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## MAX31825

# 1-Wire® Temperature Sensor with $\pm 1^\circ\text{C}$ Accuracy

## General Description

The MAX31825 temperature sensor provides 8-bit to 12-bit Celsius temperature measurements with better than  $\pm 1^\circ\text{C}$  accuracy from  $0^\circ\text{C}$  to  $+70^\circ\text{C}$  and  $\pm 1.75^\circ\text{C}$  from  $-45^\circ\text{C}$  to  $+145^\circ\text{C}$ .

The sensor communicates over a 1-Wire® bus that, by definition, requires only one data line (and ground) for communication with a microcontroller. In addition, the sensor can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply.

Each sensor has a unique 64-bit serial code, which allows multiple MAX31825 ICs to reside on the same 1-Wire bus. In addition, it includes two address input pins that, using an external resistor and pin-strapping, allow one of 64 different addresses to be selected to identify each sensor's physical location. Therefore, it is simple to use one microprocessor to control many devices distributed over a large area.

The MAX31825 is available in a 6-bump WLP package. The power supply voltage range is from 1.6V to 3.6V for external power supplies, and from 2.3V to 3.6V for parasite power. The operating temperature range is from  $-45^\circ\text{C}$  to  $+145^\circ\text{C}$ .

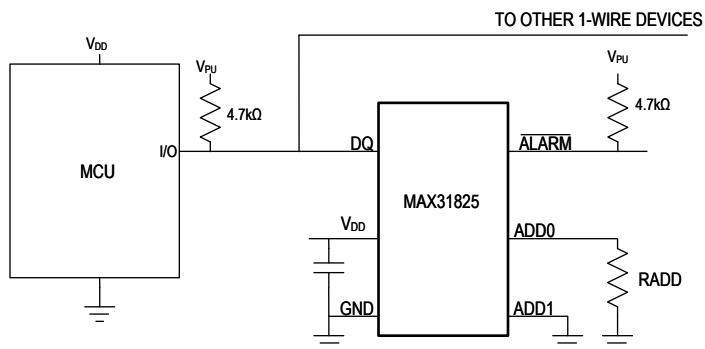
## Applications

- Industrial Equipment
- Communications Equipment
- Data Center Equipment
- Consumer Equipment

## Benefits and Features

- 1-Wire Interface Requires Only One Port Pin for Communication
- Unique 64-bit Serial Code Stored in an On-Board ROM
- External Resistor Selects Address for Location Identification
- Can Be Powered from Data Line
- Power Supply Range Is 1.6V to 3.6V (External Power), 2.3V to 3.6V (Parasite Power)
- Measures Temperatures from  $-45^\circ\text{C}$  to  $+145^\circ\text{C}$
- Better than  $\pm 1^\circ\text{C}$  Accuracy from  $0^\circ\text{C}$  to  $+70^\circ\text{C}$
- Better than  $\pm 1.75^\circ\text{C}$  Accuracy from  $-45^\circ\text{C}$  to  $+145^\circ\text{C}$
- Alarm Output for Detection of Temperature Faults
- Temperature Resolution is Selectable from 8 to 12 Bits
- Converts Temperature to 10-Bit Digital Word in 80ms (max)
- User-Definable Alarm Settings
- 4kV HBM ESD Protection
- Available in a 6-Bump WLP

*[Ordering Information](#) appears at end of data sheet.*

**Typical Application Circuit**

## Absolute Maximum Ratings

|  |              |                                |                 |
|--|--------------|--------------------------------|-----------------|
| $V_{DD}$ to GND  | -0.3V to +4V | Operating Temperature Range    | -45°C to +145°C |
| ADD0, ADD1, ALARM, DQ to GND   | -0.3V to +4V | Storage Temperature Range      | -60°C to +150°C |
| Continuous Power Dissipation (Multilayer Board, $T_A = +70^\circ\text{C}$ , derate 10.51mW/ $^\circ\text{C}$ above $+70^\circ\text{C}$ ) | 10.51mW      | Soldering Temperature (reflow) | +260°C          |

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## Package Information

### WLP

|  |                           |
|--|---------------------------|
| Package Code                                 | N61A1+1                   |
| Outline Number                               | <a href="#">21-100395</a> |
| Land Pattern Number                          | N/A                       |
| <b>Thermal Resistance, Four-Layer Board:</b> |                           |
| Junction to Ambient ( $\theta_{JA}$ )        | 95.15°C/W                 |
| Junction to Case ( $\theta_{JC}$ )           | N/A                       |

For the latest package outline information and land patterns (footprints), go to [www.maximintegrated.com/packages](http://www.maximintegrated.com/packages). Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to [www.maximintegrated.com/thermal-tutorial](http://www.maximintegrated.com/thermal-tutorial).

## Electrical Characteristics

( $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ ,  $V_{DD} = 1.6\text{V}$  to  $3.6\text{V}$ ,  $V_{PU} = 2.3\text{V}$  to  $3.6\text{V}$ , resolution = 12 bits, unless otherwise specified. Limits are 100% tested at  $T_A = +25^\circ\text{C}$ . Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization. )

| PARAMETER                     | SYMBOL     | CONDITIONS  |   | MIN  | TYP                 | MAX           | UNITS            |
|-------------------------------|------------|---|---|--|---------------------|---------------|------------------|
| Temperature Measurement Error |            | $-45^\circ\text{C}$ to $+145^\circ\text{C}$ , 6-sigma |   | -1.75  | $\pm 0.3$           | +1.75         | $^\circ\text{C}$ |
|                               |            | $0^\circ\text{C}$ to $+70^\circ\text{C}$ , 6-sigma    |   | -1   |                     | +1            |                  |
| Conversion Time               |            | 10-bit ( $0.25^\circ\text{C}$ ) resolution            |   | 35   | 80                  | ms            |                  |
| Temperature Resolution        |            | 12 bits (Configuration bits D6:D5 = 11)               |   | 0.0625                                       |                     |               | $^\circ\text{C}$ |
|                               |            | 10 bits (Configuration bits D6:D5 = 10)               |   | 0.25   |                     |               | $^\circ\text{C}$ |
|                               |            | 9 bits (Configuration bits D6:D5 = 01)                |   | 0.5  |                     |               |                  |
|                               |            | 8 bits (Configuration bits D6:D5 = 00)                |   | 1.0  |                     |               |                  |
| LOGIC DC CHARACTERISTICS      |            |   |   |  |                     |               |                  |
| Input Logic High Voltage      | $V_{IH}$   | Local Power   | $V_{DD} = 3.3\text{V}$ , $V_{DD} = 1.6\text{V}$ | $V_{DD} \times 0.7$ ,<br>$V_{DD} \times 0.8$ | 3.6                 |               | V                |
|                               |            | Parasite Power  | $V_{DD} = 3.3\text{V}$ , $V_{DD} = 2.3\text{V}$ | $V_{DD} \times 0.7$ ,<br>$V_{DD} \times 0.8$ | 3.6                 |               |                  |
| Input Logic Low Voltage       | $V_{IL}$   |   |   | -0.5   | $V_{DD} \times 0.2$ |               | V                |
| Input High Leakage Current    |            | Local Power, Excludes DQ                              |   |  | 1                   |               | $\mu\text{A}$    |
| Input Low Leakage Current     | $I_{IL}$   | $V_{IN} = 0\text{V}$                                  |   | -1   | $\pm 0.005$         | +1            | $\mu\text{A}$    |
| Input Capacitance             | $C_{IN}$   |   |   | 5  |                     |               | pF               |
| Output High Leakage Current   |            | $V_{OUT} = V_{DD}$                                    |   | $\pm 0.005$                                  | 1                   |               | $\mu\text{A}$    |
| Sink Current                  | $I_L$      | $V_{I/O} = 0.4\text{V}$                               | $V_{CC} < 2.3\text{V}$                          | 2.5  |                     |               | mA               |
|                               |            |   | $V_{CC} > 2.3\text{V}$                          | 4  |                     |               |                  |
| AC ELECTRICAL CHARACTERISTICS |            |   |   |  |                     |               |                  |
| POR Time                      | $t_{POR}$  | Local or Parasite Power                               |   | 3  | 8                   | ms            |                  |
| Time to Strong Pullup On      | $t_{SPON}$ | Start Convert T command                               |   | 10   |                     | $\mu\text{s}$ |                  |
| Time Slot                     | $t_{SLOT}$ |   |   | 60   | 120                 | $\mu\text{s}$ |                  |
| Recovery Time                 | $T_{REC}$  | 10nF bypass capacitor from $V_{CC}$ to GND            |   | 4  |                     | $\mu\text{s}$ |                  |
| Write-Zero Low Time           | $t_{LOW0}$ |   |   | 60   | 120                 | $\mu\text{s}$ |                  |
| Write-One Low Time            | $t_{LOW1}$ |   |   | 4  | 15                  | $\mu\text{s}$ |                  |
| Read Data Valid               | $t_{RDV}$  |   |   |  | 15                  | $\mu\text{s}$ |                  |
| Reset Time High               | $t_{RSTH}$ |   |   | 480  |                     | $\mu\text{s}$ |                  |
| Reset Time Low                | $t_{RSTL}$ |   |   | 480  |                     | $\mu\text{s}$ |                  |
| Presence Detect High          | $t_{PDH}$  |   |   | 15   | 60                  | $\mu\text{s}$ |                  |

## Electrical Characteristics (continued)

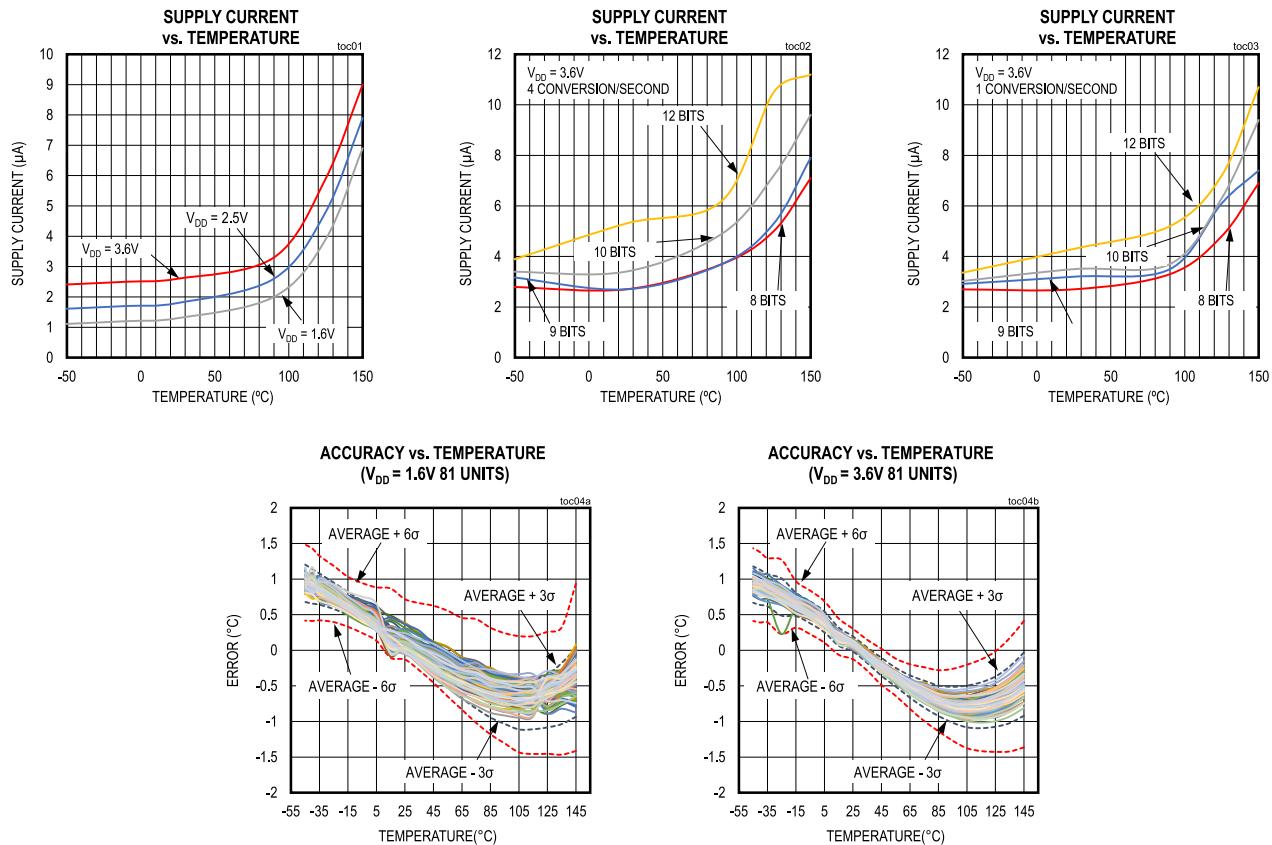
( $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ ,  $V_{DD} = 1.6\text{V}$  to  $3.6\text{V}$ ,  $V_{PU} = 2.3\text{V}$  to  $3.6\text{V}$ , resolution = 12 bits, unless otherwise specified. Limits are 100% tested at  $T_A = +25^\circ\text{C}$ . Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization. )

| PARAMETER                               | SYMBOL    | CONDITIONS  | MIN   | TYP | MAX      | UNITS         |
|---|-----------|---|---|-----|----------|---------------|
| Presence Detect Low                     | $t_{PDL}$ |   | 60  |     | 240      | $\mu\text{s}$ |
| DQ Capacitance                          | $C_{DQ}$  | Note 1  |   |     | 25       | $\text{pF}$   |
| Address Input Capacitance               | $C_{ADD}$ | Note 1  |   |     | 2        | $\text{pF}$   |
| Time to Read Address Selection Resistor |           | $C \leq 2\text{pF}$   |   | 2   |          | $\text{ms}$   |
| <b>POWER SUPPLY</b>                     |           |   |   |     |          |               |
| Operating Supply Voltage Range          |           |   | 1.6   |     | 3.6      | $\text{V}$    |
| Pullup Supply Voltage                   | $V_{PU}$  | Parasite Power  | 2.3   |     | 3.6      | $\text{V}$    |
|   |           | Local Power   | 1.6   |     | $V_{DD}$ |               |
| Conversion Power Supply Current         |           | Active temperature conversions, DQ high                             | 80  |     | 150      | $\mu\text{A}$ |
| Average Power Supply Current            |           | DQ high   | 0.25 conversions/s,<br>10-bit ( $0.25^\circ\text{C}$ )<br>resolution. | 5   | 15       | $\mu\text{A}$ |
|   |           |   | 4 conversions/s,<br>10-bit ( $0.25^\circ\text{C}$ )<br>resolution.    | 9.8 | 24       |               |
| Standby Supply Current                  |           | In Standby, Parasite power, DQ = high<br>$T_A < +85^\circ\text{C}$  |   | 2.5 | 6        | $\mu\text{A}$ |
|   |           | In Standby, Parasite Power, DQ = high<br>$T_A < +125^\circ\text{C}$ |   | 2.5 | 12       | $\mu\text{A}$ |

**Note 1:** Specifications are guaranteed by bench characterization and not automated test equipment (ATE) characterization.

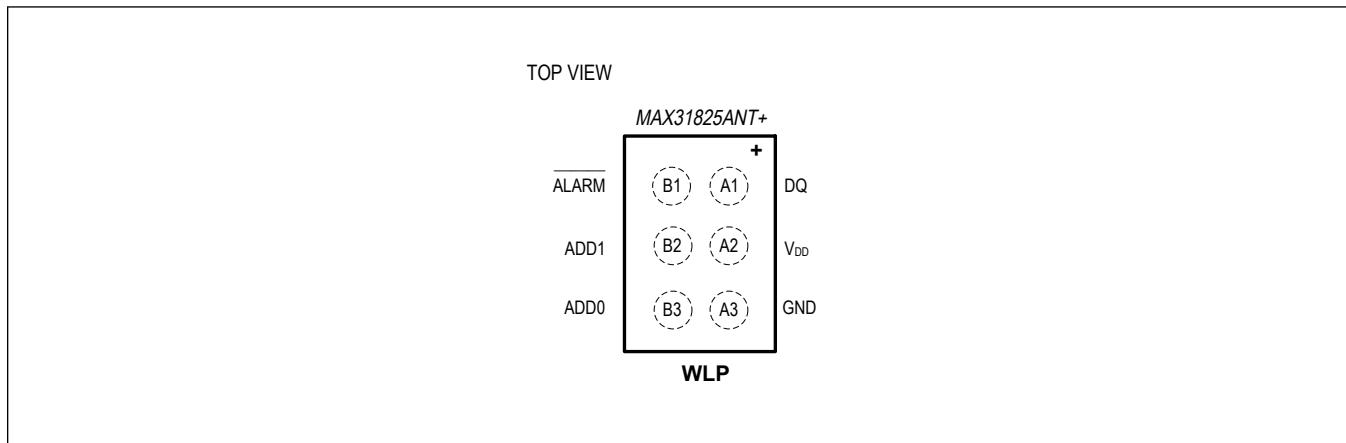
## Typical Operating Characteristics

( $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ ,  $V_{DD} = 1.6\text{V}$  to  $3.6\text{V}$ ,  $V_{PU} = 2.3\text{V}$  to  $3.6\text{V}$ , resolution = 12 bits, unless otherwise specified. Limits are 100% tested at  $T_A = +25^\circ\text{C}$ . Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization.)



## Pin Configuration

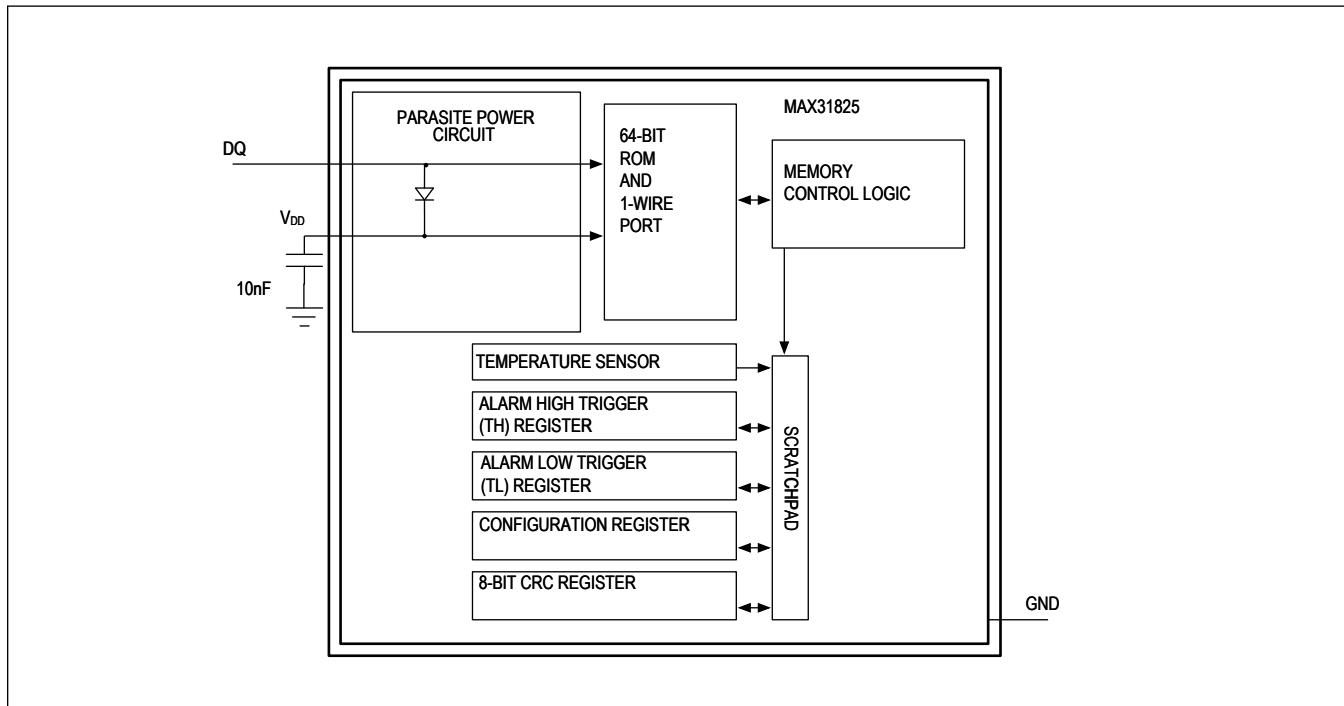
### WLP



## Pin Description

| PIN | NAME            | FUNCTION  |
|-----|-----------------|---|
| 1   | DQ              | Data In/Out   |
| 2   | V <sub>DD</sub> | External Parasite Power Capacitor and V <sub>DD</sub> Input. Connect a 3.3nF capacitor between this pin and GND for parasite power operation. Connect power supply voltage to this pin when powering from an external V <sub>DD</sub> source. |
| 3   | GND             | Ground  |
| 5   | ADD1            | Address Selection Input. Connect to GND or V <sub>DD</sub> (DQ in parasite mode) to select the location address.  |
| 4   | ADD0            | Address Selection Input. Connect a resistor to GND to select the location address.  |
| 6   | ALARM           | Alarm output. Open-drain. Note that the ALARM output generates alarm signals only in external power mode.   |

## Functional Diagram



## Detailed Description

The MAX31825 digital thermometer provides 12-bit temperature measurements and communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a microcontroller. The data line requires a weak pullup resistor since all devices are linked to the bus through a three-state or open-drain port (the MAX31825's DQ pin). Two address inputs (ADD0 and ADD1), simplify mapping of individual devices to specific locations.

Each 1-Wire device has a unique 64-bit serial code, allowing multiple devices to function on the same 1-Wire bus. Therefore, it is simple to use one microcontroller to control many devices distributed over a large area. In this bus system, the microcontroller identifies and addresses devices on the bus using each device's unique 64-bit code. Because each device has a unique code, the number of devices that can be addressed on one bus is virtually unlimited. The 1-Wire bus protocol, including detailed explanations of the commands and time slots, is described in the 1-Wire Bus System section.

Control and data registers include the 2-byte temperature register that stores the digital output from the temperature sensor, a configuration register for selecting operating modes, over-temperature and under-temperature alarm thresholds, and a CRC register.

As an alternative to supplying power through the  $V_{DD}$  pin, power can instead be supplied via the 1-Wire pullup resistor through DQ when the bus is high. The high bus signal also charges an external capacitor (CPP), which then supplies power to the device when the bus is low. This method of deriving power from the 1-Wire bus is referred to as parasite power.

## Measuring Temperature

Resolution is selectable to be 8, 9, 10, or 12 bits. 8-bit resolution corresponds to an LSB value of  $1^{\circ}\text{C}$ , while 12-bit resolution corresponds to an LSB value of  $0.0625^{\circ}\text{C}$ . The sensor powers up in a low-power idle state. To initiate a single temperature measurement, the master must issue a Convert T command, as described in [Function Commands](#). The bus requirements for parasite power are explained in the [Powering the 1-Wire Temperature Sensor](#) section.

When powered through  $V_{DD}$ , automatic conversions may be selected using the Rate bits in the Configuration register. When a rate other than 000 (standby) is selected, conversions take place at the selected rate, and the temperature registers are updated at the end of each conversion. When parasite powered, the sensor ignores the Rate bits and remains in standby mode until receiving a Convert T command.

The temperature data is stored as a 16-bit sign-extended two's complement number in the temperature register (see [Temperature Data Format](#)). The sign bit (S) indicate if the temperature is positive or negative. For positive numbers, S = 0. For negative numbers, S = 1. [Table 3](#) gives examples of digital output data and the corresponding temperature readings.

## Powering the 1-Wire Temperature Sensor

The MAX31825 can be powered by an external supply connected to the  $V_{DD}$  pin, or it can operate in “parasite power” mode, which allows it to function without a local external supply. Parasite power is useful for applications that require connection to the sensor through a cable, or those that are very space-constrained. [Figure 1](#) shows the parasite-power control circuitry, which “steals” power from the 1-Wire bus through DQ when the bus is high. The stolen charge powers the sensor while the bus is high, and some of the charge is stored on the parasite-power capacitor (CPP) to provide power when the bus is low.

In parasite-power mode, the 1-Wire bus and CPP can provide sufficient current for most operations as long as the specified timing and voltage requirements are met (see the *Logic DC Electrical Characteristics* and *AC Electrical Characteristics* sections of the [Electrical Characteristics](#) table). However, when performing temperature conversions, the operating current can be as high as  $150\mu\text{A}$ . This current can cause an unacceptable voltage drop across the 1-Wire pullup resistor and is more current than can be supplied by CPP. To ensure that the sensor has sufficient supply current, it is necessary to provide a strong pullup on the 1-Wire bus whenever temperature conversions are taking place. This can be accomplished by using a MOSFET to pull the bus directly to the supply, as shown in [Figure 1](#). The 1-Wire bus must be switched to the strong pullup within  $10\mu\text{s}$  (max) after issuing a Convert T command, and the bus must be held high by the pullup for the duration of the conversion ( $t_{CONV}$ ). No other activity can take place on the 1-Wire bus while the strong pullup is enabled.

The sensor can also be powered by the conventional method of connecting an external power supply to  $V_{DD}$ , as shown in [Figure 2](#). The advantage of this method is that the MOSFET pullup is not required, and the 1-Wire bus is free to carry other traffic during the temperature conversion period.

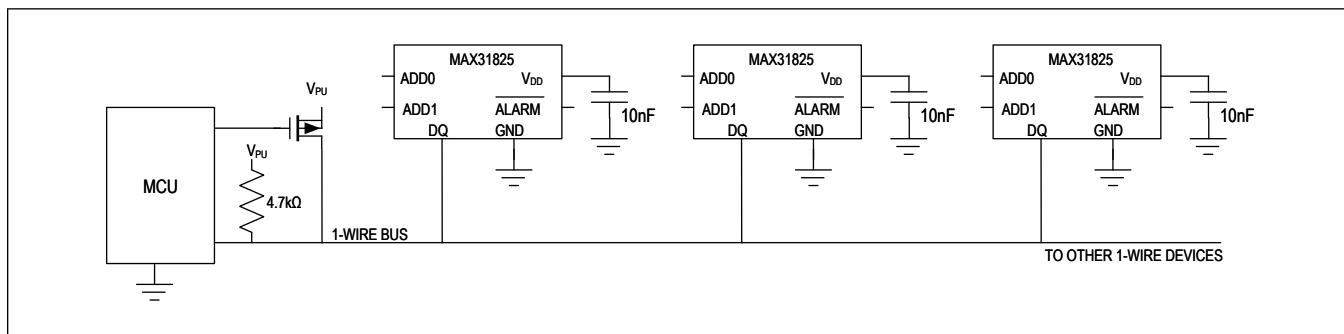


Figure 1. Powering the MAX31825 from the 1-Wire Data Input (DQ)

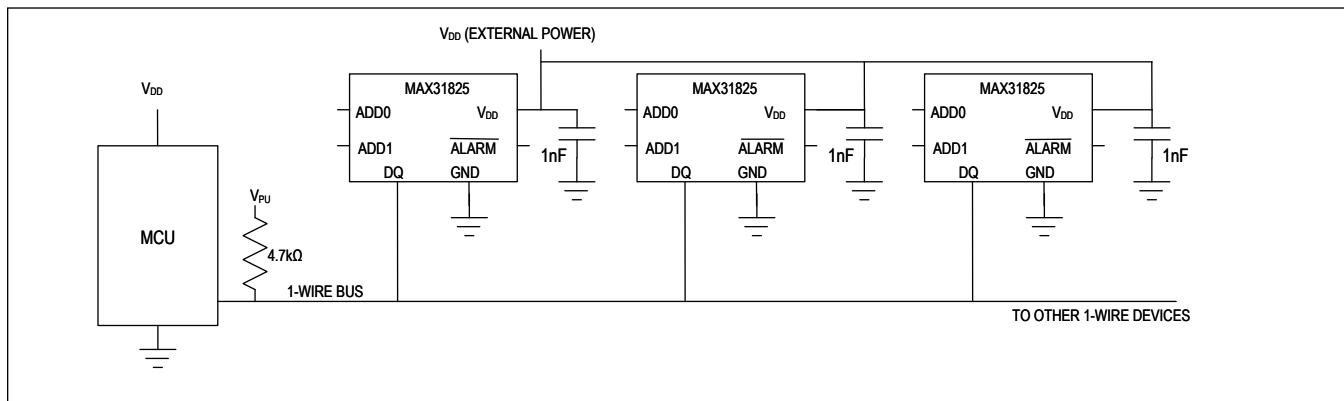


Figure 2. Powering the MAX31825 from an External Power Supply

### CPP Considerations for Parasite Power

When operating from parasite power, the values of  $\text{C}_{\text{PP}}$ , pullup resistor  $\text{R}_{\text{PU}}$ , and the pullup voltage  $\text{V}_{\text{PU}}$  should be chosen to work properly with the interface timing.

When system power is first connected, keep  $\text{V}_{\text{DD}}$  high at least 5 time constants ( $5 \times \text{C}_{\text{PP}} \times \text{R}_{\text{PU}}$ ) to fully charge  $\text{C}_{\text{PP}}$  before starting communications. For a single sensor with  $\text{C}_{\text{PP}} = 10\text{nF}$  and  $\text{R}_{\text{PU}} = 4.7\text{k}\Omega$ ,  $\text{V}_{\text{DD}}$  should therefore stay high for  $77.55\mu\text{s}$  before starting communications. Note that if multiple 1-wire devices are on the bus, each will have its own parasite power capacitor, and the total  $\text{C}_{\text{PP}}$  will be the sum of the values of all of the parasite power capacitors. If the total  $\text{C}_{\text{PP}}$  is large, it may be useful to reduce the value of  $\text{R}_{\text{PU}}$  to reduce the required  $\text{V}_{\text{DD}}$  high period.

A 1-wire reset pulls  $\text{DQ}$  low for as long as  $640\mu\text{s}$ . During this period,  $\text{C}_{\text{PP}}$  must be large enough that the voltage across it never falls below the  $1.5\text{V}$  power-on-reset voltage. The maximum supply current (up to  $125^\circ\text{C}$ ) in standby is  $12\mu\text{A}$ . The forward drop across the internal ideal diode is nominally  $50\text{mV}$ . Again using  $\text{C}_{\text{PP}} = 10\text{nF}$ , a maximum standby supply current of  $12\mu\text{A}$ , and a maximum  $\text{DQ}$  reset low period of  $640\mu\text{s}$ , we have a voltage drop on  $\text{C}_{\text{PP}}$  of  $\text{V} = \text{t} \times \text{I/C} = 640\mu\text{s} \times 12\mu\text{A}/10\text{nF} = 582\text{mV}$ , which is compatible with the  $2.3\text{V}$  specified minimum value of  $\text{V}_{\text{PU}}$ .

## 64-Bit ROM Code

Each 1-Wire component contains a unique 64-bit code stored in ROM (Figure 3). The least significant 8 bits of the ROM code contain the sensor's 1-Wire family code, 3Bh. The next 48 bits contain a unique serial number. The most significant 8 bits contain a cyclic redundancy check (CRC) byte that is calculated from the first 56 bits of the ROM code. See [CRC Generation](#) for a detailed explanation of the CRC bits. The 64-bit ROM code and associated ROM function control logic allow the device to operate as a 1-Wire device using the protocol detailed in [1-Wire Bus System](#).

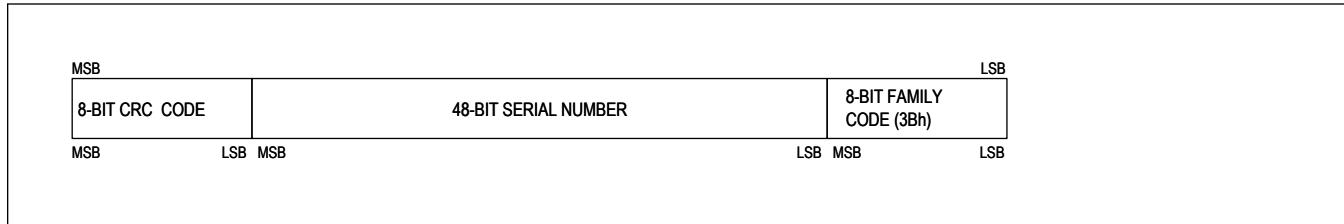


Figure 3. 64-bit ROM Code

## Address

Although the 64-bit ROM code allows each 1-Wire device on a bus to be identified for communication purposes, it does not provide any information about the location of the device. The MAX31825 includes two address pins (ADD0 and ADD1). ADD0 can be connected to an external resistor whose value is measured by the MAX31825 in response to the Convert Location command, resulting in five location address bits (A4:A0) being stored in the Status register. Because the location resistor values on the board are known, this location address allows the location of the MAX31825 to be uniquely identified. Mapping of the address selection resistor value to A4:A0 is shown in [Table 1](#). In addition to ADD0, the ADD1 input can be connected to GND or V<sub>DD</sub> (or DQ in parasite-power mode). This selects the value of bit A5, yielding a total of 64 available addresses. A5 = 1 when ADD1 is connected to V<sub>DD</sub> and 0 when ADD1 is grounded.

**Table 1. Resistor Selection of Address bits A4:A0**

| A4:A0 | 1% RESISTOR VALUE<br>(kΩ) |
|-------|---------------------------|
| 11111 | 4.2                       |
| 11110 | 5                         |
| 11101 | 5.9                       |
| 11100 | 7.1                       |
| 11011 | 8.4                       |
| 11010 | 10                        |
| 11001 | 11.9                      |
| 11000 | 14.1                      |
| 10111 | 16.8                      |
| 10110 | 20                        |
| 10101 | 23.8                      |
| 10100 | 28.3                      |
| 10011 | 33.6                      |
| 10010 | 40                        |
| 10001 | 47.6                      |
| 10000 | 56.6                      |
| 01111 | 67.3                      |
| 01110 | 80                        |
| 01101 | 95.1                      |
| 01100 | 113.1                     |
| 01011 | 134.5                     |
| 01010 | 160                       |
| 01001 | 190.3                     |
| 01000 | 226.3                     |
| 00111 | 269.1                     |
| 00110 | 320                       |
| 00101 | 380.5                     |
| 00100 | 452.5                     |
| 00011 | 538.2                     |
| 00010 | 640                       |

**Table 1. Resistor Selection of Address bits A4:A0 (continued)**

| A4:A0 | 1% RESISTOR VALUE<br>( $\text{k}\Omega$ ) |
|-------|---|
| 00001 | 761.1                                     |
| 00000 | 905.1                                     |

### Control and Data Registers

The control and data registers are organized as shown in [Table 2](#). All memory commands are described in detail in the [Function Commands](#) section.

**Table 2. Register Functions**

| BYTE ADDRESS | READ OR WRITE | BYTE FUNCTION (POWER-UP STATE)          |
|--------------|---------------|---|
| 0            | R             | Temperature LSB ( $+85^\circ\text{C}$ ) |
| 1            | R             | Temperature MSB ( $+85^\circ\text{C}$ ) |
| 2            | R             | Status [TH, TL state, address]          |
| 3            | R/W           | Configuration                           |
| 4            | R/W           | TH MSB ( $+128^\circ\text{C}$ )         |
| 5            | R/W           | TH LSB ( $+128^\circ$ )                 |
| 6            | R/W           | TL LSB ( $-55^\circ$ )                  |
| 7            | R/W           | TL MSB ( $-55^\circ$ )                  |
| 8            | R             | CRC                                     |

**Temperature Data**

Byte 0 and byte 1 contain the least significant byte and the most significant byte of the temperature register, respectively. Two different formats are available: Normal and Extended. Normal format produces temperature data up to  $128^\circ\text{C}$  - 1LSB, and Extended format produces data up to and beyond the  $145^\circ\text{C}$  operating limit.

**Table 3. Temperature Data Format (S = Sign Bit)**

| MOST SIGNIFICANT BYTE ( $^\circ\text{C}$ ) |    |    |    |     |    |    |    | LEAST SIGNIFICANT BYTE ( $^\circ\text{C}$ ) |    |    |    |     |      |       |        | COMMENT         |
|--|----|----|----|-----|----|----|----|---|----|----|----|-----|------|-------|--------|-----------------|
| D7   | D6 | D5 | D4 | D3  | D2 | D1 | D0 | D7  | D6 | D5 | D4 | D3  | D2   | D1    | D0     |                 |
| S  | S  | S  | S  | S   | 64 | 32 | 16 | 8   | 4  | 2  | 1  | 0.5 | 0.25 | 0.125 | 0.0625 | Normal format   |
| S  | S  | S  | S  | 128 | 64 | 32 | 16 | 8   | 4  | 2  | 1  | 0.5 | 0.25 | 0.125 | 0.0625 | Extended format |

**Table 4. Temperature/Data Relationship. Shown for 12-bit Resolution.**

| TEMPERATURE ( $^\circ\text{C}$ ) | NORMAL FORMAT DATA (BINARY) | NORMAL FORMAT DATA (HEX) | EXTENDED FORMAT DATA (BINARY) | EXTENDED FORMAT DATA (HEX) |
|----------------------------------|-----------------------------|--------------------------|-------------------------------|----------------------------|
| +150                             | 0000 0111 1111 1111         | 07FF                     | 0000 1001 0110 0000           | 0960h                      |
| +128                             | 0000 0111 1111 1111         | 07FFh                    | 0000 1000 0000 0000           | 0800h                      |
| +125                             | 0000 0111 1101 0000         | 07D0h                    | 0000 0111 1101 0000           | 07D0h                      |
| +85                              | 0000 0101 0101 0000         | 0550h                    | 0000 0101 0101 0000           | 0550h                      |
| +25.0625                         | 0000 0001 1001 0001         | 0191h                    | 0000 0001 1001 0001           | 0191h                      |
| +10.125                          | 0000 0000 1010 0010         | 00A2h                    | 0000 0000 1010 0010           | 00A2h                      |
| +0.5                             | 0000 0000 0000 1000         | 0008h                    | 0000 0000 0000 1000           | 0008h                      |
| 0                                | 0000 0000 0000 0000         | 0000h                    | 0000 0000 0000 0000           | 0000h                      |
| -0.5                             | 1111 1111 1111 1000         | FFF8h                    | 1111 1111 1111 1000           | FFF8h                      |
| -10.125                          | 1111 1111 0101 1110         | FF5E                     | 1111 1111 0101 1110           | FF5Eh                      |
| -25.0625                         | 1111 1110 0110 1111         | FE6Fh                    | 1111 1110 0110 1111           | FE6Fh                      |
| -55                              | 1111 1100 1001 0000         | FC90h                    | 1111 1100 1001 0000           | FC90h                      |

**Status Register**

The Status register contains the overtemperature (TH) and undertemperature (TL) status bits and the location bits. The A[5:0] bits report the address information selected by the resistor value at ADD0 and the logic state of ADD1. Initiate a Detect Address command to measure the external resistor value and populate these bits. The default value is all 0s.

**Table 5. Status Register Format**

| BIT      | 7        | 6        | 5  | 4  | 3  | 2  | 1  | 0  |
|----------|----------|----------|----|----|----|----|----|----|
| FUNCTION | TH FAULT | TL FAULT | A5 | A4 | A3 | A2 | A1 | A0 |
| DEFAULT  | 0        | 0        | 0  | 0  | 0  | 0  | 0  | 0  |

### Configuration Register

Byte 3 contains the configuration register, which is organized as shown in [Table 6](#). The configuration register provides control over several operating parameters, including data format, conversion resolution, the ALARM output mode, and the continuous conversion rate.

**Table 6. Configuration Register Format**

| BIT      | 7      | 6     | 5     | 4        | 3        | 2      | 1      | 0      |
|----------|--------|-------|-------|----------|----------|--------|--------|--------|
| FUNCTION | Format | Res 1 | Res 0 | Comp/Int | Reserved | Rate 2 | Rate 1 | Rate 0 |
| DEFAULT  | 0      | 1     | 1     | 1        | 0        | 0      | 0      | 0      |

### Temperature Data Format

As discussed in the Temperature Data section, Bit 7 of the Configuration register selects the temperature data format. When D7 is 0 (normal format), the data format is two's complement with a range of  $-128^\circ\text{C}$  to  $(128^\circ\text{C} - 1\text{LSB})$ , where the value of an LSB depends on the resolution selection. Write a 1 to bit 7 for extended temperature format. In extended format, the MSB is given a value of  $128^\circ\text{C}$ , which allows temperatures as high as  $145^\circ\text{C}$  to be measured. After changing the value of bit 7 the data format does not update until the completion of the following temperature conversion. After setting bit 7 to 1, new extended temperature data is guaranteed ready after a period equal to twice the maximum conversion time. Note that changing the data format bit does not change the format of the values in the TH and TL registers; these values must be written to the registers in the format selected by Bit 7.

### Resolution

The resolution bits (D6:D5) select the conversion resolution. The conversion time doubles with every bit of increased resolution. for example, the nominal 10-bit conversion time is 35ms. Increasing the resolution to 12 bits increases the conversion time to 140ms. The resolution bits allow resolution, conversion time, and average supply current to be optimized for the application's requirements.

**Table 7. Resolution Selection**

| D6 | D5 | RESOLUTION (BITS) |
|----|----|-------------------|
| 0  | 0  | 8                 |
| 0  | 1  | 9                 |
| 1  | 0  | 10                |
| 1  | 1  | 12 (default)      |

### Comparator/Interrupt

Set bit D4, the COMPARATOR/INTERRUPT bit, to 0 to make the ALARM output and the Overtemperature and Undertemperature Status bits operate in Comparator mode. In Comparator mode, the ALARM output asserts and the Status bit is set to 1 when the temperature rises above the TH value or falls below the TL value. The ALARM output de-asserts and the Status bits return to 0 when the measured temperature returns to a value ranging from TH to TL.

Set bit D4 to 1 to operate the ALARM output and Status bits in interrupt mode. In interrupt mode, exceeding TH or going below TL also asserts the ALARM output and sets the Status bits to 1. ALARM remains asserted and the Status bits remain set to 1 until a read operation is performed on any of the registers, at which point ALARM is de-asserted and the Status bits return to 0. Note that if the result of the next conversion is greater than TH or less than TL, the ALARM output will assert and the Status bit(s) will set.

Note that the ALARM output functions only in external power mode.

### Conversion Rate

The conversion rate bits, D2:D0, select the rate for automatic continuous conversions. These bits apply only when external power is used; they must be set to 000 when operating in parasite power mode. Rates from approximately one sample per minute to 8sps are available, as well as 0sps (or Standby). The nominal conversion time is 35ms at a resolution of 10 bits, with the conversion time changing by a factor of two for each bit of resolution change. In automatic conversion mode, available only when  $V_{DD}$  is connected to a power supply, conversions are started at the selected rate and shutdown mode is entered between conversions to reduce average power supply current. Note that the highest conversion rate can't be achieved at 12-bit resolution. When the conversion rate bits are set to 000, the ConvertT command initiates a single conversion and a return to shutdown. When the bits are set to a different value, the ConvertT command initiates continuous conversions. Continuous conversions may be stopped or the rate may be changed by changing the value of the conversion rate bits.

Conversion Rate Selection

| D2 | D1 | D0 | CONVERSION RATE        |
|----|----|----|------------------------|
| 0  | 0  | 0  | 0 (Shutdown)           |
| 0  | 0  | 1  | 1 conversion/64 second |
| 0  | 1  | 0  | 1 conversion/32 second |
| 0  | 1  | 1  | 1 conversion/16 second |
| 1  | 0  | 0  | 1 conversion/4 second  |
| 1  | 0  | 1  | 1 conversion/second    |
| 1  | 1  | 0  | 4 conversion/second    |
| 1  | 1  | 1  | 8 conversion/second    |

### Alarm Thresholds

Bytes 4 through 7 contain the 16-bit alarm thresholds TH and TL. The default value of TH is  $160^\circ\text{C}$ , and the default value of TL is  $-65^\circ\text{C}$ . The data format is the same as that of the temperature register.

### CRC

Byte 8 is read-only and contains the CRC code for bytes 0–7 of the scratchpad. The sensor generates this CRC using the method described in [CRC Generation](#).

## CRC Generation

CRC bytes are provided as part of the device's 64-bit ROM code, in the 9th byte of the Scratchpad. The ROM code CRC is calculated from the first 56 bits of the ROM code and is contained in the most significant byte of the ROM. The scratchpad CRC is calculated from the data in the scratchpad, and therefore changes when the data in the scratchpad changes. The CRC provides the bus master with a method of data validation when data is read from the device. To verify that data has been read correctly, the bus master must recalculate the CRC from the received data and then compare this value to either the ROM code CRC (for ROM reads) or to the scratchpad's CRC (for scratchpad reads). If the calculated CRC matches the read CRC, the data has been received error-free. The comparison of CRC values and the decision to continue with an operation are determined entirely by the bus master. There is no circuitry inside the device that prevents a command sequence from proceeding if the CRC (ROM or scratchpad) does not match the value generated by the bus master.

The equivalent polynomial function of the CRC (ROM or scratchpad) is:

$$\text{CRC} = X^8 + X^5 + X^4 + 1$$

The bus master can recalculate the CRC and compare it to the CRC values from the device using the polynomial generator shown in [Figure 4](#). This circuit consists of a shift register and XOR gates, and the shift register bits are initialized to 0. Starting with the least significant bit of the ROM code or the least significant bit of byte 0 in the scratchpad, one bit at a time should be shifted into the shift register. After shifting in the 56th bit from the ROM or the most significant bit of byte 7 from the Scratchpad 1 or byte 10 from Scratchpad 2, the polynomial generator contains the recalculated CRC. Next, the 8-bit ROM code or scratchpad CRC from the device must be shifted into the circuit. At this point, if the recalculated CRC was correct, the shift register contains all zeros. Additional information about the Maxim 1-Wire CRC is available in [Application Note 27: Understanding and Using Cyclic Redundancy Checks with Maxim iButton® Products](#).

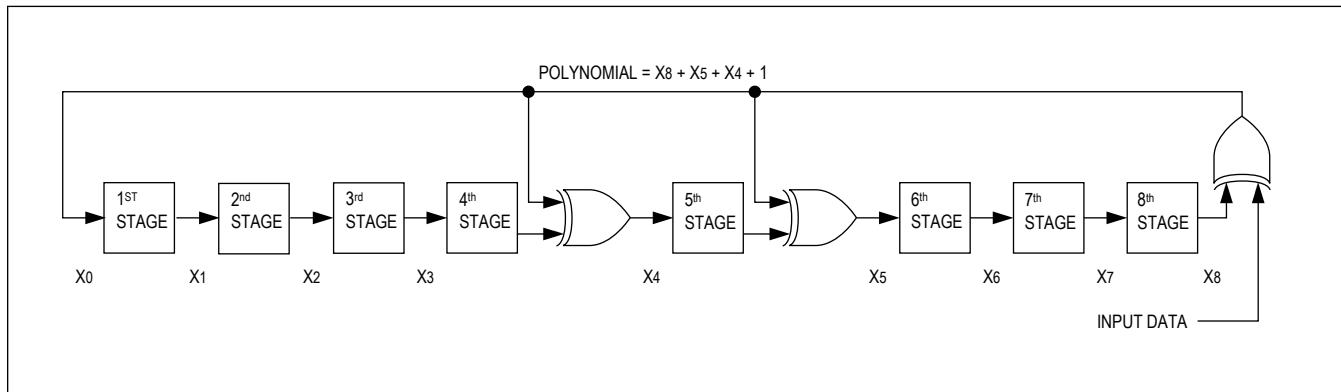


Figure 4. CRC Polynomial Generator

## 1-Wire Bus System

The 1-Wire bus system uses a single bus master to control one or more slave devices. The temperature sensor is always a slave. When there is only one slave on the bus, the system is referred to as a single-drop system; the system is multidrop if there are multiple slaves on the bus. All data and commands are transmitted least significant bit first over the 1-Wire bus.

The following discussion of the 1-Wire bus system is broken down into three topics: hardware configuration, transaction sequence, and 1-Wire signaling (signal types and timing).

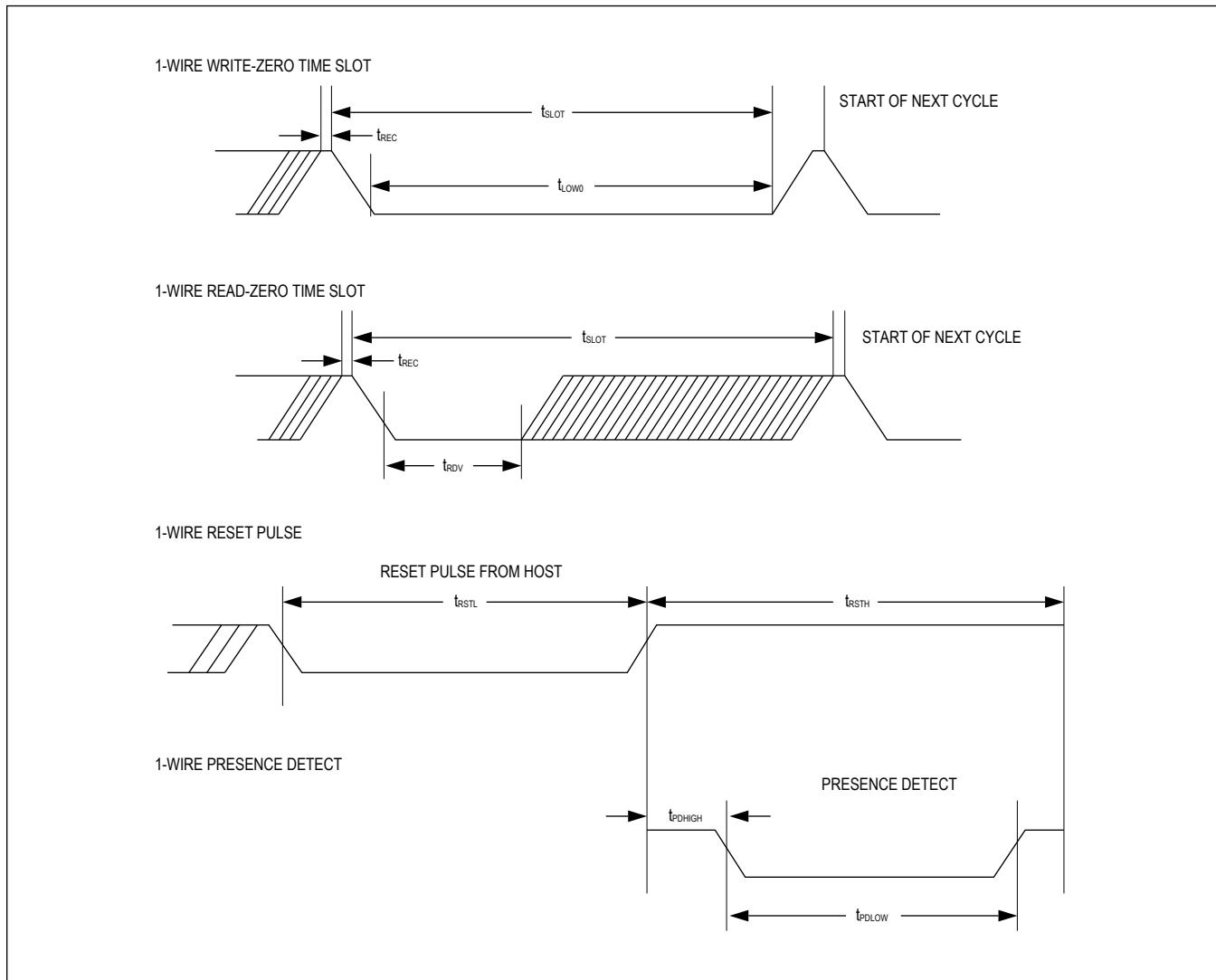


Figure 5. 1-Wire Bus Timing Diagram

## Hardware Configuration

The 1-Wire bus has by definition only a single data line. Each device (master or slave) interfaces to the data line by using an open-drain or three-state port. This allows each device to “release” the data line when the device is not transmitting data, thereby making the bus available for use by another device. The device’s 1-Wire port (DQ) is open drain with an internal circuit equivalent to that shown in [Figure 6](#).

The 1-Wire bus requires an external pullup resistor of approximately  $5\text{k}\Omega$ ; thus, the idle state for the 1-Wire bus is high. If for any reason a transaction needs to be suspended, the bus must be left in the idle state if the transaction is to resume. Infinite recovery time can occur between bits so long as the 1-Wire bus is in the inactive (high) state during the recovery period. If the bus is held low for more than  $480\text{\mu s}$ , all components on the bus are reset.

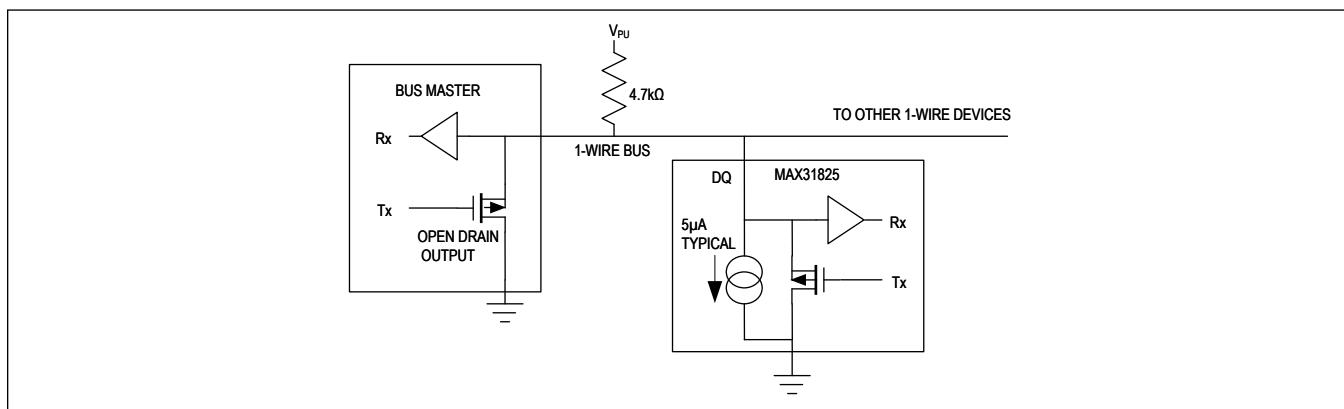


Figure 6. Hardware Configuration

## Transaction Sequence

The transaction sequence for accessing the device is as follows:

Step 1: Initialization

Step 2: ROM Command (followed by any required data exchange)

Step 3: Function Command (followed by any required data exchange)

It is very important to follow this sequence every time the MAX31825 is accessed, as the MAX31825 does not respond if any steps in the sequence are missing or out of order. An exception to this rule is the Search ROM command. After issuing this ROM command, the master must return to step 1 in the sequence.

## Initialization

All transactions on the 1-Wire bus begin with an initialization sequence. The initialization sequence consists of a reset pulse transmitted by the bus master followed by presence pulse(s) transmitted by the slave(s). The presence pulse lets the bus master know that slave devices (MAX31825) are on the bus and are ready to operate. Timing for the reset and presence pulses is detailed in [1-Wire Signaling](#).

## ROM Commands

After the bus master has detected a presence pulse, it can issue a ROM command. These commands operate on the unique 64-bit ROM codes of each slave device and allow the master to single out a specific device if many are present on the 1-Wire bus. These commands also allow the master to determine how many and what types of devices are present on the bus. There are four ROM commands, and each command is 8 bits long. The master device must issue an appropriate ROM command before issuing a MAX31825 function command. An exception to the rule is when detect address is used to communicate with devices. ROM commands are not used when selecting an address to communicate. [Figure 7](#) shows a flowchart for operation of the ROM commands.

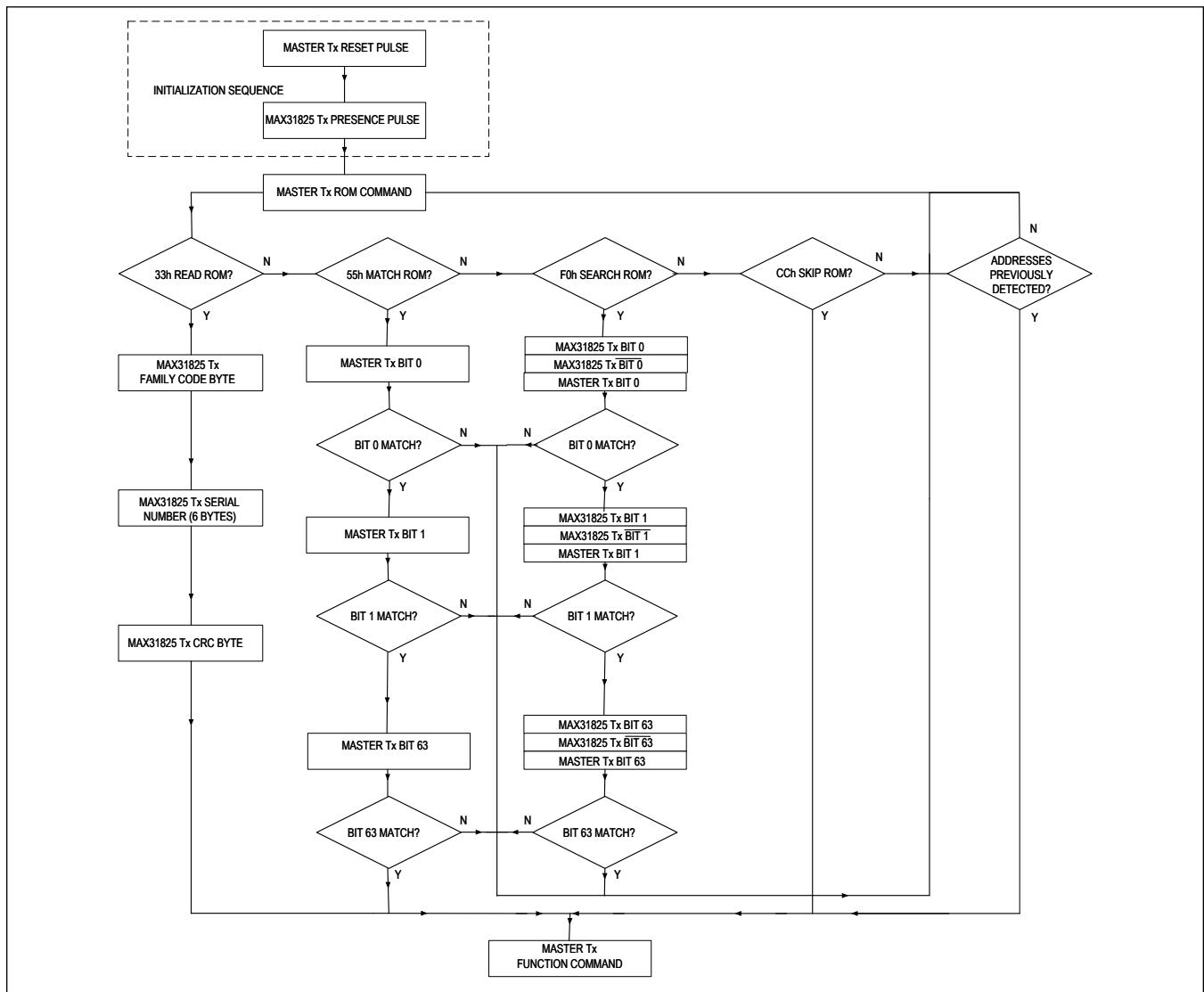


Figure 7. MAX31825 ROMs Command Flowchart

**Search ROM [F0h]**

When a system is initially powered up, the master must identify the ROM codes of all slave devices on the bus, which allows the master to determine the number of slaves and their device types. The master learns the ROM codes through a process of elimination that requires the master to perform a Search ROM cycle (i.e., Search ROM command followed by data exchange) as many times as necessary to identify all the slave devices. If there is only one slave on the bus, the simpler Read ROM command can be used in place of the Search ROM process. For a detailed explanation of the Search ROM command procedure, refer to *Application Note 937: Book of iButton® Standards*. After every Search ROM cycle, the bus master must return to step 1 (initialization) in the transaction sequence.

**Read ROM [33h]**

This command can be used only when there is one slave on the bus. It allows the bus master to read the slave's 64-bit ROM code without using the Search ROM command procedure. If this command is used when there is more than one slave present on the bus, a data collision occurs when all the slaves attempt to respond at the same time.

**Match ROM [55h]**

The Match ROM command followed by a 64-bit ROM code sequence allows the bus master to address a specific slave device on a multidrop or single-drop bus. Only the slave that exactly matches the 64-bit ROM code sequence responds to the function command issued by the master; all other slaves on the bus wait for a reset pulse.

**Skip ROM [CCh]**

The master can use this command to address all devices on the bus simultaneously without sending out any ROM code information. For example, the master can make all devices on the bus perform simultaneous temperature conversions by issuing a Skip ROM command followed by a Convert T function command.

Note that the Read Scratchpad command can follow the Skip ROM command only if there is a single slave device on the bus. In this case, time is saved by allowing the master to read from the slave without sending the device's 64-bit ROM code. A Skip ROM command followed by a Read Scratchpad command causes a data collision on the bus if there is more than one slave because multiple devices attempt to transmit data simultaneously.

## Function Commands

After the bus master has used a ROM command to address the unit with which it wishes to communicate, the master can issue one of the available function commands. These commands allow the master to read from the device's scratchpad memory, and initiate temperature conversions. The function commands are summarized in [Table 8](#) and illustrated by the flowchart in [Figure 8](#).

**Table 8. Function Commands Summary**

| COMMAND          | DESCRIPTION   | PROTOCOL | 1-WIRE BUS ACTIVITY AFTER COMMAND IS ISSUED  |
|------------------|---|----------|--|
| Convert T        | Initiates temperature conversion.   | 44h      | The MAX31825 transmits conversion status to master (not applicable for parasite-powered devices).  |
| Read Scratchpad  | Reads the 9-byte scratchpad including the CRC byte.   | BEh      | The MAX31825 transmits up to 9 data bytes to master. The 9th byte is the CRC byte.   |
| Write Scratchpad | Writes bytes 3 through 7 (Configuration and thresholds) to the scratchpad.                                    | 4Eh      | The master transmits five bytes to the scratchpad.   |
| Detect Address   | Loads location bits   | 88h      | The MAX31825 measures the external resistor value and writes location bits to Status register.   |
| Select Address   | Selects device with location bits that match transmitted bits. Follow with a Convert, Read, or Write command. | 70h      | Host transmits desired location bits to devices on the bus, then transmits another Function Command (Read, Write, or Convert). Only the MAX31825 with the transmitted location bits responds to the second Function Command. |

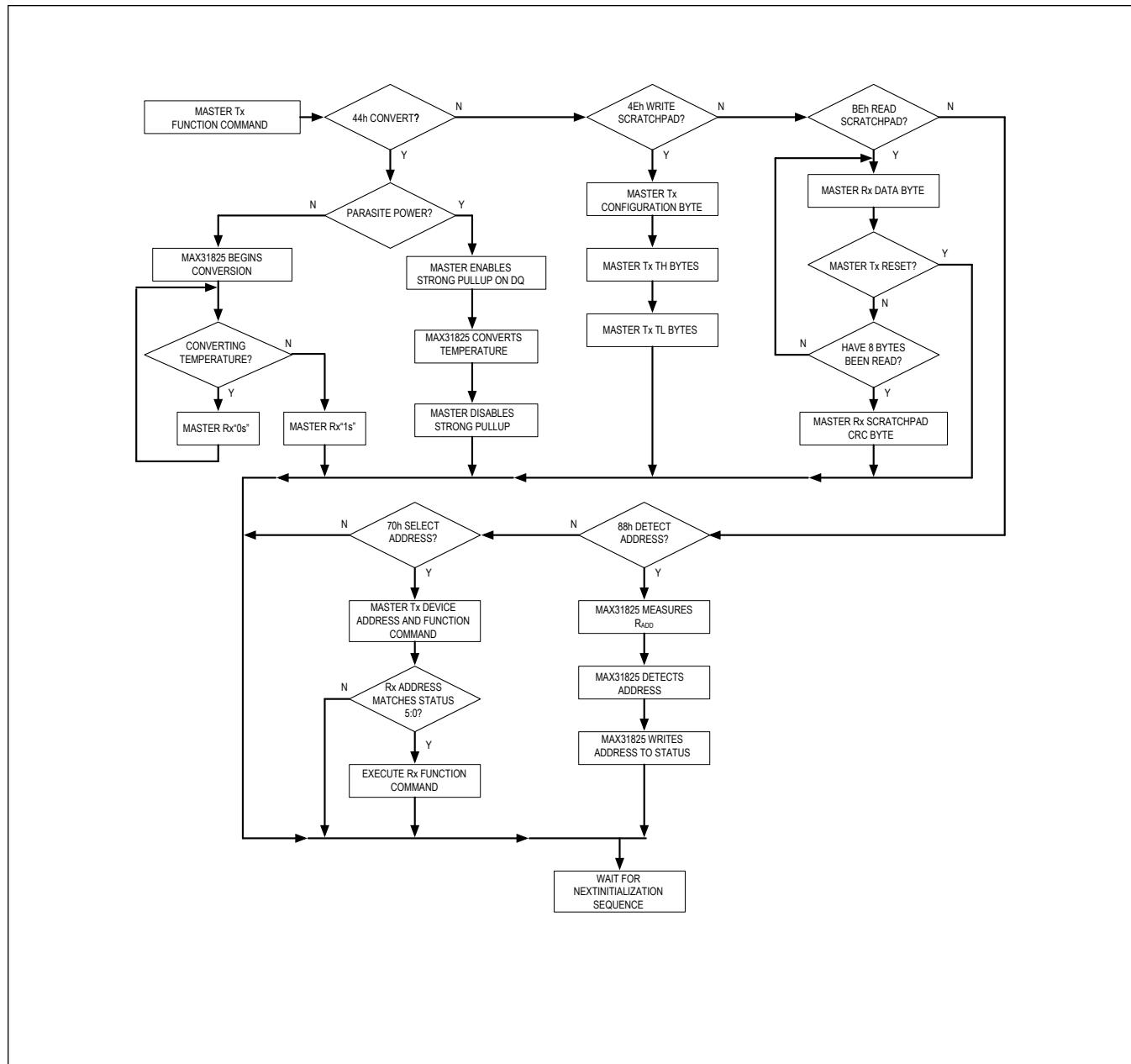


Figure 8. MAX31825 Function Commands Flowchart

**Convert T [44h]**

This command initiates a single temperature conversion. Following the conversion, the resulting thermal data is stored in the 2-byte temperature register in the Scratchpad memory and the sensor returns to its low-power idle state. If used in parasite-power mode, within 10 $\mu\text{s}$  (max) after this command is issued, the master must enable a strong pullup on the 1-Wire bus for the duration of the conversion (t<sub>CONV</sub>), as described in [Powering the 1-Wire Temperature Sensor](#). If the sensor is powered by an external supply, the master can issue read time slots after the Convert T command, and the sensor responds by transmitting 0 while the temperature conversion is in progress and 1 when the conversion is done. In parasite-power mode, this notification technique cannot be used because the bus is pulled high by the strong pullup during the conversion.

When in automatic conversion mode, Convert T is ignored if a conversion is in progress. After performing a convert T the MAX31825 returns to standby or automatic conversions, whichever was in effect before the command was given.

**Write Scratchpad (4Eh)**

Writes bytes 3 through 7 (Configuration and thresholds) to the scratchpad.

**Read Scratchpad [BEh]**

This command allows the master to read the contents of the Scratchpad. The data transfer starts with the least significant bit of byte 0 and continues through the scratchpad until the 9th byte (byte 8, CRC) is read. The master can issue a reset to terminate reading at any time if only part of the scratchpad data is needed. The CRC is computed while data is read from bytes 0–7, and is shifted out as byte 8.

**Detect Address [88h]**

The MAX31825 measures the external resistor value and writes location bits to Status register.

**Select Address [70h]**

The Select Address command allows faster transaction sequences by bypassing the 64-bit ROM code, while still identifying a unique MAX31825 on the bus. The resistor connected to the ADD0 and ADD1 input determines the values of the six least-significant address bits in the Status register. The Select Address command selects the unit with location bits that match the bit transmitted by the host. The operation sequence is as follows:

1. Initialization sequence
2. The host transmits the Select Address command, followed by the desired address bits to devices on the bus. The address bits are transmitted as the six LSBs of a byte whose remaining bits are set to 0.
3. The host then transmits another Function Command (Read, Write, or Convert). Only the MAX31825 with the location bits equal to the values transmitted in step 2 responds to this command.

Note that this command may be used only when each MAX31825 on the bus has a unique address. If multiple sensors share an address, collisions will occur.

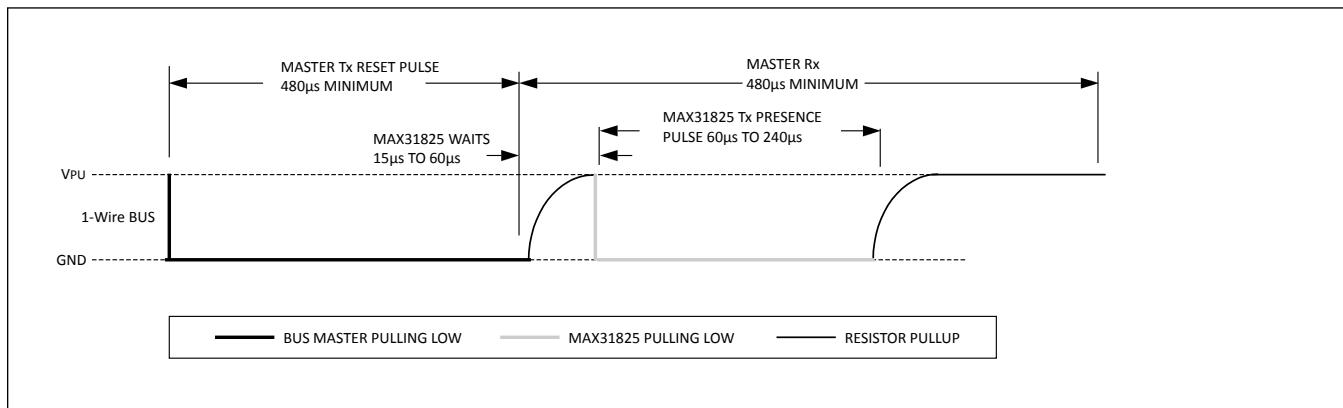
**1-Wire Signaling**

Using a strict 1-Wire communication protocol helps to ensure data integrity. Several signal types are defined by this protocol: reset pulse, presence pulse, write-zero, write-one, read-zero, and read-one. The bus master initiates all these signals except the presence pulse.

### Initialization Procedure: Reset and Presence Pulses

All communication with the device begins with an initialization sequence that consists of a reset pulse from the master followed by a presence pulse from the device (illustrated in [Figure 9](#)). When the device sends the presence pulse in response to the reset, it is indicating to the master that it is on the bus and ready to operate.

During the initialization sequence, the bus master transmits (Tx) the reset pulse by pulling the 1-Wire bus low for 480 $\mu\text{s}$  (min). The bus master then releases the bus and goes into receive mode (Rx). When the bus is released, the pullup resistor pulls the 1-Wire bus high. When the device detects this rising edge, it waits 15 $\mu\text{s}$  to 60 $\mu\text{s}$  and then transmits a presence pulse by pulling the 1-Wire bus low for 60 $\mu\text{s}$  to 240 $\mu\text{s}$ .



*Figure 9. Initialization Timing*

### Read/Write Time Slots

The bus master writes data to the device during write time slots and reads data from the device during read time slots. One bit of data is transmitted over the 1-Wire bus per time slot.

## Write Time Slots

There are two types of write time slots: write-one time slots and write-zero time slots. The bus master uses a write-one time slot to write a logic 1 to the device and a write-zero time slot to write a logic 0 to the device. All write time slots must have a  $60\mu\text{s}$  (min) duration with a  $1\mu\text{s}$  (min) recovery time between individual write slots. Both types of write time slots are initiated by the master pulling the 1-Wire bus low [Figure 10](#).

To generate a write-one time slot, after pulling the 1-Wire bus low, the bus master must release the 1-Wire bus within  $15\mu\text{s}$ . When the bus is released, the pullup resistor pulls the bus high. To generate a write-zero time slot, after pulling the 1-Wire bus low, the bus master must continue to hold the bus low for the duration of the time slot (at least  $60\mu\text{s}$ ).

The device samples the 1-Wire bus during a window that lasts from  $15\mu\text{s}$  to  $60\mu\text{s}$  after the master initiates the write time slot. If the bus is high during the sampling window, a 1 is written to the device. If the line is low, a 0 is written to the device.

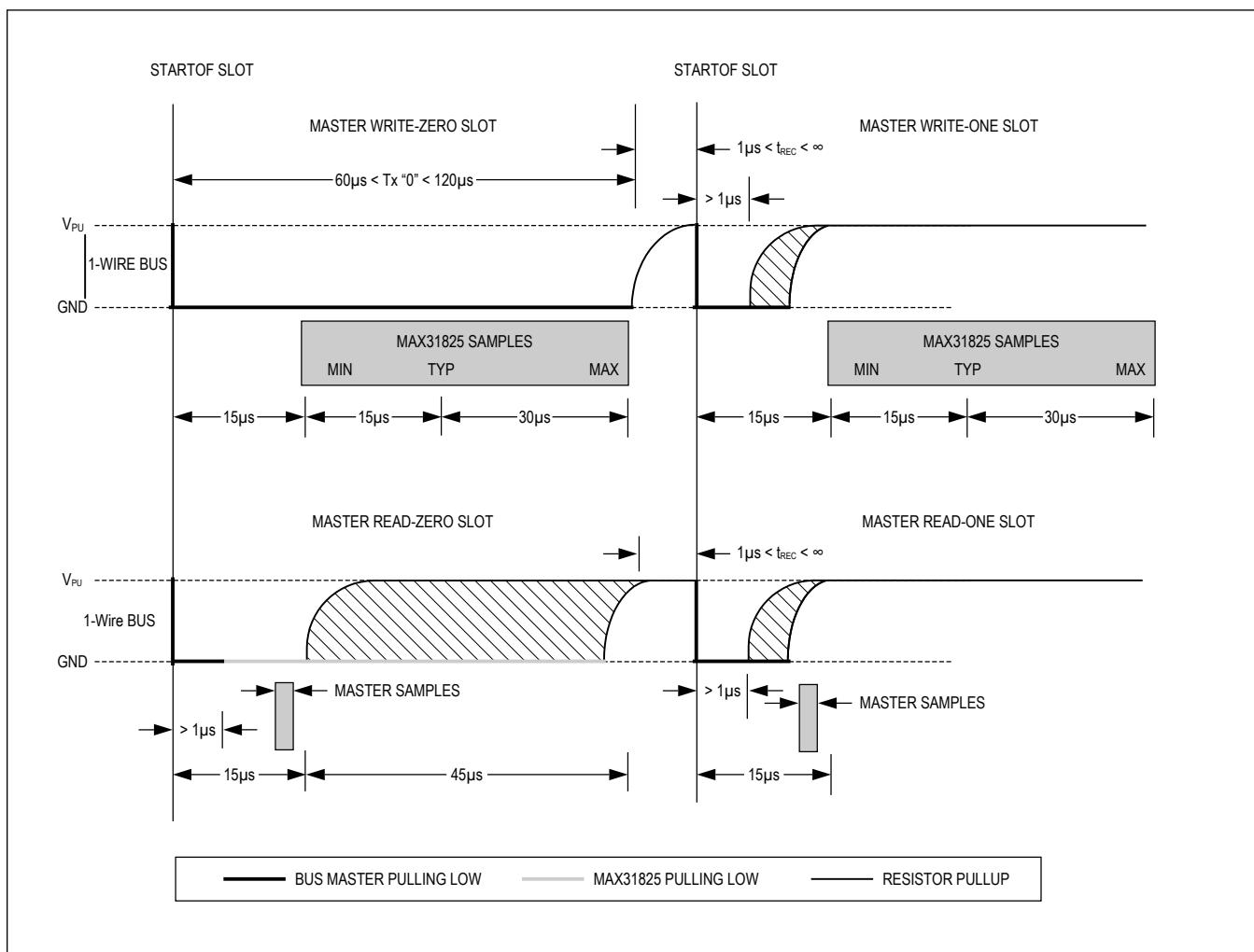


Figure 10. Read/Write Time Slot Timing Diagram

## Read Time Slots

The device can only transmit data to the master when the master issues read time slots. Therefore, the master must generate read time slots immediately after issuing a Read Scratchpad command, so that the device can provide the requested data. In addition, the master can generate read time slots after issuing a Convert T command to verify the operation status, as explained in [Function Commands](#).

All read time slots must be  $60\mu\text{s}$  (min) in duration with a  $1\mu\text{s}$  (min) recovery time between slots. A read time slot is initiated by the master device pulling the 1-Wire bus low for a minimum of  $1\mu\text{s}$  ( $t_{\text{INIT}}$ ) and then releasing the bus ([Figure 10](#)). After the master initiates the read time slot, the device begins transmitting a 1 or 0 on bus. The device transmits a 1 by leaving the bus high and transmits a 0 by pulling the bus low. When transmitting a 0, the device releases the bus by the end of the time slot, and the pullup resistor pulls the bus back to its high idle state. Output data from the device is valid for  $15\mu\text{s}$  after the falling edge that initiated the read time slot. Therefore, the master must release the bus and then sample the bus state within  $15\mu\text{s}$  from the start of the slot. [Figure 11](#) illustrates that the sum of  $t_{\text{INIT}}$ ,  $t_{\text{RC}}$ , and the master sample window must be less than  $15\mu\text{s}$  for a read time slot.  $t_{\text{RC}}$  is the rise time due to the resistive and capacitive characteristics of the bus. [Figure 12](#) shows that system timing margin is maximized by keeping  $t_{\text{INIT}}$  and  $t_{\text{RC}}$  as short as possible and by locating the master sample time during read time slots near the end of the  $15\mu\text{s}$  period.

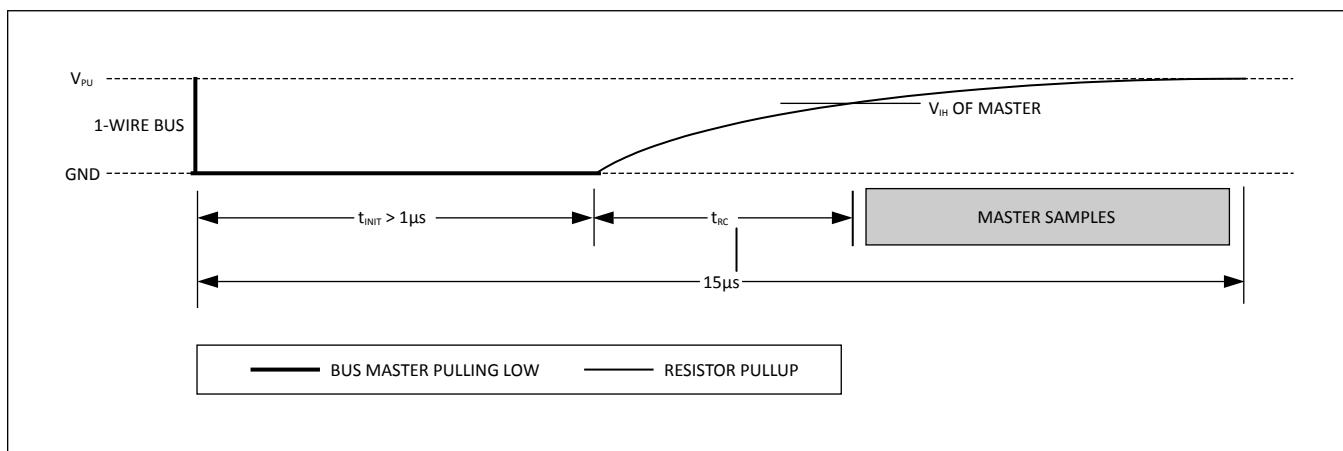


Figure 11. Detailed Master Read-One Timing

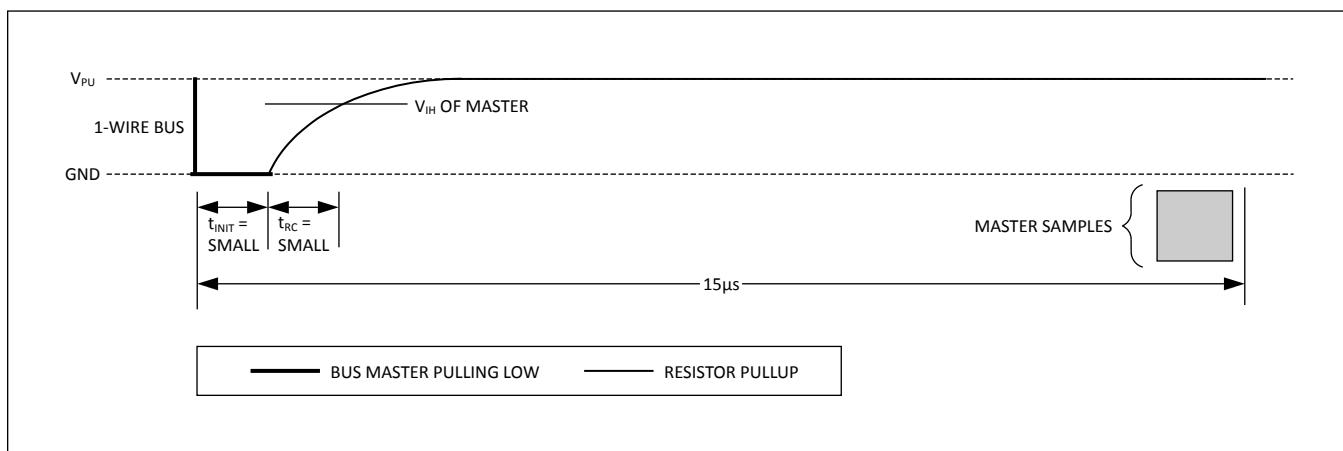


Figure 12. Recommended Master Read-One Timing

### Ordering Information

| PART NUMBER  | TEMPERATURE RANGE | PIN-PACKAGE |
|--------------|-------------------|-------------|
| MAX31825ANT+ | -40°C to +125°C   | 6-WLP       |

+ Denotes a lead(Pb)-free/RoHS-compliant package.

T = Tape and reel.

## Revision History

| REVISION NUMBER | REVISION DATE | DESCRIPTION  | PAGES CHANGED   |
|-----------------|---------------|--|-----------------|
| 0               | 2/20          | Initial Release  | —               |
| 1               | 10/20         | Updated <i>Benefits and Features</i> , <i>Electrical Characteristics</i> , and <i>Detailed Description</i> | 1, 4, 5, 16, 17 |

For pricing, delivery, and ordering information, please visit Maxim Integrated's online storefront at <https://www.maximintegrated.com/en/storefront/storefront.html>.

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