



Hex Nonvolatile Potentiometer with I/O and Memory

DS3930

General Description

The DS3930 contains six 256-position nonvolatile (NV) potentiometers, 64 bytes of NV user EEPROM memory, and four programmable NV I/O pins. The six potentiometers all share a common low side. The potentiometers are separated into two groups of three 50kΩ potentiometers in parallel. Each group of three potentiometers shares a common high side and forms an equivalent resistance of 16.6kΩ (three 50kΩ potentiometers in parallel).

Applications

- RF Transceivers
- Voltage References
- Power Supply Calibration
- Mobile Phones and PDAs
- Fiber Optic Transceiver Modules
- Portable Electronics
- Radio Tuners
- Small, Low-Cost Replacement for Mechanical Potentiometers

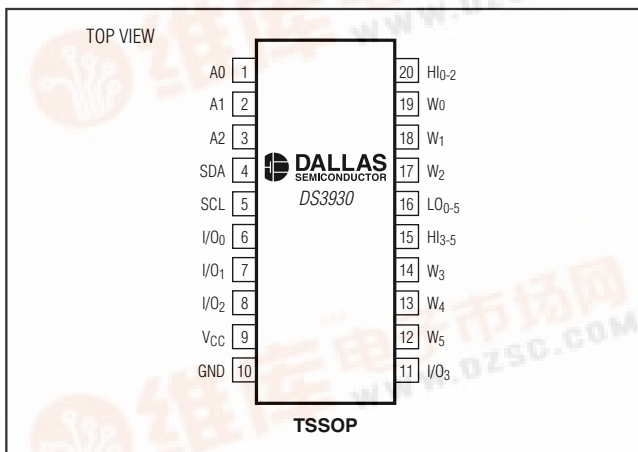
Features

- ◆ Six 256-Position NV Potentiometers
- ◆ Four General-Purpose NV I/O Pins
- ◆ 64 Bytes of User EEPROM Memory
- ◆ 0 to 5.5V on Any Potentiometer Terminal, Independent of V_{CC}
- ◆ All Six Potentiometers Share a Common Low Side
- ◆ Potentiometers Separated into Two Groups of Three Potentiometers, Each Sharing a Common High Side
- ◆ 2-Wire Serial Interface
- ◆ Wide Supply Range (2.7V to 5.5V)
- ◆ Up to Eight DS3930s Can Share the Same 2-Wire Bus

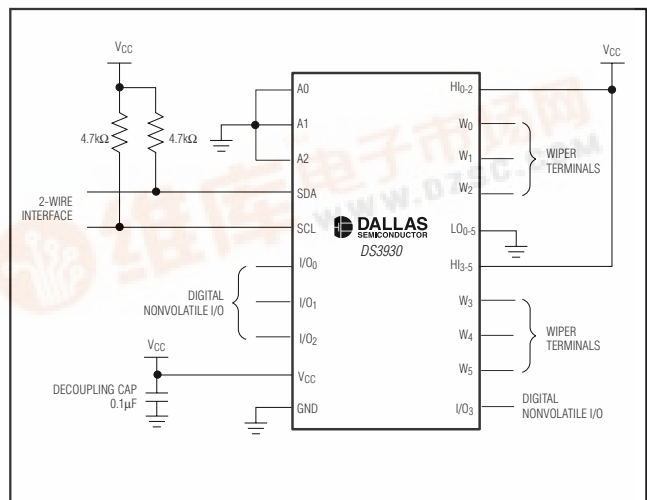
Ordering Information

| PART | PIN-PACKAGE |
|---------|-------------|
| DS3930E | 20 TSSOP |

Pin Configuration



Typical Operating Circuit



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ABSOLUTE MAXIMUM RATINGS

Voltage on V_{CC} Relative to Ground -0.5V to +6.0V
 Voltage on I/O₀, I/O₁, I/O₂, I/O₃, SDA, SCL, A0, A1, and A2
 Relative to Ground* -0.5V to (V_{CC} + 0.5V)
 Voltage on LO₀₋₅, W₀₋₅, HI₀₋₂, and HI₃₋₅
 Relative to Ground -0.5V to +6.0V
 Current Through W₀₋₅ ±1mA

Operating Temperature Range -40°C to +85°C
 Programming Temperature Range 0°C to +70°C
 Storage Temperature Range -55°C to +125°C
 Soldering Temperature See IPC/JEDEC J-STD-020A

*This voltage must not exceed 6.0V.

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.

RECOMMENDED DC OPERATING CONDITIONS

(T_A = -40° to +85°C)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|-----------------|----------------------------------|--------------------------|-----|--------------------------|-------|
| Supply Voltage | V _{CC} | (Note 1) | +2.7 | | +5.5 | V |
| Input Logic 1 (SDA, SCL, A0, A1, A2, I/O ₀ , I/O ₁ , I/O ₂ , I/O ₃) | V _{IH} | | 0.7 x V _{CC} | | V _{CC} + 0.3 | V |
| Input Logic 0 (SDA, SCL, A0, A1, A2, I/O ₀ , I/O ₁ , I/O ₂ , I/O ₃) | V _{IL} | | -0.3 | | 0.3 x V _{CC} | V |
| Wiper Current | I _W | | -1 | | +1 | mA |
| Potentiometer Terminals (LO ₀₋₅ , W ₀₋₅ , HI ₀₋₂ , and HI ₃₋₅) | | V _{CC} = +2.7V to +5.5V | -0.3 | | +5.5 | V |

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = +2.7V to +5.5V; T_A = -40°C to +85°C, unless otherwise specified.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|-------------------|------------------|-----|-----|-----|-------|
| Input Leakage | I _{IL} | | -1 | | +1 | μA |
| Low-Level Output Voltage (SDA, I/O ₀ , I/O ₁ , I/O ₂ , I/O ₃) | V _{OL1} | 3mA sink current | 0 | | 0.4 | V |
| | V _{OL2} | 6mA sink current | 0 | | 0.6 | V |
| I/O Capacitance | C _{I/O} | | | | 10 | pF |
| I/O Pullup Resistor Value | R _{I/O} | | 3.5 | 5 | 7.0 | kΩ |
| Standby Current | I _{STBY} | 3V (Note 2) | | 160 | 300 | μA |
| | | 5V (Note 2) | | 195 | 350 | |

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ANALOG RESISTOR CHARACTERISTICS

(V_{CC} = +2.7V to +5.5V; T_A = -40°C to +85°C, unless otherwise specified.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|-------------------------------------|----------------|--|------|------|------|--------|
| End-to-End Resistance | | T _A = +25°C (three 50kΩ pots in parallel) | 13.2 | 16.5 | 19.8 | kΩ |
| Wiper Resistance | R _W | | | 400 | 1000 | Ω |
| Factory Default Wiper Setting | | | | FF | | Hex |
| Factory Default I/O Setting | | | | 0F | | Hex |
| POT-to-POT Matching | | | -1 | | +1 | LSB |
| Differential Linearity | | | -0.5 | | +0.5 | LSB |
| Integral Linearity | | | -1 | | +1 | LSB |
| End-to-End Temperature Coefficient | | 3 potentiometers in parallel | -250 | 0 | +250 | ppm/°C |
| Ratiometric Temperature Coefficient | | | | 2 | | ppm/°C |

AC ELECTRICAL CHARACTERISTICS

(V_{CC} = +2.7V to +5.5V; T_A = -40°C to +85°C, unless otherwise specified.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---------------------|---------------|-----|-----|-----|-------|
| SCL Clock Frequency (Note 3) | f _{SCL} | Fast mode | 0 | | 400 | kHz |
| | | Standard mode | 0 | | 100 | |
| Bus Free Time Between STOP and START Condition (Note 3) | t _{BUF} | Fast mode | 1.3 | | | μs |
| | | Standard mode | 4.7 | | | |
| Hold Time (Repeated) START Condition (Notes 3 and 4) | t _{HD:STA} | Fast mode | 0.6 | | | μs |
| | | Standard mode | 4.0 | | | |
| Low Period of SCL Clock (Note 3) | t _{LOW} | Fast mode | 1.3 | | | μs |
| | | Standard mode | 4.7 | | | |
| High Period of SCL Clock (Note 3) | t _{HIGH} | Fast mode | 0.6 | | | μs |
| | | Standard mode | 4.0 | | | |

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AC ELECTRICAL CHARACTERISTICS (continued)

($V_{CC} = +2.7V$ to $+5.5V$; $T_A = -40^{\circ}C$ to $+85^{\circ}C$, unless otherwise specified.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|--------------|---------------|---------------|-----|------|---------|
| Data Hold Time (Notes 3, 5, 7) | $t_{HD:DAT}$ | Fast mode | 0 | | 0.9 | μs |
| | | Standard mode | 0 | | 0.9 | |
| Data Setup Time (Note 3) | $t_{SU:DAT}$ | Fast mode | 100 | | | ns |
| | | Standard mode | 250 | | | |
| Start Setup Time (Note 3) | $t_{SU:STA}$ | Fast mode | 0.6 | | | μs |
| | | Standard mode | 4.7 | | | |
| Rise Time of Both SDA and SCL Signals (Note 7) | t_R | Fast mode | $20 + 0.1C_B$ | | 300 | ns |
| | | Standard mode | $20 + 0.1C_B$ | | 1000 | |
| Fall Time of Both SDA and SCL Signals (Note 7) | t_F | Fast mode | $20 + 0.1C_B$ | | 300 | ns |
| | | Standard mode | $20 + 0.1C_B$ | | 300 | |
| Setup Time for STOP Condition | $t_{SU:STO}$ | Fast mode | 0.6 | | | μs |
| | | Standard mode | 4.0 | | | |
| Capacitive Load for Each Bus | C_B | (Note 7) | | | 400 | pF |
| EEPROM Write Time | t_W | (Note 8) | | 5 | 20 | ms |

EEPROM CHARACTERISTICS

($V_{CC} = +2.7V$ to $+5.5V$; $T_A = -40^{\circ}C$ to $+85^{\circ}C$, unless otherwise specified.)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|-----------|--------|----------------|--------|-----|-----|-------|
| Writes | | $+70^{\circ}C$ | 50,000 | | | |

Note 1: All voltages are referenced to ground.

Note 2: I_{STBY} specified for V_{CC} equal 3.0V and 5.0V, SDA = SCL = V_{CC} , and $I/O_0 = I/O_1 = I/O_2 = I/O_3 = A_0 = A_1 = A_2 = GND$.

Note 3: A fast-mode device can be used in a standard-mode system, but the requirement $t_{SU:DAT} > 250ns$ must then be met. This is automatically the case if the device does not stretch the LOW period of the SCL signal. If such a device does stretch the LOW period of the SCL signal, it must output the next data bit to the SDA line $t_{RMAX} + t_{SU:DAT} = 1000ns + 250ns = 1250ns$ before the SCL line is released.

Note 4: After this period, the first clock pulse is generated.

Note 5: The maximum $t_{HD:DAT}$ has only to be met if the device does not stretch the LOW period (t_{LOW}) of the SCL signal.

Note 6: A device must internally provide a hold time of at least 300ns for the SDA signal (referred to the $V_{IH\ MIN}$ of the SCL signal) in order to bridge the undefined region of the falling edge of SCL.

Note 7: C_B —total capacitance of one bus line in picofarads, timing referenced to $0.9V_{CC}$ and $0.1V_{CC}$.

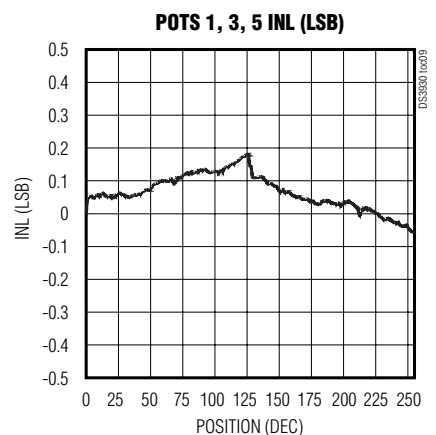
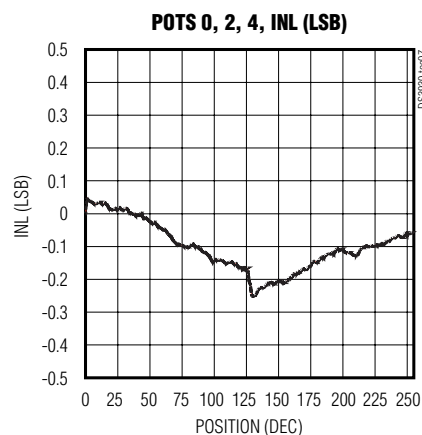
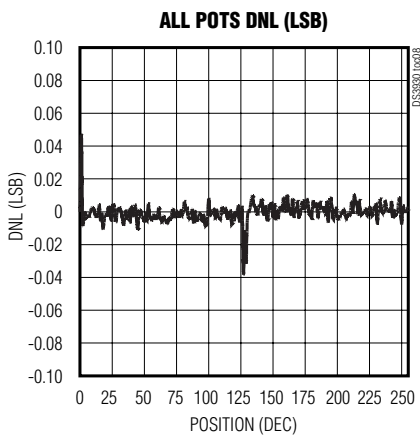
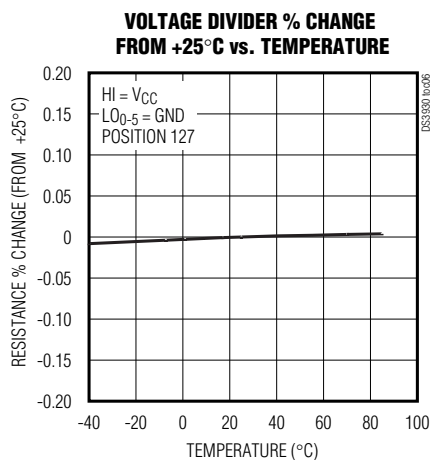
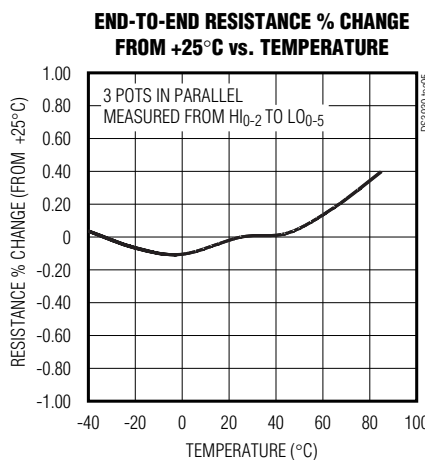
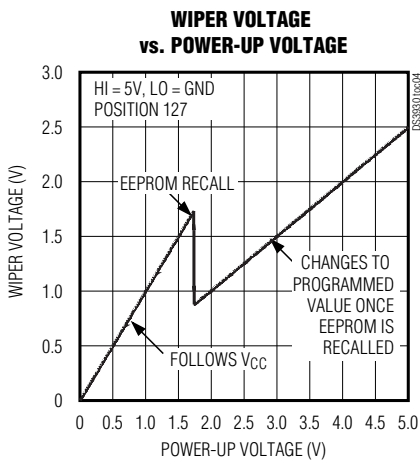
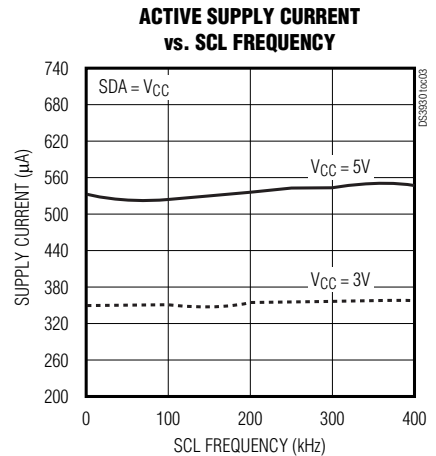
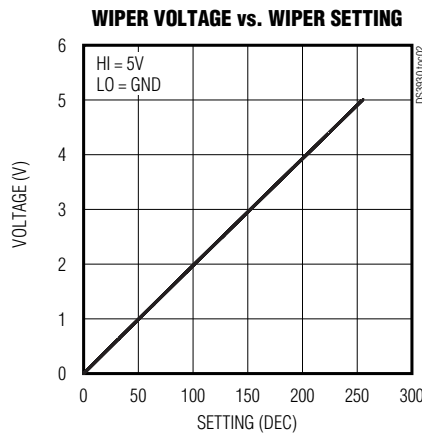
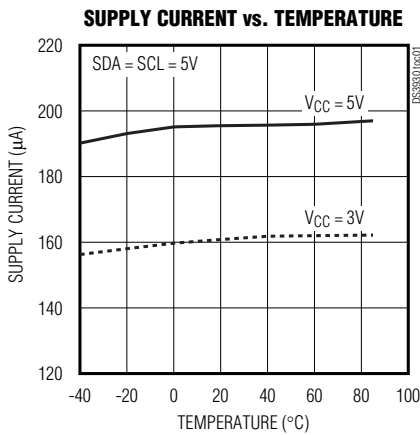
Note 8: EEPROM write begins after a STOP condition occurs.

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Typical Operating Characteristics

($V_{CC} = 5.0V$; $T_A = +25^\circ C$, unless otherwise specified.)

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Pin Description

| PIN | NAME | FUNCTION |
|-----|-------------------|--|
| 1 | A0 | Address Input. The address input pins determine the 2-wire address of the device. |
| 2 | A1 | Address Input |
| 3 | A2 | Address Input |
| 4 | SDA | 2-Wire Serial Data I/O. This pin is for serial data transfer to and from the device. |
| 5 | SCL | 2-Wire Serial Clock Input. The serial clock input is used to clock data into and out of the device. |
| 6 | I/O ₀ | General-Purpose NV I/O Pin |
| 7 | I/O ₁ | General-Purpose NV I/O Pin |
| 8 | I/O ₂ | General-Purpose NV I/O Pin |
| 9 | V _{CC} | Supply Voltage |
| 10 | GND | Ground |
| 11 | I/O ₃ | General-Purpose NV I/O Pin |
| 12 | W ₅ | Wiper Terminal of Potentiometer 5 |
| 13 | W ₄ | Wiper Terminal of Potentiometer 4 |
| 14 | W ₃ | Wiper Terminal of Potentiometer 3 |
| 15 | HI ₃₋₅ | High-End Terminal of Potentiometers 3 to 5. This is the common high-side terminal of potentiometers 3, 4, and 5. |
| 16 | LO ₀₋₅ | Low-End Terminal of the Potentiometers. This is the common low-side terminal of all six potentiometers. |
| 17 | W ₂ | Wiper Terminal of Potentiometer 2 |
| 18 | W ₁ | Wiper Terminal of Potentiometer 1 |
| 19 | W ₀ | Wiper Terminal of Potentiometer 0 |
| 20 | HI ₀₋₂ | High-End Terminal of Potentiometers 0 to 2. This is the common high-side terminal of potentiometers 0, 1, and 2. |

Hex Nonvolatile Potentiometer with I/O and Memory

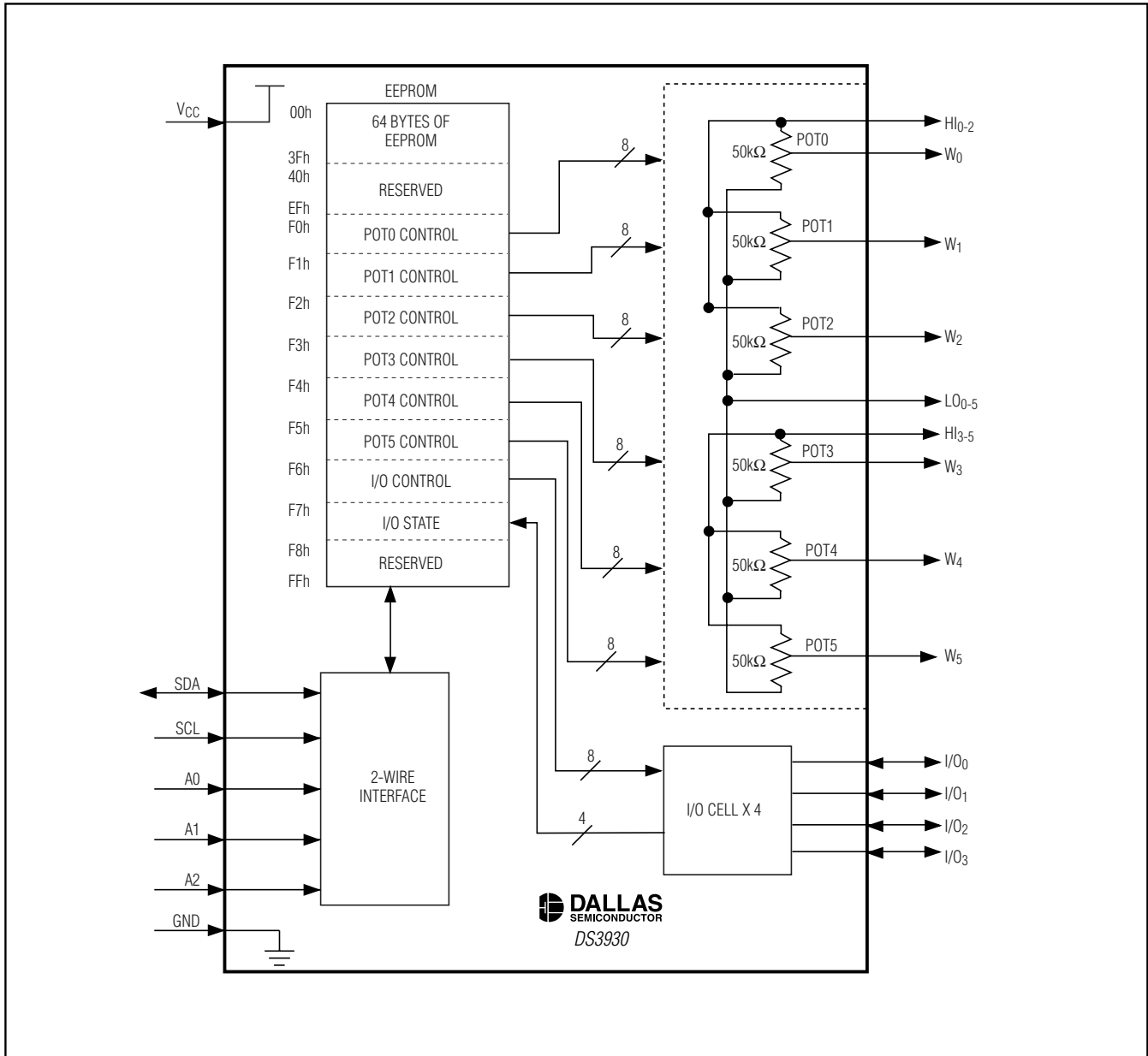


Figure 1. DS3930 Functional Diagram

Detailed Description

The DS3930 contains six NV potentiometers with 64 bytes of NV user memory (EEPROM), and four programmable NV I/O pins. Figure 1 is a functional diagram of the DS3930.

Potentiometers

The six potentiometers share a common low side and are separated into two groups of three potentiometers, each group sharing a common high side. The six 256-position potentiometers are controllable using six 8-bit EEPROM registers through the 2-wire interface.

Hex Nonvolatile Potentiometer with I/O and Memory

I/O Signals

The I/O pins can be used as general-purpose digital I/O signals. The I/O pins have CMOS outputs with an

internal pullup resistor (see Figure 2). The I/O pins are configured with the I/O Control register (F6h) and monitored with the I/O State register (F7h). The I/O Control register controls the state of the internal pullup resistor ($R_{I/O}$) with bits 7 to 4 and the I/O pin setting with bits 3 to 0 (see Table 1). The read-only values of the I/O State register contains the values of the I/O pin setting bits of the I/O Control register unless the I/O output is tri-stated. When the I/O is tri-stated the I/O State register will read high or low depending on the external source on the I/O pin. Since the I/O pins are controlled by EEPROM, the number of writes is limited.

Memory

The memory map is shown in Table 2.

Table 1. I/O Pin Truth Table

| PULLUP CTRL (I/O CONTROL REGISTER) (BITS 7 TO 4) | I/O PIN SETTING (I/O CONTROL REGISTER) (BITS 3 TO 0) | I/O PIN OUTPUT |
|--|--|------------------------|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 0 |
| 1 | 1 | Pullup disabled (HI-Z) |

Table 2. Memory Map

| ADDRESS | BIT | DEFAULT (HEX) | FUNCTION |
|------------|-------|---------------|--|
| 00h to 3Fh | | FF | 64 bytes of general-purpose EEPROM |
| 40h to EFh | | FF | Reserved |
| F0h | | FF | Controls potentiometer 0 |
| F1h | | FF | Controls potentiometer 1 |
| F2h | | FF | Controls potentiometer 2 |
| F3h | | FF | Controls potentiometer 3 |
| F4h | | FF | Controls potentiometer 4 |
| F5h | | FF | Controls potentiometer 5 |
| F6h | | 0F | I/O Control |
| | Bit 7 | | Set to 0 to enable I/O ₃ pullup, set to 1 to disable pullup |
| | Bit 6 | | Set to 0 to enable I/O ₂ pullup, set to 1 to disable pullup |
| | Bit 5 | | Set to 0 to enable I/O ₁ pullup, set to 1 to disable pullup |
| | Bit 4 | | Set to 0 to enable I/O ₀ pullup, set to 1 to disable pullup |
| | Bit 3 | | Sets I/O ₃ to 0 or 1 |
| | Bit 2 | | Sets I/O ₂ to 0 or 1 |
| | Bit 1 | | Sets I/O ₁ to 0 or 1 |
| | Bit 0 | | Sets I/O ₀ to 0 or 1 |
| F7h | | 0X | I/O State |
| | Bit 7 | | 0 |
| | Bit 6 | | 0 |
| | Bit 5 | | 0 |
| | Bit 4 | | 0 |
| | Bit 3 | | Contains state of I/O ₃ pin (read only) |
| | Bit 2 | | Contains state of I/O ₂ pin (read only) |
| | Bit 1 | | Contains state of I/O ₁ pin (read only) |
| | Bit 0 | | Contains state of I/O ₀ pin (read only) |
| F8h to FFh | | FF | Reserved |

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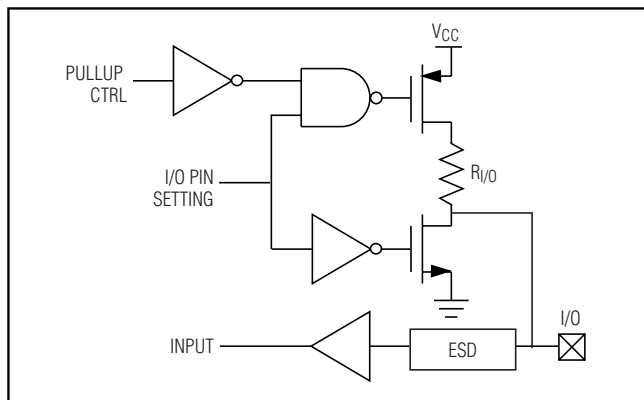


Figure 2. I/O Cell

2-Wire Serial Port Operation

The 2-wire serial port interface supports a bidirectional data transmission protocol with device addressing. A device that sends data on the bus is defined as a transmitter, and a device receiving data as a receiver. The device that controls the message is called a “master.” The devices that are controlled by the master are “slaves.” The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates the start and stop conditions. The DS3930 operates as a slave on the 2-wire bus. Connections to the bus are made through the open-drain I/O lines, SDA and SCL. The following I/O terminals control the 2-wire serial port: SDA, SCL, and A0. Timing diagrams for the 2-wire serial port can be

found in Figures 3 and 5. Timing information for the 2-wire serial port is provided in the *AC Electrical Characteristics* table for 2-wire serial communications.

The following bus protocol has been defined:

- Data transfer can be initiated only when the bus is not busy.
- During data transfer, the data line must remain stable whenever the clock line is high. Changes in the data line while the clock line is high are interpreted as control signals.

Accordingly, the following bus conditions have been defined:

Bus Not Busy: Both data and clock lines remain high.

Start Data Transfer: A change in the state of the data line from high to low while the clock is high defines a start condition.

Stop Data Transfer: A change in the state of the data line from low to high while the clock line is high defines the stop condition.

Data Valid: The state of the data line represents valid data when, after a start condition, the data line is stable for the duration of the high period of the clock signal. The data on the line can be changed during the low period of the clock signal. There is one clock pulse per bit of data. Figures 3 and 5 detail how data transfer is accomplished on the 2-wire bus. Depending upon the state of the R/W bit, two types of data transfer are possible.

Each data transfer is initiated with a start condition and

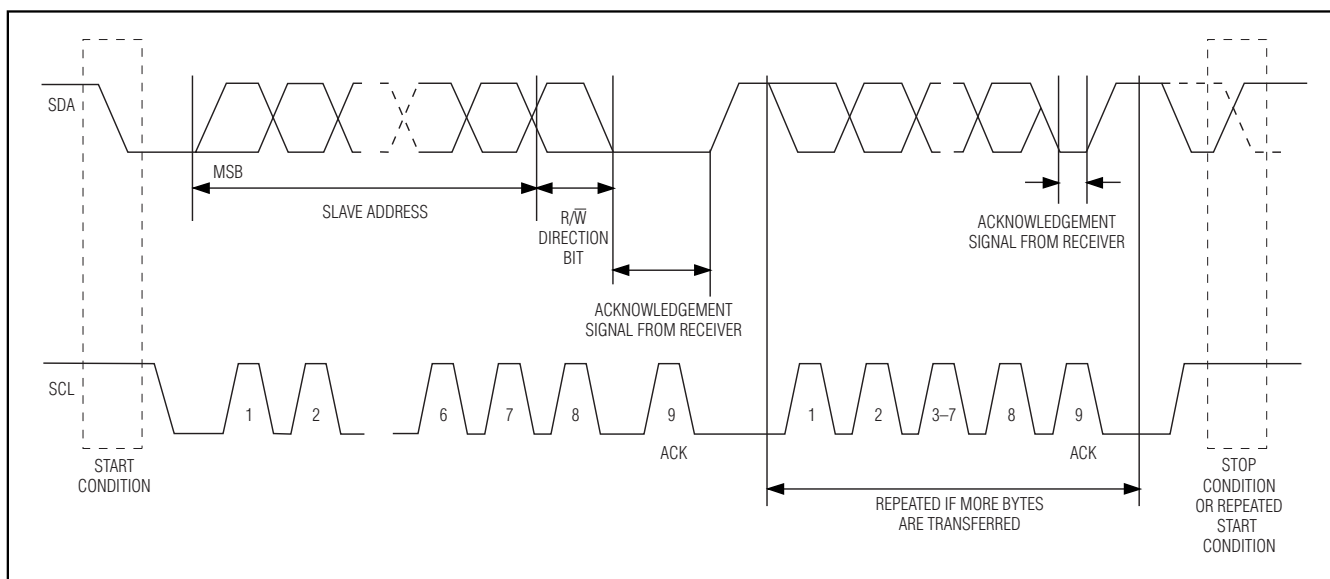


Figure 3. 2-Wire Data Transfer Protocol

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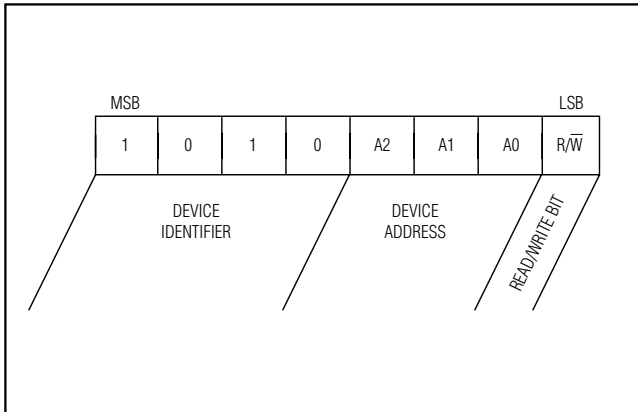


Figure 4. Slave Address

terminated with a stop condition. The number of data bytes transferred between start and stop conditions is not limited and is determined by the master device. The information is transferred byte-wise and each receiver acknowledges with a ninth bit.

Within the bus specifications, a regular mode (100kHz clock rate) and a fast mode (400kHz clock rate) are defined. The DS3930 works in both modes.

Acknowledge: Each receiving device, when addressed, is obliged to generate an acknowledge after the byte has been received. The master device must generate an extra clock pulse that is associated with this acknowledge bit.

A device that acknowledges must pull down the SDA line during the acknowledge clock pulse in such a way that the SDA line is a stable low during the high period of the acknowledge-related clock pulse. Of course, setup and hold times must be taken into account. A master must signal an end of data to the slave by not generating an acknowledge bit on the last byte that has been clocked out of the slave. In this case, the slave must leave the data line high to enable the master to generate the stop condition.

Data transfer from a master transmitter to a slave receiver. The first byte transmitted by the master is the command/control byte. Next follows a number of data bytes. The slave returns an acknowledge bit after each received byte.

Data transfer from a slave transmitter to a master receiver. The master transmits the first byte (the command/control byte) to the slave. The slave then returns an acknowledge bit. Next follows a number of data bytes transmitted by the slave to the master. The master returns an acknowledge bit after all received bytes other than the last byte. At the end of the last received

byte, a not acknowledge can be returned.

The master device generates all serial clock pulses and the start and stop conditions. A transfer is ended with a stop condition or with a repeated start condition. Since a repeated start condition is also the beginning of the next serial transfer, the bus is not released.

The DS3930 can operate in the following three modes:

- 1) Slave Receiver Mode:** Serial data and clock are received through SDA and SCL, respectively. After each byte is received, an acknowledge bit is transmitted. Start and stop conditions are recognized as the beginning and end of a serial transfer. Address recognition is performed by hardware after the slave (device) address and direction bit have been received.
- 2) Slave Transmitter Mode:** The first byte is received and handled as in the slave receiver mode. However, in this mode the direction bit indicates that the transfer direction is reversed. Serial data is transmitted on SDA by the DS3930 while the serial clock is input on SCL. Start and stop conditions are recognized as the beginning and end of a serial transfer.
- 3) Slave Address:** This is the first byte received following the start condition from the master device. The slave address consists of a 4-bit control code. For the DS3930, this is set as 1010 binary for read/write operations. The next bits of the slave address are the device address (A2–A0). The last bit of the slave address (R/W) defines the operation to be performed. When set to a '1,' a read operation is selected, and when set to a '0,' a write operation is selected (see Figure 4).

Following the start condition, the DS3930 monitors the SDA bus checking the device type identifier being transmitted. Upon receiving the 1010 device identifier, the appropriate device address bit, and the read/write bit, the slave device outputs an acknowledge signal on the SDA line.

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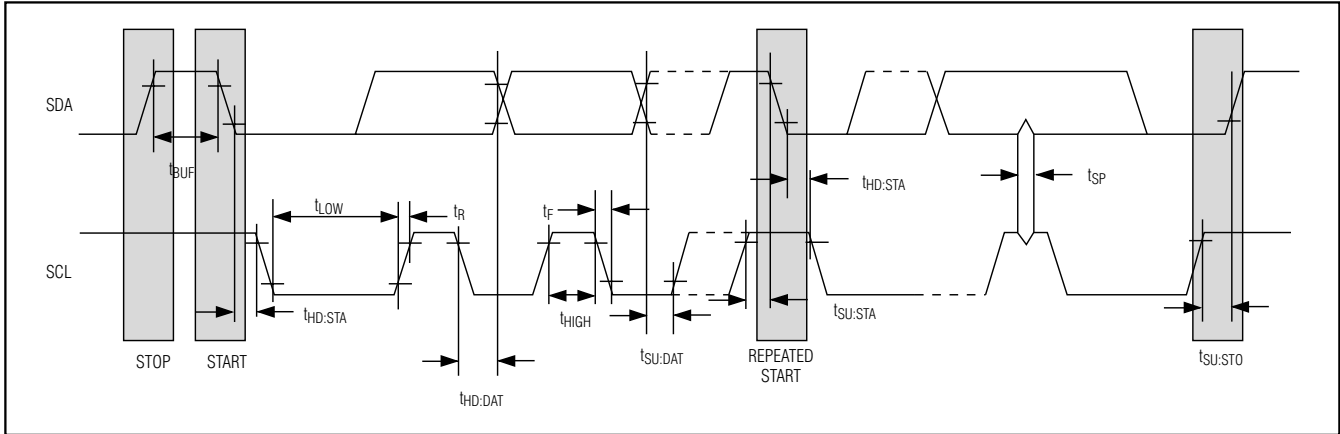


Figure 5. 2-Wire AC Characteristics

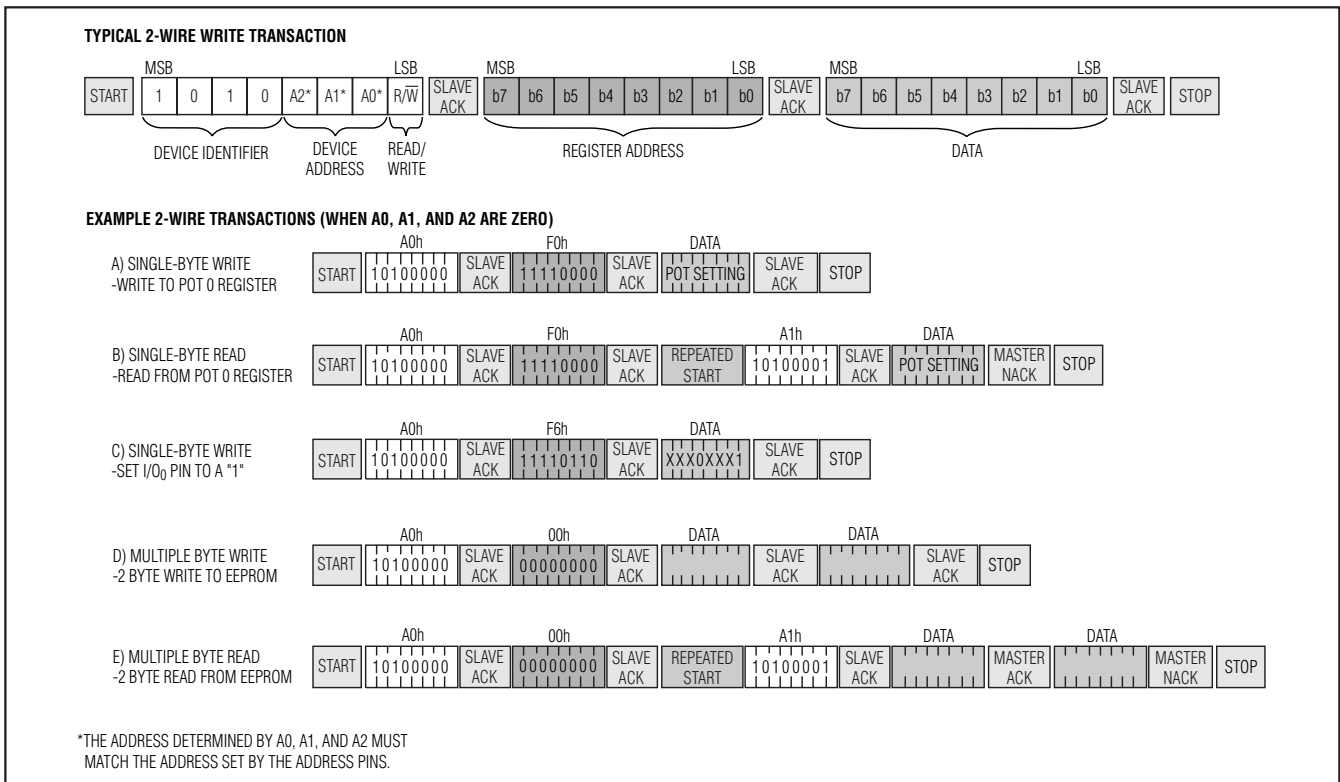


Figure 6. Example 2-Wire Transactions

Applications Information

Power Supply Decoupling

To achieve the best results when using the DS3930, decouple the power supply with a 0.1µF high-quality, ceramic, surface-mount capacitor. Surface-mount com-

ponents minimize lead inductance, which improves performance, and ceramic capacitors tend to have adequate high-frequency response for decoupling applications. The capacitor should be placed as close as possible to the V_{CC} and GND pins.

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Wiper Resistance

One difference between digital potentiometers and mechanical potentiometers is the wiper resistance. The wiper resistance (R_W) is a result of the interconnecting materials on the IC between the internal resistive elements and the wiper pin. This can be modeled by using an ideal potentiometer, with a resistance of R_W connected between the ideal wiper and wiper terminal of the digital potentiometer.

Chip Information

TRANSISTOR COUNT: 27,000
SUBSTRATE CONNECTED TO GROUND.

Package Information

For the latest package outline information, go to www.maxim-ic.com/DallasPackInfo.

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