.*

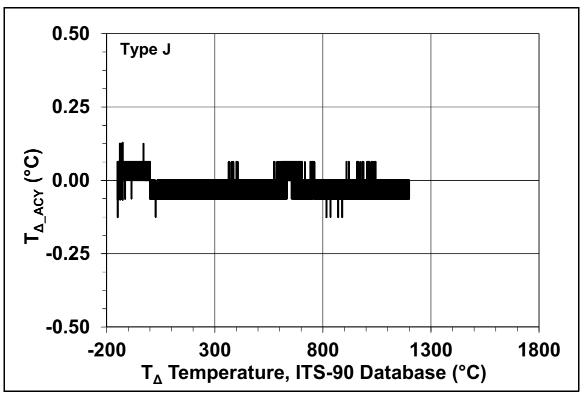


FIGURE 2-2: *Typical Temperature Accuracy from NIST ITS-90 Database, Type J.*

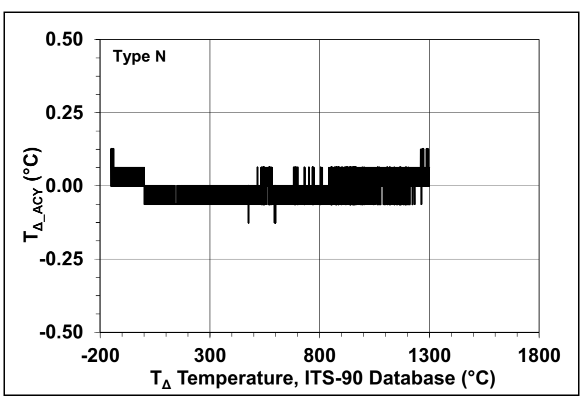


FIGURE 2-3: *Typical Temperature Accuracy from NIST ITS-90 Database, Type N.*

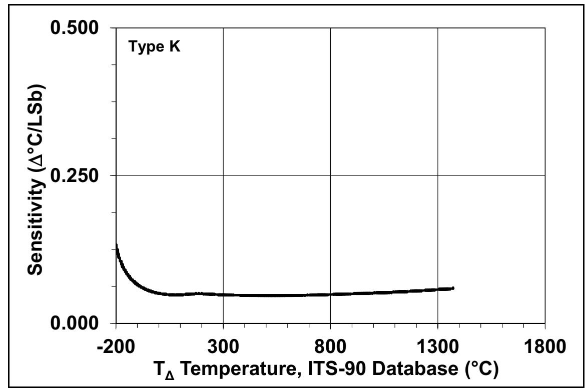


FIGURE 2-4: *Temperature Sensitivity with 18-Bit Resolution, Type K.*

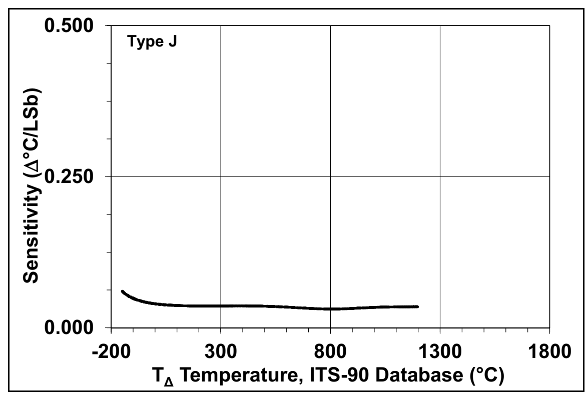


FIGURE 2-5: *Temperature Sensitivity with 18-Bit Resolution, Type J.*

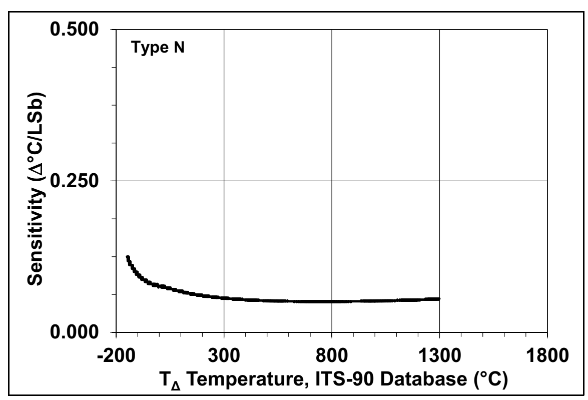


FIGURE 2-6: *Temperature Sensitivity with 18-Bit Resolution, Type N.*

Note: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, SDA/SCL pulled-up to V_{DD} and T_A = -40°C to +125°C.

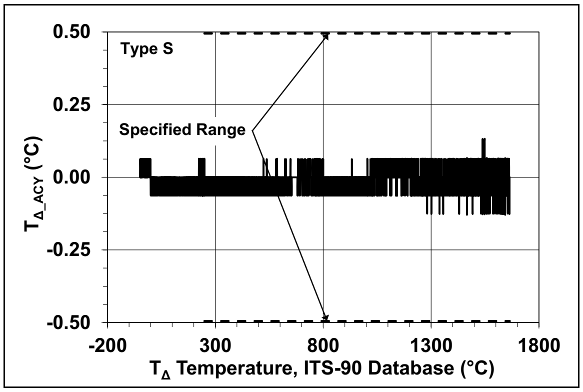


FIGURE 2-7: *Typical Temperature Accuracy from NIST ITS-90 Database, Type S.*

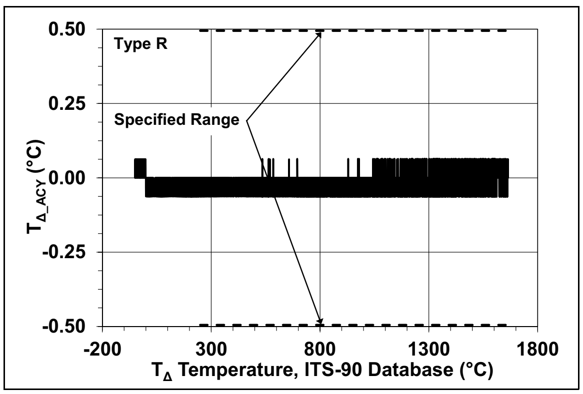


FIGURE 2-8: *Typical Temperature Accuracy from NIST ITS-90 Database, Type R.*

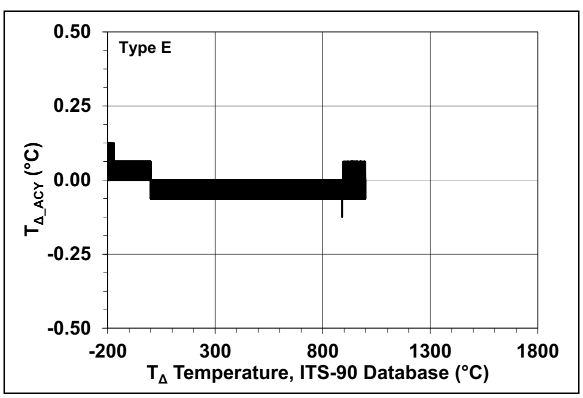


FIGURE 2-9: *Typical Temperature Accuracy from NIST ITS-90 Database, Type E.*

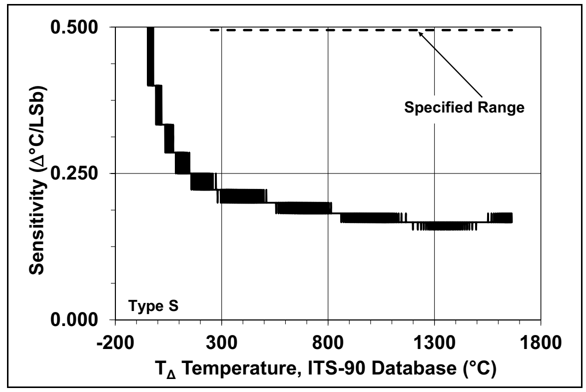


FIGURE 2-10: *Temperature Sensitivity with 18-Bit Resolution, Type S.*

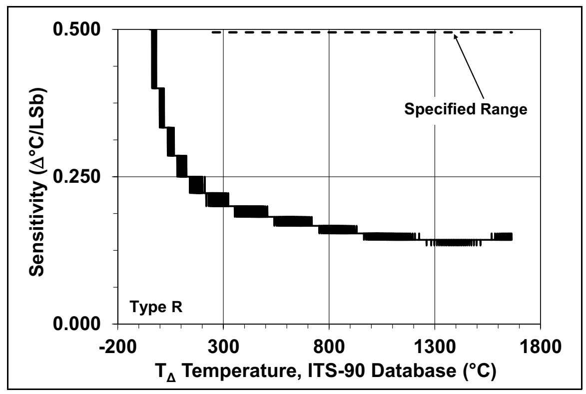


FIGURE 2-11: *Temperature Sensitivity with 18-Bit Resolution, Type R.*

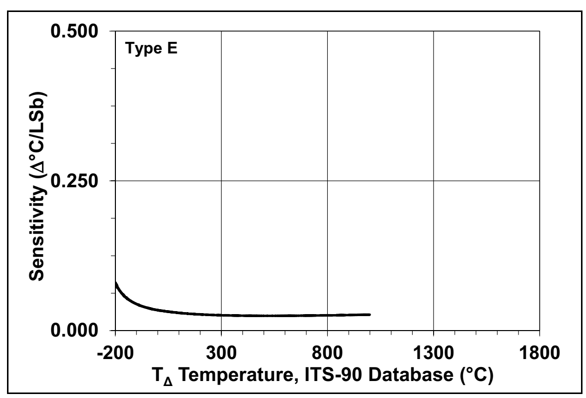


FIGURE 2-12: *Temperature Sensitivity with 18-Bit Resolution, Type E.*

Note: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, SDA/SCL pulled-up to V_{DD} and T_A = -40°C to +125°C.

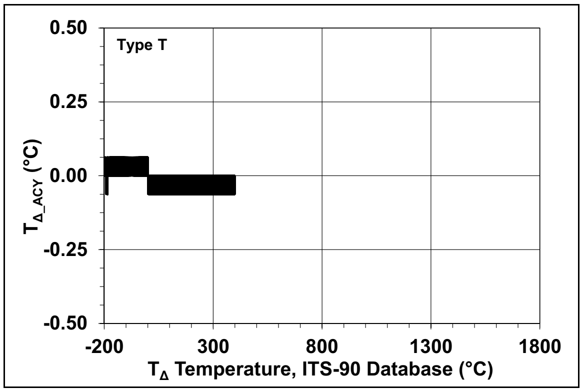


FIGURE 2-13: *Typical Temperature Accuracy from NIST ITS-90 Database, Type T.*

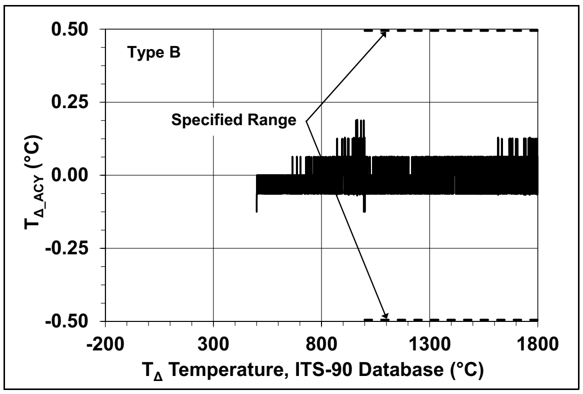


FIGURE 2-14: *Typical Temperature Accuracy from NIST ITS-90 Database, Type B.*

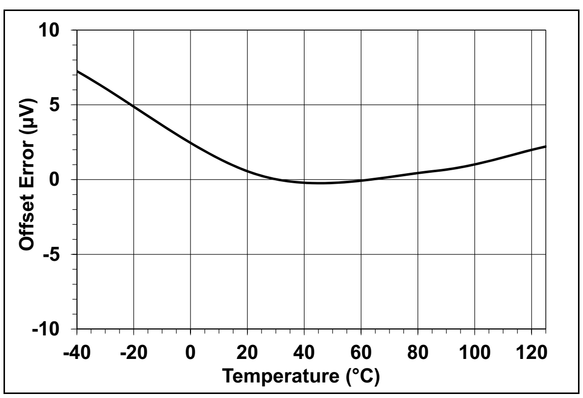


FIGURE 2-15: *Input Offset Error Voltage (V_{IN+}, V_{IN-}).*

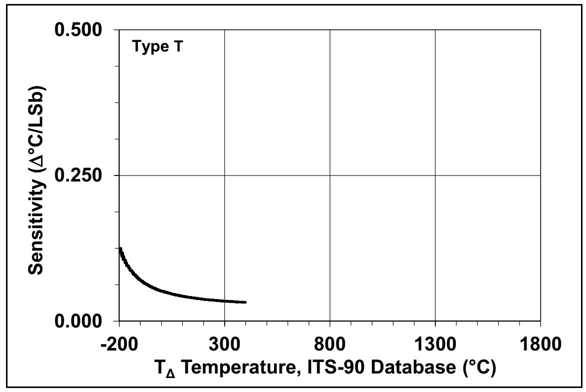


FIGURE 2-16: *Temperature Sensitivity with 18-Bit Resolution, Type T.*

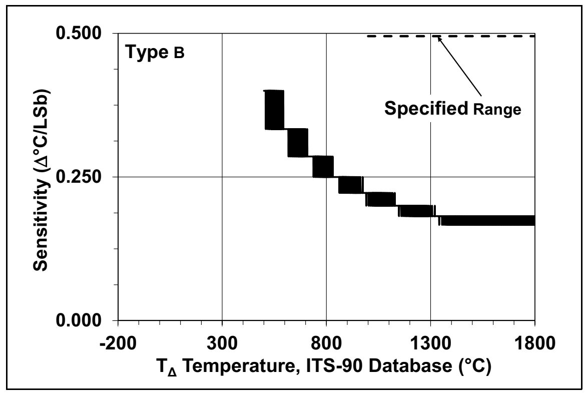


FIGURE 2-17: *Temperature Sensitivity with 18-Bit Resolution, Type B.*

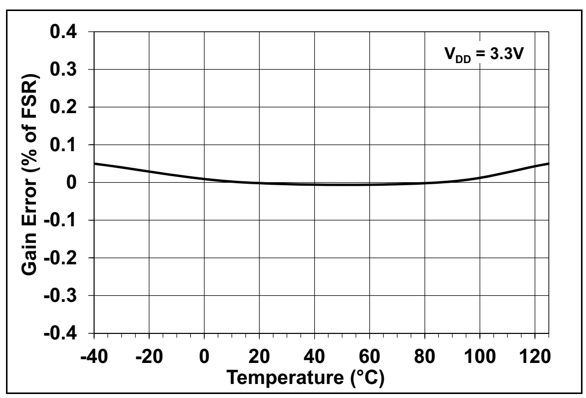


FIGURE 2-18: *Full-Scale Gain Error.*

Note: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, SDA/SCL pulled-up to V_{DD} and T_A = -40°C to +125°C.

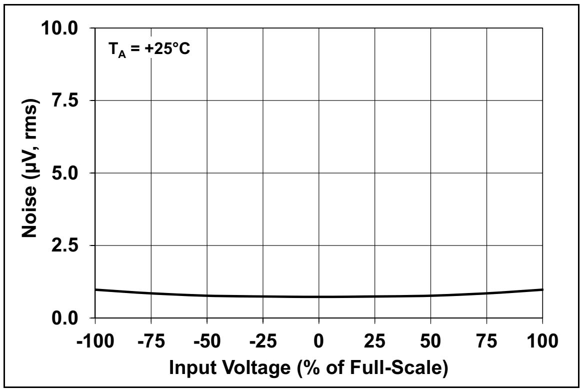


FIGURE 2-19: *Input Noise, % of Full-Scale.*

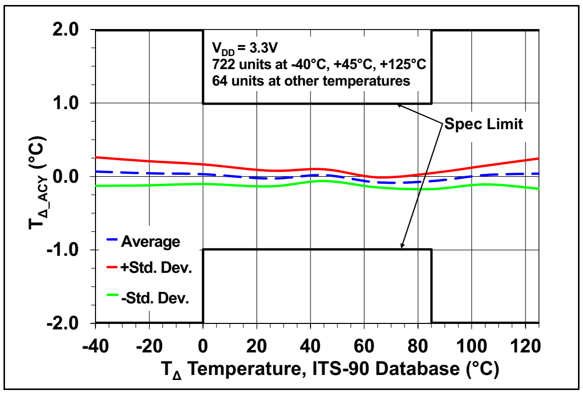


FIGURE 2-20: *Cold-Junction Sensor Temperature Accuracy.*

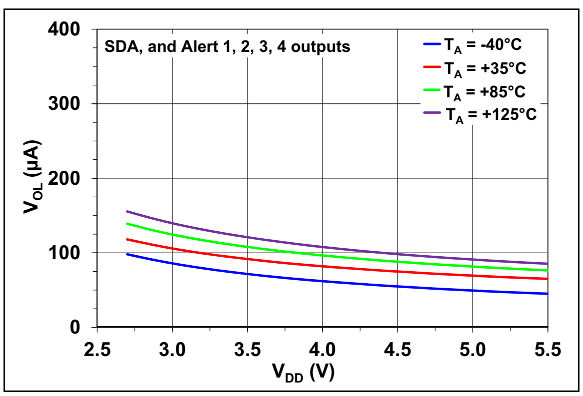


FIGURE 2-21: *SDA and Alert Outputs, V_{OL} across V_{DD}.*

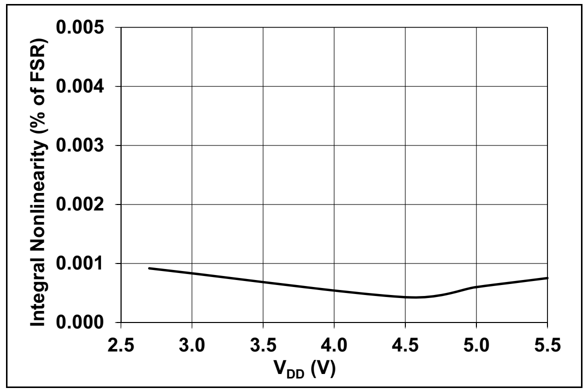


FIGURE 2-22: *Integral Nonlinearity across V_{DD}.*

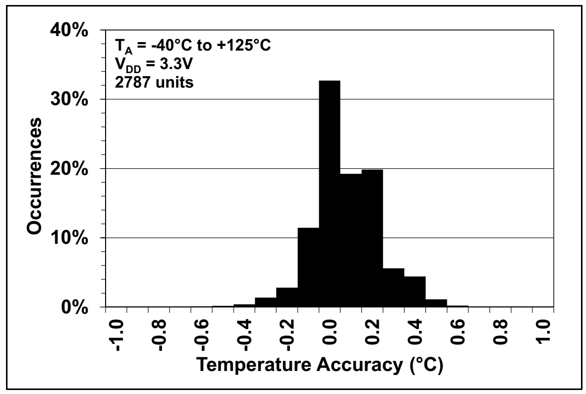


FIGURE 2-23: *Cold-Junction Sensor Temperature Accuracy Distribution.*

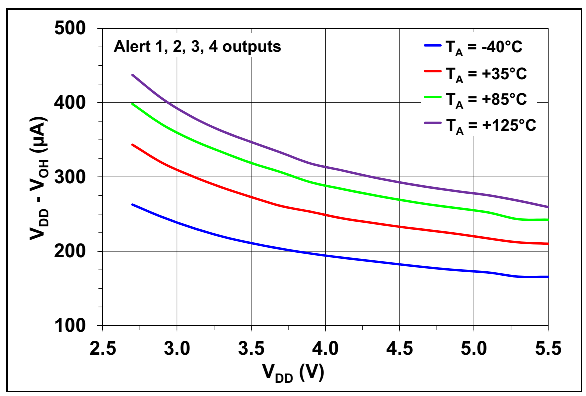


FIGURE 2-24: *Alert Outputs, V_{OH} across V_{DD}.*

Note: Unless otherwise indicated, V_{DD} = 2.7V to 5.5V, GND = Ground, SDA/SCL pulled-up to V_{DD} and T_A = -40°C to +125°C.

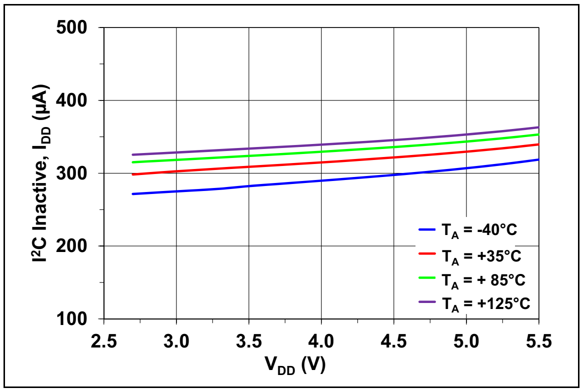


FIGURE 2-25: *I^2C Inactive I_{DD} across V_{DD}.*

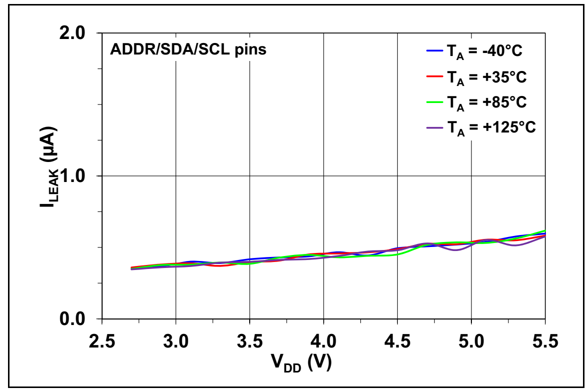


FIGURE 2-28: *SDA, SCL and ADDR Input Pins Leakage Current, I_{LEAK} across V_{DD}.*

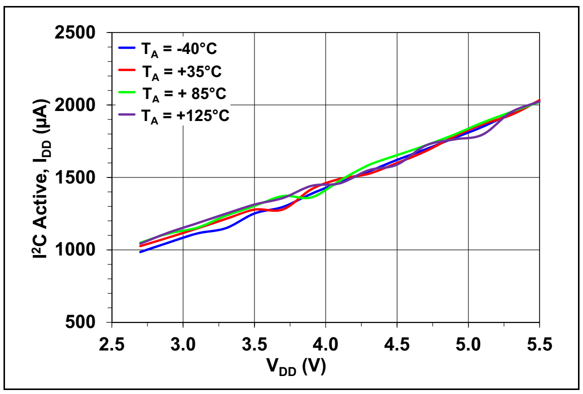


FIGURE 2-26: *I^2C Active I_{DD} across V_{DD}.*

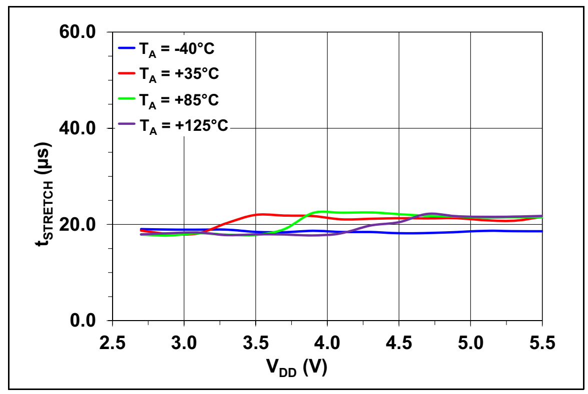


FIGURE 2-29: *I^2C Interface Clock Stretch Duration, $t_{STRETCH}$ across V_{DD}.*

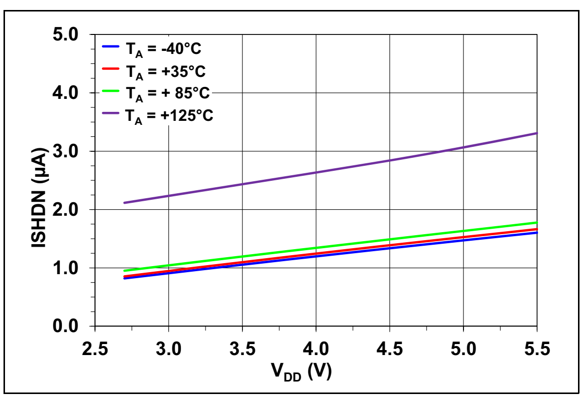


FIGURE 2-27: *Shutdown Current, I_{SHDN} across V_{DD}.*

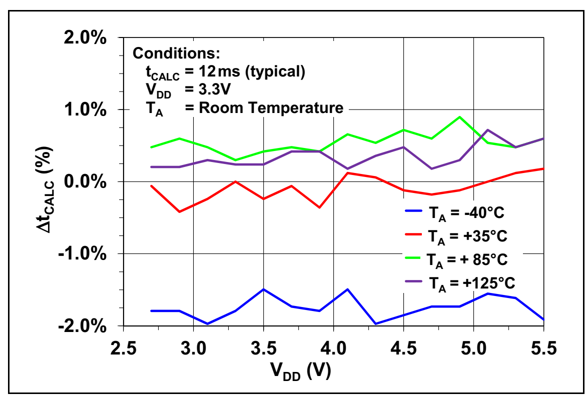


FIGURE 2-30: *Temperature Calculation Duration, t_{CALC} change across V_{DD}.*

NOTES:

3.0 PIN DESCRIPTION

The descriptions of the pins are listed in Table 3-1.

TABLE 3-1: PIN FUNCTION TABLE

5x5 MQFN	Symbol	Pin Function
1, 3, 5,13, 17	GND	Electrical ground
2	V_{IN}+	Thermocouple Positive Terminal input
4	V_{IN}-	Thermocouple Negative Terminal input
6, 7, 9, 10, 18	GND	Not electrical ground; must be tied to ground
8	V_{DD}	Power
11	Alert 1	Alert Output 1
12	Alert 2	Alert Output 2
14	Alert 3	Alert Output 3
15	Alert 4	Alert Output 4
16	ADDR	I^2C Save Address selection voltage input
19	SCL	I^2C Clock Input
20	SDA	I^2C Data Input
21	EP	Exposed Thermal Pad (EP); must be connected to GND

3.1 Ground Pin (GND)

The GND pin is the system ground pin. Pins 1, 3, 5, 13 and 17 are system ground pins and they are at the same potential. However, pins 6, 7, 9, 10 and 18 must be connected to ground for normal operation.

3.2 Thermocouple Input (V_{IN+}, V_{IN-})

The thermocouple wires are directly connected to these inputs. The positive node is connected to the V_{IN+} pin while the negative node connects to the V_{IN-} node. The thermocouple voltage is converted to degree Celsius.

3.3 Power Pin (V_{DD})

V_{DD} is the power pin. The operating voltage range, as specified in the DC Electrical Specification table, is applied on this pin.

3.4 Push-Pull Alert Outputs (Alert 1, 2, 3, 4)

The MCP9600's Alert pins are user-programmable push-pull outputs which can be used to detect rising or falling temperatures. The device outputs signals when the ambient temperature exceeds the user-programmed temperature alert limit.

3.5 I^2C Slave Address Pin (ADDR)

This pin is used to set the I^2C slave address. This pin can be tied to V_{DD}, GND, or a ratio of V_{DD} can be selected to set up to eight address levels using a resistive voltage divider network.

3.6 Serial Clock Line (SCL)

The SCL is a clock input pin. All communication and timing is relative to the signal on this pin. The clock is generated by the host or master controller on the bus (see **Section 4.0 "Serial Communication"**).

3.7 Serial Data Line (SDA)

SDA is a bidirectional input/output pin used to serially transmit data to/from the host controller. This pin requires a pull-up resistor (see **Section 4.0 "Serial Communication"**).

NOTES:

4.0 SERIAL COMMUNICATION

4.1 2-Wire Standard Mode I²C Protocol-Compatible Interface

The MCP9600's serial clock input (SCL) and the bidirectional serial data line (SDA) form a 2-Wire bidirectional data communication line (refer to the Input/Output Pin DC Characteristics table and Sensor Serial Interface Timing Specifications table).

The following bus protocol has been defined:

TABLE 4-1: MCP9600 SERIAL BUS PROTOCOL DESCRIPTIONS

Term	Description
Master	The device that controls the serial bus, typically a microcontroller
Slave	The device addressed by the master, such as the MCP9600
Transmitter	Device sending data to the bus
Receiver	Device receiving data from the bus
START	A unique signal from master to initiate serial interface with a slave
STOP	A unique signal from the master to terminate serial interface from a slave
Read/Write	A read or write to the MCP9600 registers
ACK	A receiver Acknowledges (ACK) the reception of each byte by polling the bus
NAK	A receiver Not-Acknowledges (NAK) or releases the bus to show End-of-Data (EOD)
Busy	Communication is not possible because the bus is in use
Not Busy	The bus is in the idle state, both SDA and SCL remain high
Data Valid	SDA must remain stable before SCL becomes high in order for a data bit to be considered valid. During normal data transfers, SDA only changes state while SCL is low.

4.1.1 DATA TRANSFER

Data transfers are initiated by a Start condition (START), followed by a 7-bit device address and a read/write bit. An Acknowledge (ACK) from the slave confirms the reception of each byte. Each access must be terminated by a Stop condition (STOP).

Repeated communication is initiated after $t_{B\text{-}FREE}$.

This device supports the Receive Protocol. The register can be specified using the pointer for the initial read. Each repeated read or receive begins with a Start condition and address byte. The MCP9600 retains the previously selected register. Therefore, it outputs data from the previously-specified register (repeated pointer specification is not necessary).

4.1.2 MASTER/SLAVE

The bus is controlled by a master device (typically a microcontroller) that controls the bus access and generates the Start and Stop conditions. The MCP9600 is a slave device and does not control other devices in the bus. Both master and slave devices can operate as either transmitter or receiver. However, the master device determines which mode is activated.

4.1.3 START/STOP CONDITION

A high-to-low transition of the SDA line (while SCL is high) is the Start condition. All data transfers must be preceded by a Start condition from the master. A low-to-high transition of the SDA line (while SCL is high) signifies a Stop condition.

If a Start or Stop condition is introduced during data transmission, the MCP9600 releases the bus. All data transfers are ended by a Stop condition from the master.

4.1.4 ADDRESS BYTE

Following the Start condition, the host must transmit an 8-bit address byte to the MCP9600. The address for the MCP9600 Temperature Sensor is '`11,0,0,A2,A1,A0`' in binary, where the A2, A1 and A0 bits are set externally by connecting the corresponding V_{ADDR} voltage levels on the ADDR pin (see **Section "Input/Output Pin DC Characteristics"**). The 7-bit address transmitted in the serial bit stream must match the selected address for the MCP9600 to respond with an ACK. Bit 8 in the address byte is a read/write bit. Setting this bit to '`1`' commands a read operation, while '`0`' commands a write operation (see Figure 4-1).

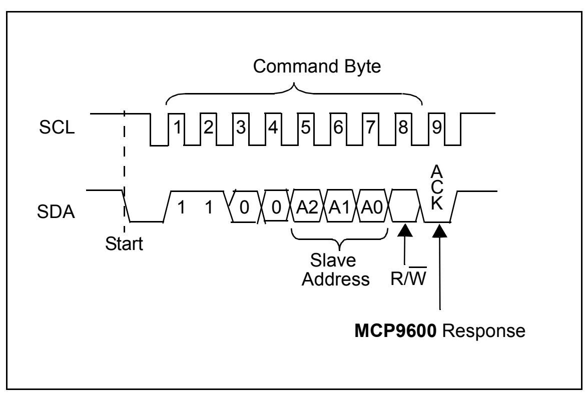


FIGURE 4-1: Device Addressing.

4.1.5 DATA VALID

After the Start condition, each bit of data in transmission needs to be settled for a time specified by $t_{SU\text{-}DATA}$ before SCL toggles from low-to-high (see the Sensor Serial Interface Timing Specifications section).

4.1.6 ACKNOWLEDGE (ACK/NAK)

Each receiving device, when addressed, is expected to generate an ACK bit after the reception of each byte. The master device must generate an extra clock pulse for ACK to be recognized.

The acknowledging device pulls down the SDA line for $t_{SU\text{-}DATA}$ before the low-to-high transition of SCL from the master. SDA also needs to remain pulled-down for $t_{HD\text{-}DAT}$ after a high-to-low transition of SCL.

During read, the master must signal an End-of-Data (EOD) to the slave by not generating an ACK bit (NAK) once the last bit has been clocked out of the slave. In this case, the slave will leave the data line released to enable the master to generate the Stop condition.

4.1.7 CLOCK STRETCHING

During the I^2C read operation, this device will hold the I^2C clock line low for t_{STRECH} after the falling edge of the ACK signal. In order to prevent bus contention, the master controller must release or hold the SCL line low during this period.

In addition, the master controller must provide eight consecutive clock cycles after generating the ACK bit from a read command. This allows the device to push out data from the SDA output shift registers. Missing clock cycles could result in bus contention. At the end of the data transmission, the master controller must provide the NAK bit, followed by a STOP bit to terminate communication.

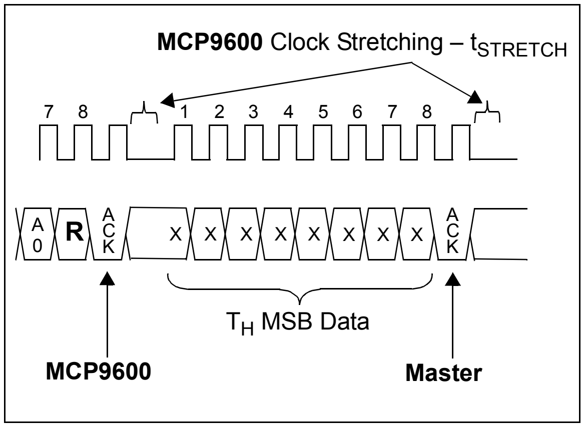


FIGURE 4-2: *Clock Stretching.*

4.1.8 SEQUENTIAL READ

During sequential read, the device transmits data from the proceeding register starting from the previously set register pointer. The MCP9600 maintains an internal address pointer, which is incremented at the completion of each read-data transmission followed by ACK from the master. A stop bit terminates the sequential read.

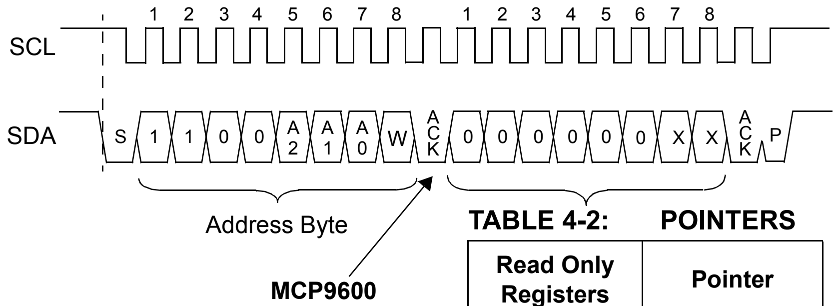
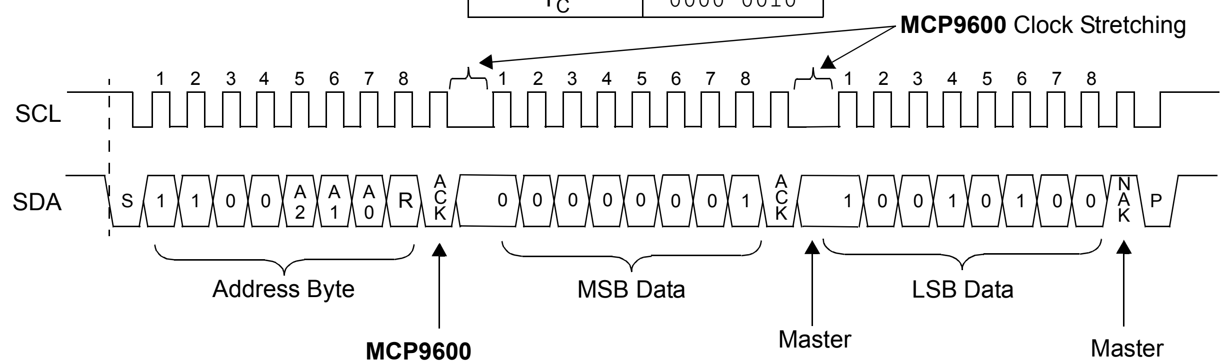


TABLE 4-2: POINTERS

Read Only Registers	Pointer
T_H	0000 0000
T_Δ	0000 0001
T_C	0000 0010



Note: this is an example pseudo routine:

```
i2c_start();                     // send START command
i2c_write(b'1100 0000');         // WRITE Command
                                 // also, make sure bit 0 is cleared '0'
i2c_write(b'0000 00XX');         // Write TH, TΔ, or TC registers
i2c_stop();                      // send STOP command
i2c_start();                     // send START command
i2c_write(b'1100 0001');         // READ Command
                                 // also, make sure bit 0 is set '1'
UpperByte = i2c_read(ACK);       // READ 8 bits
                                 // and Send ACK bit
LowerByte = i2c_read(NAK);       // READ 8 bits
                                 // and Send NAK bit
i2c_stop();                      // send STOP command

//Convert the temperature data
if ((UpperByte & 0x80) == 0x80){                  //TA < 0°C
   UpperByte = UpperByte & 0x7F;                  //Clear SIGN
   Temperature = 1024 - (UpperByte x 16 + LowerByte / 16);
}else                                             //TA ≥ 0°C
   Temperature = (UpperByte x 16 + LowerByte / 16);
                                 //Temperature = Ambient Temperature (°C)
```

FIGURE 4-3: *Timing Diagram to Set a Register Pointer and Read a Two Byte Data.*

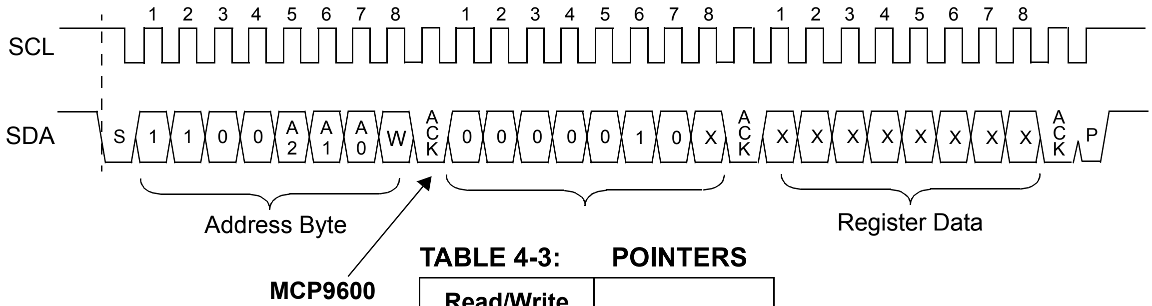
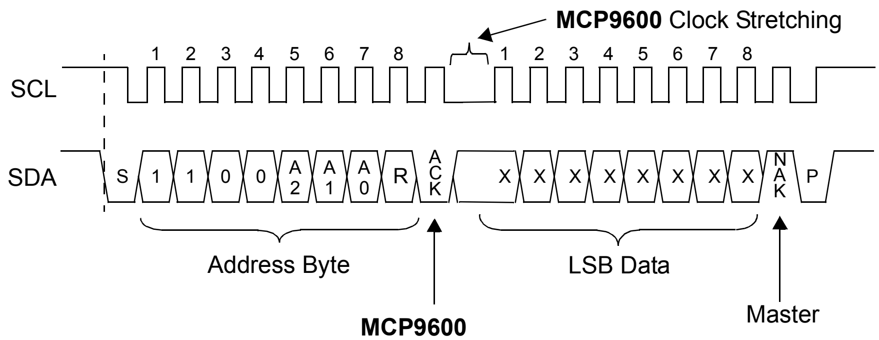


TABLE 4-3: POINTERS

Read/Write Registers	Pointer
Status	`0000 0100`
Configuration	`0000 0101`
	`0000 0110`



Note: this is an example pseudo routine:

```
i2c_start();                // send START command
i2c_write(b'1100 0000');    // WRITE Command
                            // also, make sure bit 0 is cleared '0'
i2c_write(b'0000 01XX');    // Write Status or Configuration registers
i2c_write(b'XXXX XXXX');    // Write register data
i2c_stop();                 // send STOP command
i2c_start();                // send START command
i2c_write(b'1100 0001');    // READ Command
                            // also, make sure bit 0 is set '1'
Data = i2c_read(NAK);       // READ 8 bits
                            // and Send NAK bit
i2c_stop();                 // send STOP command
```

FIGURE 4-4: *Timing Diagram to Set a Register Pointer and Read a Two Byte Data.*

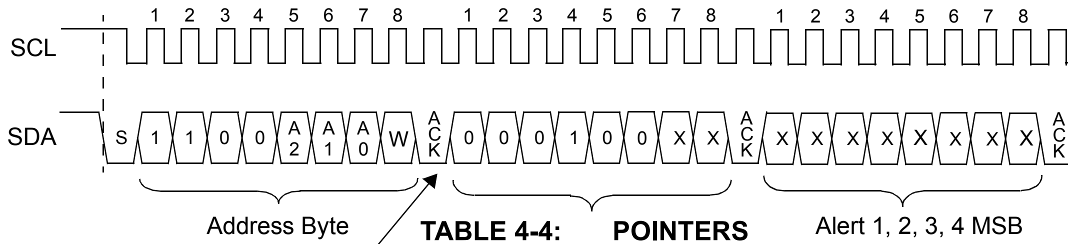
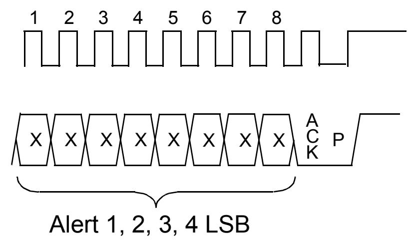
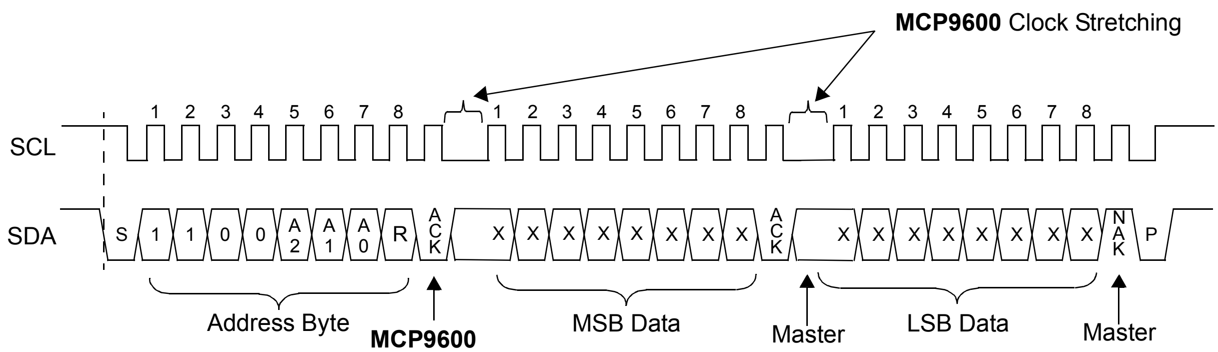


TABLE 4-4: POINTERS

Alert Limit Registers	Pointer
Alert 1	`0001 0000`
Alert 2	`0001 0001`
Alert 3	`0001 0010`
Alert 4	`0001 0011`

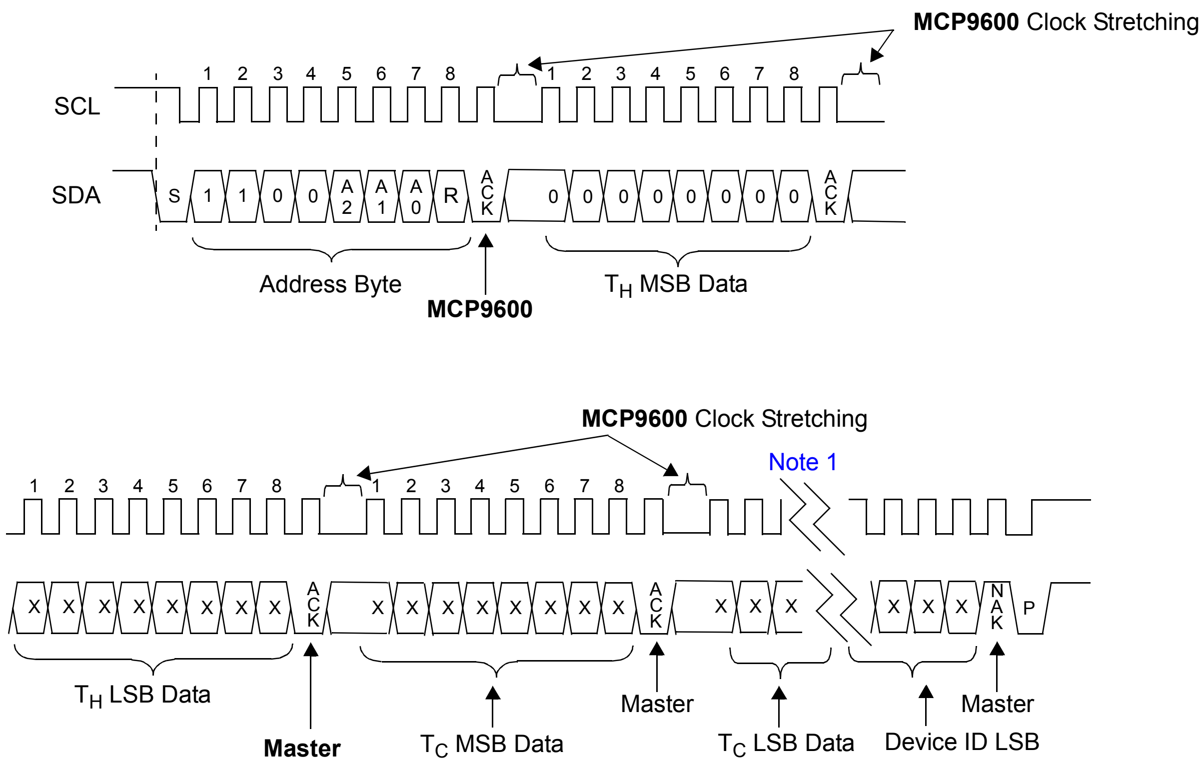




Note: this is an example pseudo routine:

```
i2c_start();                    // send START command
i2c_write(b'1100 0000');        //WRITE Command
                                //also, make sure bit 0 is cleared '0'
i2c_write(b'0001 00XX');        // Write Alert registers
i2c_write(b'XXXX XXXX');        // Write register Upper Byte
i2c_write(b'XXXX XXXX');        // Write register Lower Byte
i2c_stop();                     // send STOP command
i2c_start();                    // send START command
i2c_write(b'1100 0001');        //READ Command
                                //also, make sure bit 0 is set '1'
UpperByte = i2c_read(ACK);      // READ 8 bits
                                //and Send ACK bit
LowerByte = i2c_read(NAK);      // READ 8 bits
                                //and Send NAK bit
i2c_stop();                     // send STOP command
```

FIGURE 4-5: *Timing Diagram to Set a Register Pointer and Read a Two Byte Data.*



Note 1: All registers can be read sequentially starting from the previously set register pointer.

Note: this is an example pseudo routine:

```
i2c_start();                      // send START command
i2c_write(b'1100 0000');          // WRITE Command
                                  // also, make sure bit 0 is cleared '0'
i2c_write(b'0000 0000');          // Write TH register to set the starting register for sequential read
i2c_stop();                       // send STOP command
i2c_start();                      // send START command
i2c_write(b'1100 0001');          // READ Command
                                  // also, make sure bit 0 is set '1'
for (i=0; i<29, i++){
    Data_Buffer[i] = i2c_read(ACK);     // READ 8 bits
                                        // and Send ACK bit
}
Data_Buffer[i] = i2c_read(NAK);         // READ 8 bits
                                        // and Send NAK bit
i2c_stop();                             // send STOP command
```

FIGURE 4-6: *Timing Diagram to Sequential Read all Registers Starting from T_H Register.*

5.0 FUNCTIONAL DESCRIPTION

The MCP9600 temperature sensor consists of an 18-bit delta-sigma analog-to-digital converter which is used to measure the thermocouple voltage or EMF, a digital temperature sensor used to measure cold-junction or ambient temperature and a processor core which is used to compute the EMF to degree Celsius conversion using coefficients derived from NIST ITS-90 coefficients. Figure 5-1 shows a block diagram of how these functions are structured in the device.

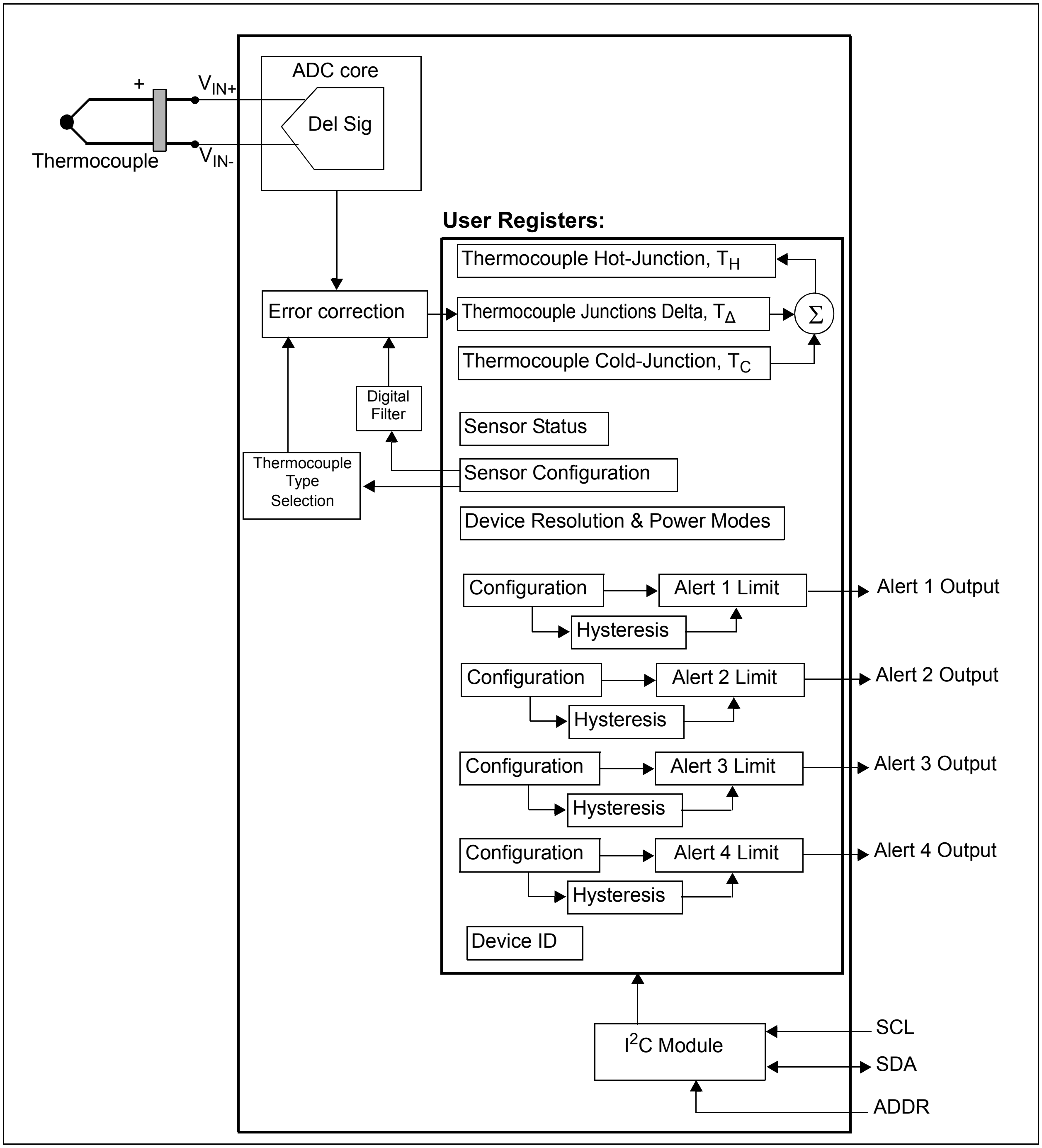


FIGURE 5-1: *Functional Block Diagram.*

The MCP9600 device has several registers that are user-accessible. These registers include the thermocouple temperature (cold-junction compensated), hot-junction temperature, cold-junction temperature, raw ADC data, user programmable Alert limit registers, and status and configuration registers.

The temperature and the raw ADC data registers are read-only registers, used to access the thermocouple and the ambient temperature data. In addition, the four Alert Temperature registers are individually controlled and can be used to detect a rising and/or a falling temperature change. If the ambient temperature drifts beyond the user-specified limits, the MCP9600 device outputs an alert flag at the corresponding pin (refer to **Section 5.3.3 "Alert configuration Registers"**). The Alert limits can also be used to detect critical temperature events.

The MCP9600 also provides a status and configuration registers which allow users to detect device statuses. The configuration registers provide various features such as adjustable temperature measurement resolution and Shutdown modes. The thermocouple types can also be selected using the configuration registers.

The registers are accessed by sending a Register Pointer to the MCP9600 using the serial interface. This is an 8-bit write-only pointer. Register 5-1 describes the pointer definitions.

REGISTER 5-1: REGISTER POINTER

U-0	U-0	U-0	U-0	W-0	W-0	W-0	W-0
—	—	—	—	P3	P2	P1	P0
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7-4 **Unimplemented:** Write '0'

bit 3-0 **P<3:0>:** Pointer bits

`0000 0000` = Thermocouple Hot-Junction Register - T_H
`0000 0001` = Junctions Temperature Delta Register - T_Δ
`0000 0010` = Cold-Junction Temperature Register - T_C
`0000 0011` = Raw ADC Data
`0000 0100` = Status
`0000 0101` = Thermocouple Sensor Configuration
`0000 0110` = Device Configuration
`0000 1000` = Alert 1 Configuration
`0000 1001` = Alert 2 Configuration
`0000 1010` = Alert 3 Configuration
`0000 1011` = Alert 4 Configuration
`0000 1100` = Alert 1 Hysteresis - T_{HYST1}
`0000 1101` = Alert 2 Hysteresis - T_{HYST2}
`0000 1110` = Alert 3 Hysteresis - T_{HYST3}
`0000 1111` = Alert 4 Hysteresis - T_{HYST4}
`0001 0000` = Temperature Alert 1 Limit - T_{ALERT1}
`0001 0001` = Temperature Alert 2 Limit - T_{ALERT2}
`0001 0010` = Temperature Alert 3 Limit - T_{ALERT3}
`0001 0011` = Temperature Alert 4 Limit - T_{ALERT4}
`0010 0000` = Device ID/Rev Register

TABLE 5-1: SUMMARY OF REGISTERS AND BIT ASSIGNMENTS

Register	Pointer	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
Hot-Junction Temperature – T_H	00000000	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C
Junctions Temperature Delta – T_Δ	00000001	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C
Cold-Junction Temperature – T_C	00000010	SIGN				128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C
Raw data ADC	00000011	SIGN						bit 17	bit 16
		bit 15							bit 8
		bit 7							bit 0
Status	00000100	Flag, Burst Complete	Flag, T_H Updated	—	Flag, Input Range	Alert 4 Status	Alert 3 Status	Alert 2 Status	Alert 1 Status
Thermocouple Sensor Configuration	00000101	—	Thermocouple Type Select Type K, J, T, N, S, E, B, R			—	Filter Coefficients		
Device Configuration	00000110	Cold-Junc. Resolution	ADC Resolution		Burst Mode Temperature Samples			Shutdown Modes	
Alert 1 Configuration	00001000	Interrupt Clear	—	—	Monitor T_H or T_C	Detect Rising or Falling Temps	Active-High or Active-Low Output	Comparator or Interrupt Mode	Enable Alert Output
Alert 2 Configuration	00001001								
Alert 3 Configuration	00001010								
Alert 4 Configuration	00001011								
Alert 1 Hysteresis	00001100	128°C	64°C	32°C	16°C	8°C	4°C	2°C	1°C
Alert 2 Hysteresis	00001101								
Alert 3 Hysteresis	00001110								
Alert 4 Hysteresis	00001111								
Alert 1 Limit	00010000	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	—	—
Alert 2 Limit	00010001	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	—	—
Alert 3 Limit	00010010	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	—	—
Alert 4 Limit	00010011	SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
		8°C	4°C	2°C	1°C	0.5°C	0.25°C	—	—
Device ID/Rev	00100000	0	1	0	0	0	0	0	0
		Rev ID Major				Rev ID Minor			

5.1 Thermocouple Temperature Sensor Registers

This device integrates three temperature registers that are used to read the cold and hot-junction temperatures and the sum of the two junctions to output the absolute thermocouple temperature. In addition, the raw ADC data which is used to derive the thermocouple temperature is available. The following sections describe each register in detail.

5.1.1 THERMOCOUPLE TEMPERATURE REGISTER – T_H

This register contains the cold-junction compensated and error-corrected Thermocouple temperature in degree Celsius. The temperature data from this register is the absolute Thermocouple Hot-Junction Temperature T_H to the specified accuracy, **Section 1.0 "Electrical Characteristics"**. T_H is the sum of the values in T_Δ and T_C registers as shown in Figure 5-2.

EQUATION 5-1: TEMPERATURE CONVERSION

Temperature ≥ 0°C

$$T_H = (UpperByte \ x \ 2^4 + LowerByte \ x \ 2^{-4})$$

Temperature < 0°C

$$T_H = 1024 - (UpperByte \ x \ 2^4 + LowerByte \ x \ 2^{-4})$$

The temperature bits are in two's complement format, therefore, positive temperature data and negative temperature data are computed differently. Equation 5-1 shows how to convert the binary data to temperature in degree Celsius.

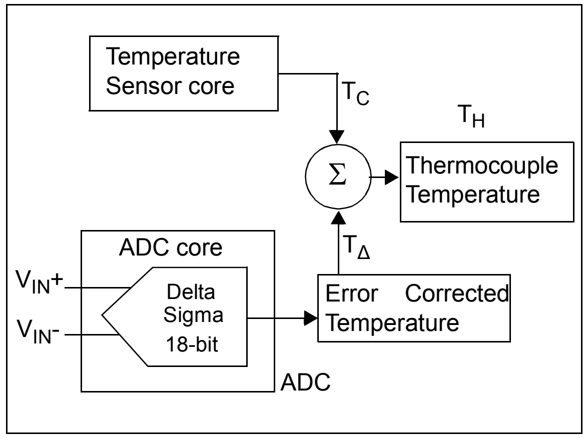


FIGURE 5-2: *Thermocouple Register's Block Diagram.*

REGISTER 5-2: THERMOCOUPLE TEMPERATURE REGISTER (READ ONLY)

R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
bit 15							bit 8

R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 15 **SIGN:**
1 = T_A < 0°C
0 = T_A ≥ 0°C

bit 14-0 **T_H:** Data in two's complement format
This register contains the error corrected and cold-junction compensated Thermocouple temperature.

5.1.2 THERMOCOUPLE JUNCTIONS DELTA TEMPERATURE REGISTER – T_Δ

This register contains the error corrected Thermocouple Hot-Junction temperature without the Cold-Junction compensation. The error correction methodology uses several coefficients to convert the digitized Thermocouple EMF voltage to degree Celsius. Each Thermocouple type has a unique set of coefficients as specified by NIST, and these coefficients are available in the configuration register for user selection as shown in Figure 5-3.

EQUATION 5-2: TEMPERATURE CONVERSION

Temperature ≥ 0°C

$$T_\Delta = (UpperByte \times 2^4 + LowerByte \times 2^{-4})$$

Temperature < 0°C

$$T_\Delta = 1024 - (UpperByte \times 2^4 + LowerByte \times 2^{-4})$$

The temperature bits are in two's complement format, therefore, positive temperature data and negative temperature data are computed differently, as shown in Equation 5-2.

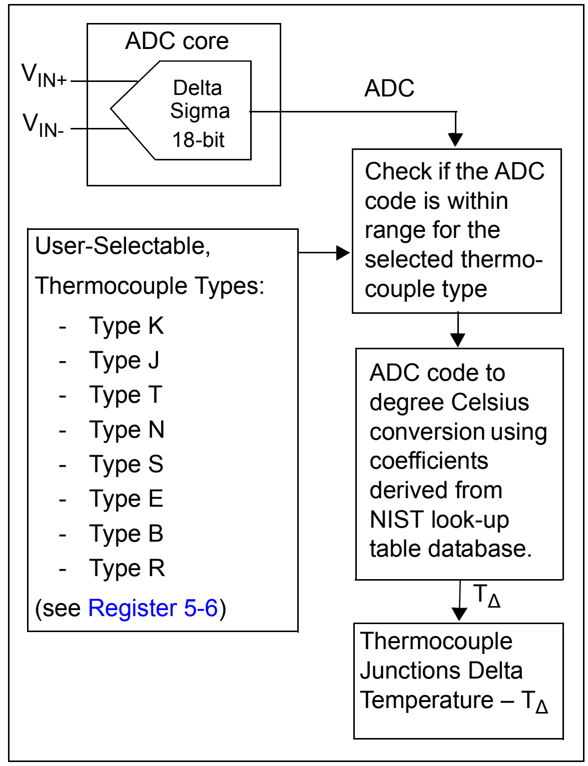


FIGURE 5-3: *Thermocouple Hot-Junction Register – T_Δ Block Diagram.*

REGISTER 5-3: HOT-JUNCTION TEMPERATURE REGISTER (READ ONLY)

R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
SIGN	1024°C	512°C	256°C	128°C	64°C	32°C	16°C
bit 15							bit 8

R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 15 **SIGN:**
1 = $T_A < 0°C$
0 = $T_A \geq 0°C$

bit 14-0 **T_Δ:** Data in two's complement format
This register contains Thermocouple Hot-Junction temperature data.