



# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

MAX5403/MAX5404/MAX5405

## General Description

The MAX5403/MAX5404/MAX5405 is a family of dual linear taper digital potentiometers. Each device has one 3-terminal potentiometer and one 2-terminal variable resistor (Figure 1). The MAX5403/MAX5404/MAX5405 operate from +2.7V to +5.5V single-supply voltages and use an ultra-low supply current of 0.1 $\mu$ A. These devices also provide glitchless switching between resistors taps as well as a convenient power-on reset (POR) that sets the wiper to the midscale position at power-up. The potentiometer consists of a fixed resistor with a wiper contact that is digitally controlled through a 3-wire serial interface and has 256-tap points. It performs the same function as a discrete potentiometer or variable resistor.

These parts are ideal for applications requiring digitally controlled resistors. Three resistance values are available: 10k $\Omega$  (MAX5403), 50k $\Omega$  (MAX5404), and 100k $\Omega$  (MAX5405). A nominal resistor-temperature coefficient of 35ppm/ $^{\circ}$ C end-to-end and 5ppm/ $^{\circ}$ C ratiometric make the MAX5403/MAX5404/MAX5405 ideal for applications requiring low temperature-coefficient variable resistors, such as adjustable-gain circuit configurations.

The MAX5403/MAX5404/MAX5405 are available in a 10-pin  $\mu$ MAX<sup>®</sup> package. Each device is guaranteed over the extended industrial temperature range (-40 $^{\circ}$ C to +85 $^{\circ}$ C).

## Applications

- Mechanical Potentiometer Replacement
- Low-Drift Programmable Gain Amplifier (PGA)
- Volume Control
- LCD Screen Adjustment
- Adjustable Voltage Reference
- Programmable Filters, Delays, Time Constant
- Impedance Matching

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## Features

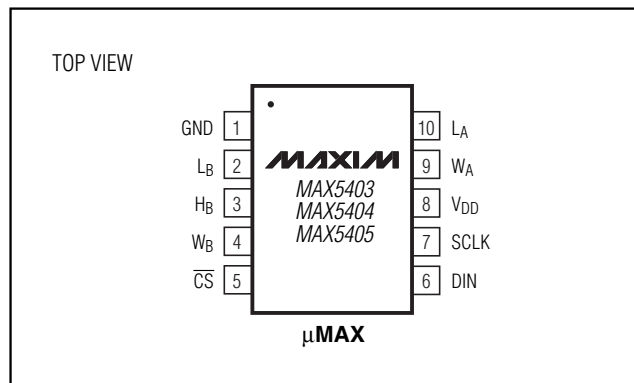
- ◆ 10-Pin  $\mu$ MAX Small Footprint Package
- ◆ 256-Tap Positions
- ◆ Ultra Low 0.1 $\mu$ A Supply Current
- ◆ +2.7V to +5.5V Single-Supply Operation
- ◆ Low End-To-End Temperature Coefficient: 35ppm/ $^{\circ}$ C
- ◆ Low Ratiometric Temperature Coefficient: 5ppm/ $^{\circ}$ C
- ◆ Power-On Reset: Wiper Goes to Midscale (Position 128)
- ◆ Glitchless Switching Between Resistor Taps
- ◆ 3-Wire SPI<sup>™</sup> -Interface Compatible
- ◆ 10k $\Omega$ /50k $\Omega$ /100k $\Omega$  Resistor Values

## Ordering Information

| PART       | PIN-PACKAGE  | R (k $\Omega$ ) | PKG CODE |
|------------|--------------|-----------------|----------|
| MAX5403EUB | 10 $\mu$ MAX | 10              | U10C-4   |
| MAX5404EUB | 10 $\mu$ MAX | 50              | U10C-4   |
| MAX5405EUB | 10 $\mu$ MAX | 100             | U10C-4   |

**Note:** All devices operate over the -40 $^{\circ}$ C to +85 $^{\circ}$ C temperature range.

## Pin Configuration



# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

## ABSOLUTE MAXIMUM RATINGS

V<sub>DD</sub> to GND .....-0.3V to +6V  
 DIN, SCLK,  $\overline{CS}$  .....-0.3V to +6V  
 H<sub>X</sub>, L<sub>X</sub>, W<sub>X</sub> to GND .....-0.3V to (V<sub>DD</sub> + 0.3)  
 Maximum Continuous Current Into H<sub>X</sub>, L<sub>X</sub>, and W<sub>X</sub> ..... $\pm$ 1mA  
 Continuous Power Dissipation (T<sub>A</sub> = +70°C)  
 10-Pin  $\mu$ MAX (derate 5.6mW/°C above +70°C) .....444mW

Operating Temperature Range .....-40°C to +85°C  
 Junction Temperature .....+150°C  
 Storage Temperature Range .....-65°C to +150°C  
 Lead Temperature (soldering, 10s) .....+300°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.*

## ELECTRICAL CHARACTERISTICS

(V<sub>DD</sub> = +5V, unless otherwise noted. V<sub>H</sub> = V<sub>DD</sub>, V<sub>L</sub> = 0, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>. Typical values are at V<sub>DD</sub> = +5V, T<sub>A</sub> = +25°C, unless otherwise noted.)

| PARAMETER  | SYMBOL          | CONDITIONS            |                 | MIN | TYP  | MAX       | UNITS    |
|--|-----------------|-----------------------|-----------------|-----|------|-----------|----------|
| <b>DC PERFORMANCE (Voltage Divider Mode)</b>     |                 |                       |                 |     |      |           |          |
| Resolution                                       | N               |                       |                 | 8   |      |           | Bits     |
| Integral Nonlinearity (Notes 1, 2)               | INL             |                       |                 |     |      | $\pm$ 1/2 | LSB      |
| Differential Nonlinearity (Notes 1, 2)           | DNL             |                       |                 |     |      | $\pm$ 1/2 | LSB      |
| End-to-End Resistor Tempco                       | TC <sub>R</sub> |                       |                 |     | 35   |           | ppm/°C   |
| Ratiometric Resistor Tempco                      |                 |                       |                 |     | 5    |           | ppm/°C   |
| Full-Scale Error                                 |                 | MAX5403               |                 |     | -8   |           | LSB      |
| Zero-Scale Error                                 |                 | MAX5403               |                 |     | +8   |           | LSB      |
| Full-Scale Error                                 |                 | MAX5404               |                 |     | -1.6 |           | LSB      |
| Zero-Scale Error                                 |                 | MAX5404               |                 |     | +1.6 |           | LSB      |
| Full-Scale Error                                 |                 | MAX5405               |                 |     | -0.8 |           | LSB      |
| Zero-Scale Error                                 |                 | MAX5405               |                 |     | +0.8 |           | LSB      |
| <b>DC PERFORMANCE (Variable Resistor Mode)</b>   |                 |                       |                 |     |      |           |          |
| Resolution                                       | N               |                       |                 | 8   |      |           | Bits     |
| Integral Nonlinearity (Notes 1, 3)               | INL             | V <sub>DD</sub> = +5V | MAX5403 (Pot A) |     |      | $\pm$ 2.5 | LSB      |
|  |                 |                       | MAX5403 (Pot B) |     |      | $\pm$ 1   |          |
|  |                 |                       | MAX5404         |     |      | $\pm$ 1   |          |
|  |                 |                       | MAX5405         |     |      | $\pm$ 1   |          |
|  |                 | V <sub>DD</sub> = +3V | MAX5403 (Pot A) |     |      | $\pm$ 4.5 |          |
|  |                 |                       | MAX5403 (Pot B) |     |      | $\pm$ 3   |          |
|  |                 |                       | MAX5404         |     |      | $\pm$ 1.5 |          |
|  |                 |                       | MAX5405         |     |      | $\pm$ 1.5 |          |
| Differential Nonlinearity (Notes 1, 3)           | DNL             | V <sub>DD</sub> = +5V |                 |     |      | $\pm$ 1/2 | LSB      |
|  |                 | V <sub>DD</sub> = +3V |                 |     |      |           |          |
| <b>DC PERFORMANCE (Resistor Characteristics)</b> |                 |                       |                 |     |      |           |          |
| Wiper Resistance (Note 4)                        | R <sub>W</sub>  | V <sub>DD</sub> = +5V |                 |     | 275  |           | $\Omega$ |
|  |                 | V <sub>DD</sub> = +3V |                 |     |      | 550       |          |
| Wiper Capacitance                                | C <sub>W</sub>  | MAX5403               |                 |     | 50   |           | pF       |
|  |                 | MAX5404/MAX5405       |                 |     | 30   |           |          |

# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

MAX5403/MAX5404/MAX5405

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{DD} = +5V$ , unless otherwise noted.  $V_H = V_{DD}$ ,  $V_L = 0$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ . Typical values are at  $V_{DD} = +5V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)

| PARAMETER  | SYMBOL    | CONDITIONS                            | MIN                 | TYP | MAX  | UNITS      |         |
|--|-----------|---------------------------------------|---------------------|-----|------|------------|---------|
| End-to-End Resistance                            | $R_{HL}$  | MAX5403                               | 7.5                 | 10  | 12.5 | k $\Omega$ |         |
|  |           | MAX5404                               | 37.5                | 50  | 62.5 |            |         |
|  |           | MAX5405                               | 75                  | 100 | 125  |            |         |
| <b>DIGITAL INPUTS</b>                            |           |                                       |                     |     |      |            |         |
| Input High Voltage                               | $V_{IH}$  |                                       | $0.7 \times V_{DD}$ |     |      | V          |         |
| Input Low Voltage                                | $V_{IL}$  |                                       | $0.3 \times V_{DD}$ |     |      | V          |         |
| Input Leakage Current                            |           |                                       | $\pm 1.0$           |     |      | $\mu A$    |         |
| Input Capacitance                                |           |                                       | 5                   |     |      | pF         |         |
| <b>TIMING CHARACTERISTICS (ANALOG)</b>           |           |                                       |                     |     |      |            |         |
| Wiper-Settling Time                              | $t_s$     | MAX5403                               | 100                 |     |      | ns         |         |
|  |           | MAX5404                               | 325                 |     |      |            |         |
|  |           | MAX5405                               | 650                 |     |      |            |         |
| <b>TIMING CHARACTERISTICS (DIGITAL)</b> (Note 5) |           |                                       |                     |     |      |            |         |
| Maximum SCLK Frequency                           |           |                                       | 10                  |     |      | MHz        |         |
| SCLK Clock Period                                | $t_{CP}$  |                                       | 100                 |     |      | ns         |         |
| SCLK Pulse Width High                            | $t_{CH}$  |                                       | 40                  |     |      | ns         |         |
| SCLK Pulse Width Low                             | $t_{CL}$  |                                       | 40                  |     |      | ns         |         |
| $\overline{CS}$ Fall to SCLK Rise Setup Time     | $t_{CSS}$ |                                       | 40                  |     |      | ns         |         |
| SCLK Rise to $\overline{CS}$ Rise Hold Time      | $t_{CSH}$ |                                       | 0                   |     |      | ns         |         |
| DIN Setup Time                                   | $t_{DS}$  |                                       | 40                  |     |      | ns         |         |
| DIN Hold Time                                    | $t_{DH}$  |                                       | 0                   |     |      | ns         |         |
| SCLK Rise to $\overline{CS}$ Fall Delay          | $t_{CS0}$ |                                       | 10                  |     |      | ns         |         |
| $\overline{CS}$ Rise to SCLK Rise Hold           | $t_{CS1}$ |                                       | 40                  |     |      | ns         |         |
| $\overline{CS}$ Pulse Width High                 | $t_{CSW}$ |                                       | 100                 |     |      | ns         |         |
| <b>POWER SUPPLIES</b>                            |           |                                       |                     |     |      |            |         |
| Supply Voltage                                   | $V_{DD}$  |                                       | 2.7                 |     | 5.5  | V          |         |
| Supply Current                                   | $I_{DD}$  | $\overline{CS} = SCLK = DIN = V_{DD}$ | $V_{DD} = +5V$      | 0.8 |      | 5          | $\mu A$ |
|  |           |                                       | $V_{DD} = +2.7V$    | 0.1 |      |            | $\mu A$ |

**Note 1:** Linearity is defined in terms of the  $H_X$  to  $L_X$  code-dependent resistance.

**Note 2:** The DNL and INL are measured with the potentiometer configured as a voltage divider with  $H_X = V_{DD}$  and  $L_X = 0$ . The wiper terminal is unloaded and measured with an ideal voltmeter.

**Note 3:** The DNL and INL are measured with the potentiometer configured as a variable resistor. For the 3-terminal potentiometer (Pot A),  $H_A$  is unconnected and  $L_A = 0$ . For the 2-terminal potentiometer (Pot B), only  $L_B = 0$ . At  $V_{DD} = +5V$ , the wiper terminal is driven with a source current of 400 $\mu A$  for the 10k $\Omega$  configuration, 80 $\mu A$  for the 50k $\Omega$  configuration, and 40 $\mu A$  for the 100k $\Omega$  configuration. At  $V_{DD} = +3V$ , 200 $\mu A$ /40 $\mu A$ /20 $\mu A$  for 10k $\Omega$ /50k $\Omega$ /100k $\Omega$  configuration respectively.

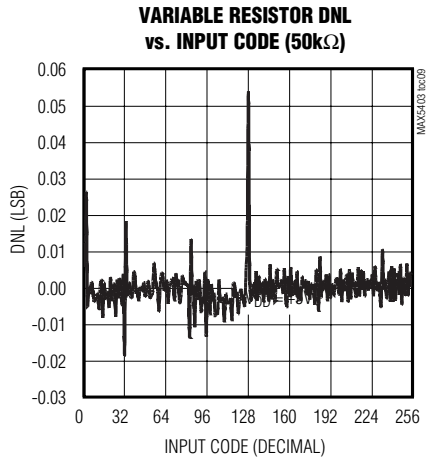
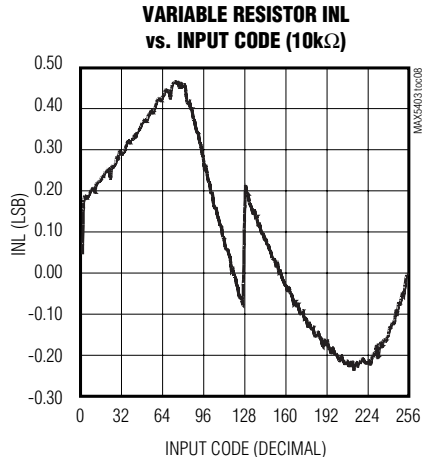
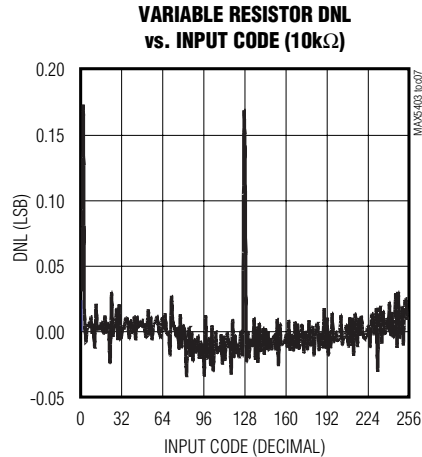
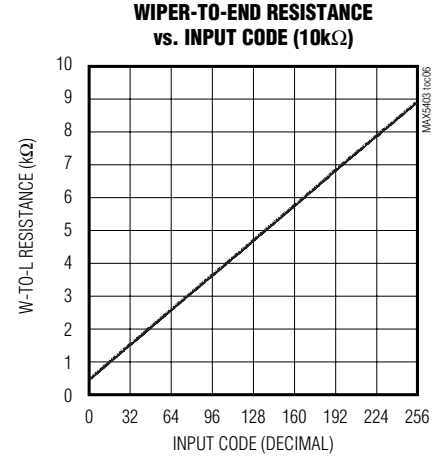
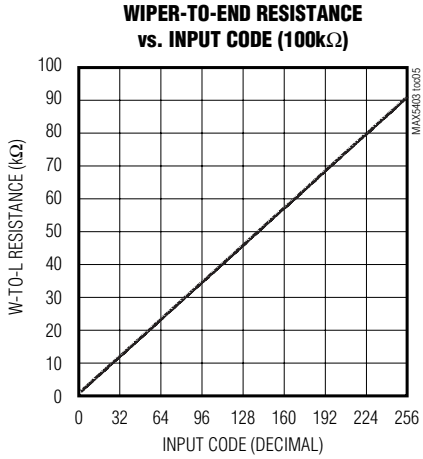
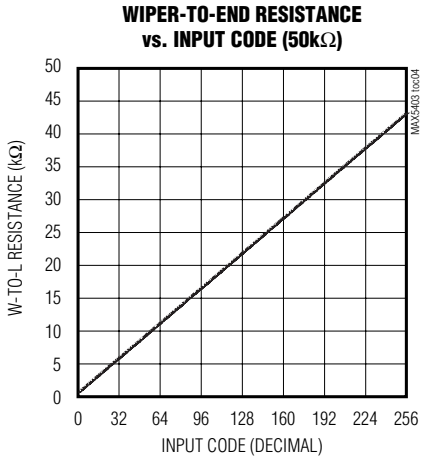
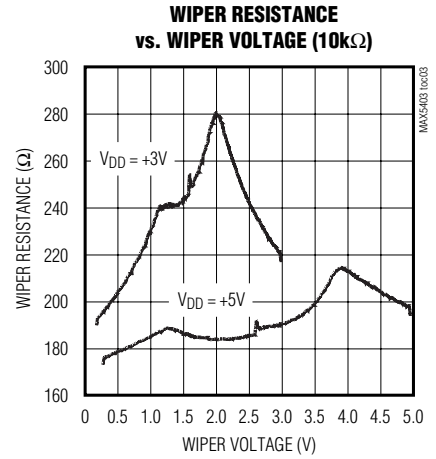
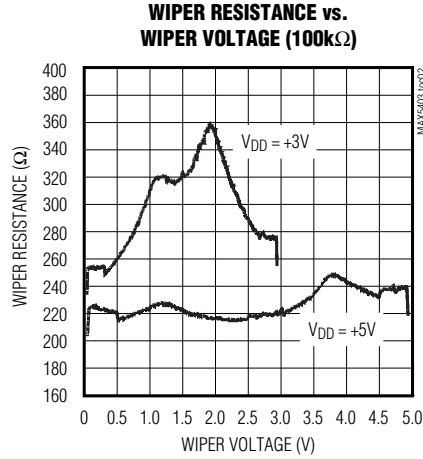
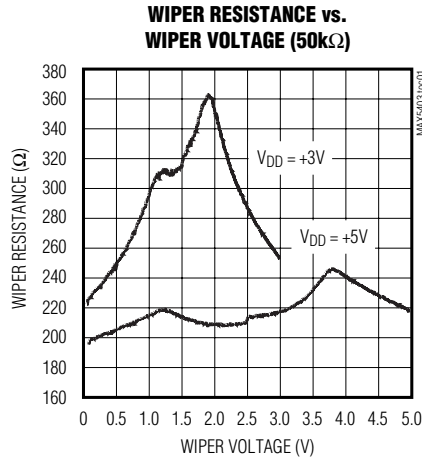
**Note 4:** The wiper resistance is the worst value measured by injecting into  $W_X$ , a current  $I_W = V_{DD} / R_{HL}$ .

**Note 5:** Digital timing is guaranteed by design.

# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

## Typical Operating Characteristics

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

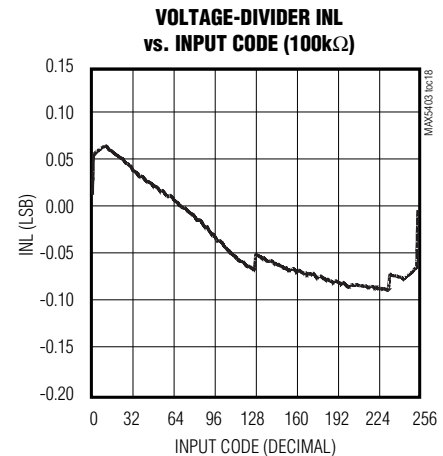
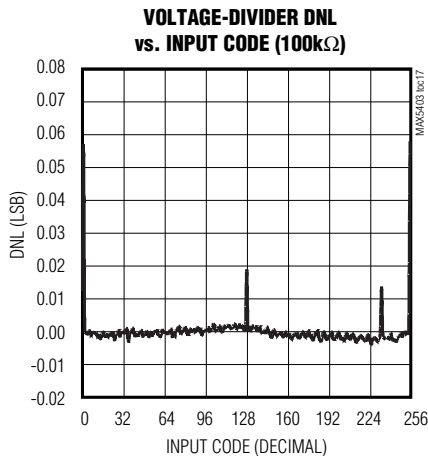
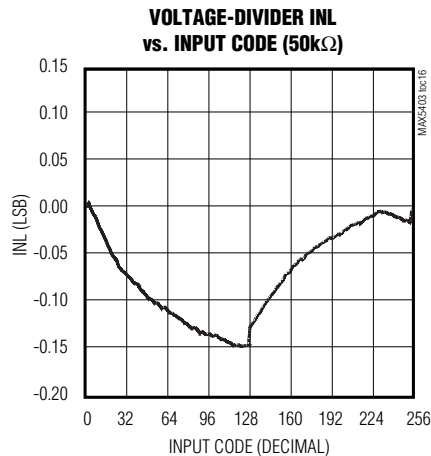
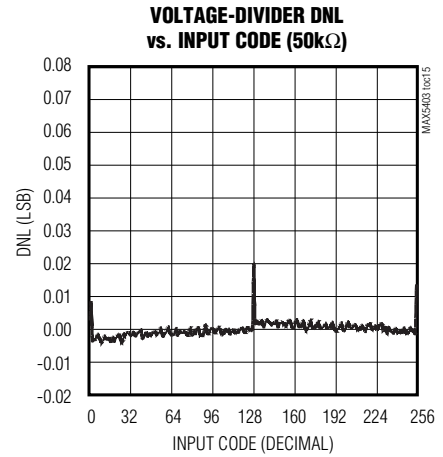
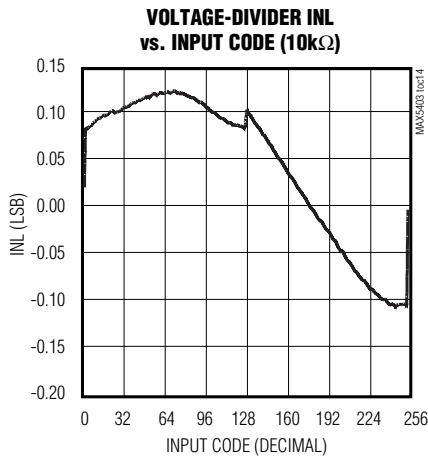
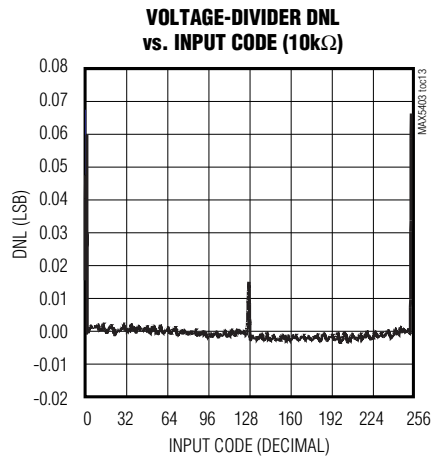
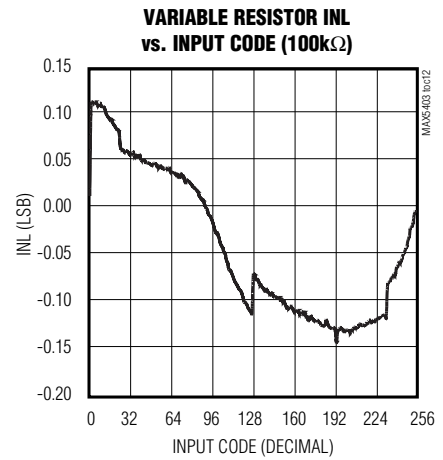
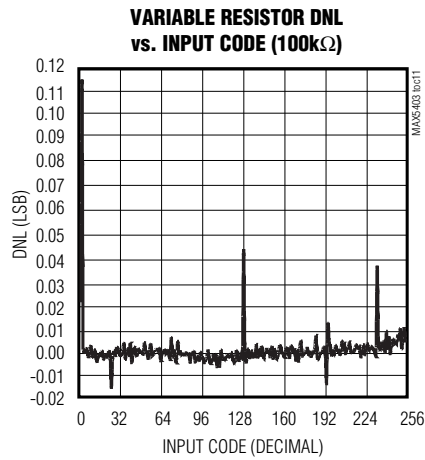
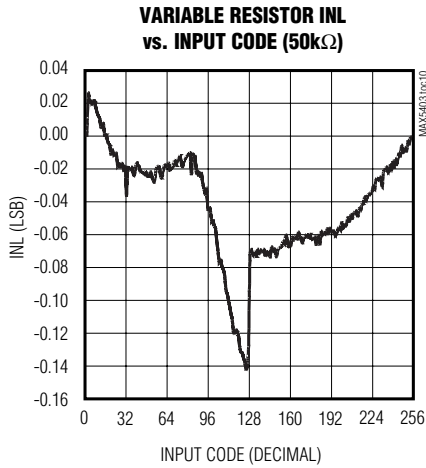


# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

## Typical Operating Characteristics (continued)

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

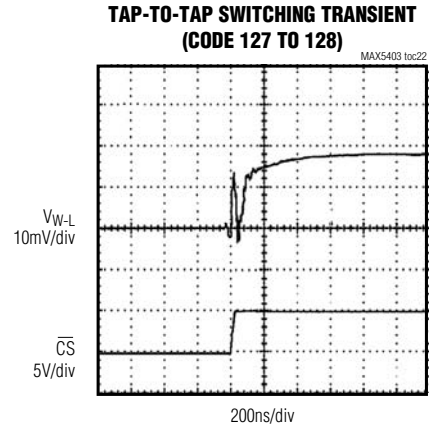
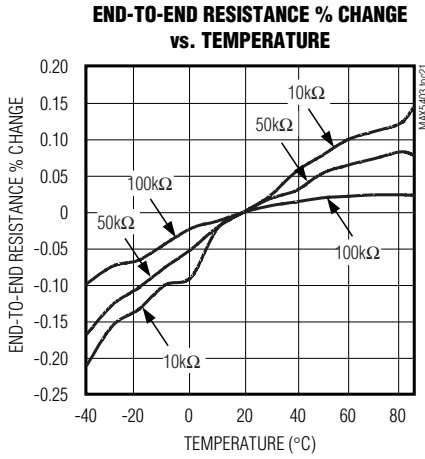
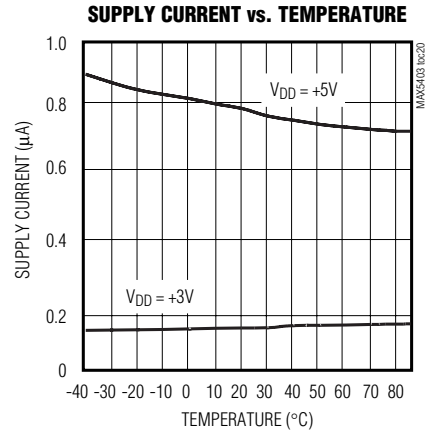
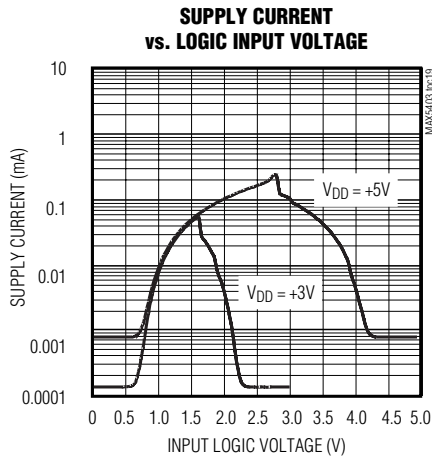
MAX5403/MAX5404/MAX5405



# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

## Typical Operating Characteristics (continued)

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



# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

## Pin Description

| PIN | NAME                   | FUNCTION  |
|-----|------------------------|---|
| 1   | GND                    | Ground  |
| 2   | L <sub>B</sub>         | Low Terminal of Resistor B  |
| 3   | H <sub>B</sub>         | High Terminal of Resistor B   |
| 4   | W <sub>B</sub>         | Wiper Terminal of Resistor B  |
| 5   | $\overline{\text{CS}}$ | SPI Chip Select   |
| 6   | DIN                    | SPI Serial Data Input   |
| 7   | SCLK                   | SPI Clock Input   |
| 8   | V <sub>DD</sub>        | Power Supply, +2.7V to +5.5V. Connect a 0.1 $\mu$ F capacitor to GND. |
| 9   | W <sub>A</sub>         | Wiper Terminal of Resistor A  |
| 10  | L <sub>A</sub>         | Low Terminal of Resistor A  |

MAX5403/MAX5404/MAX5405

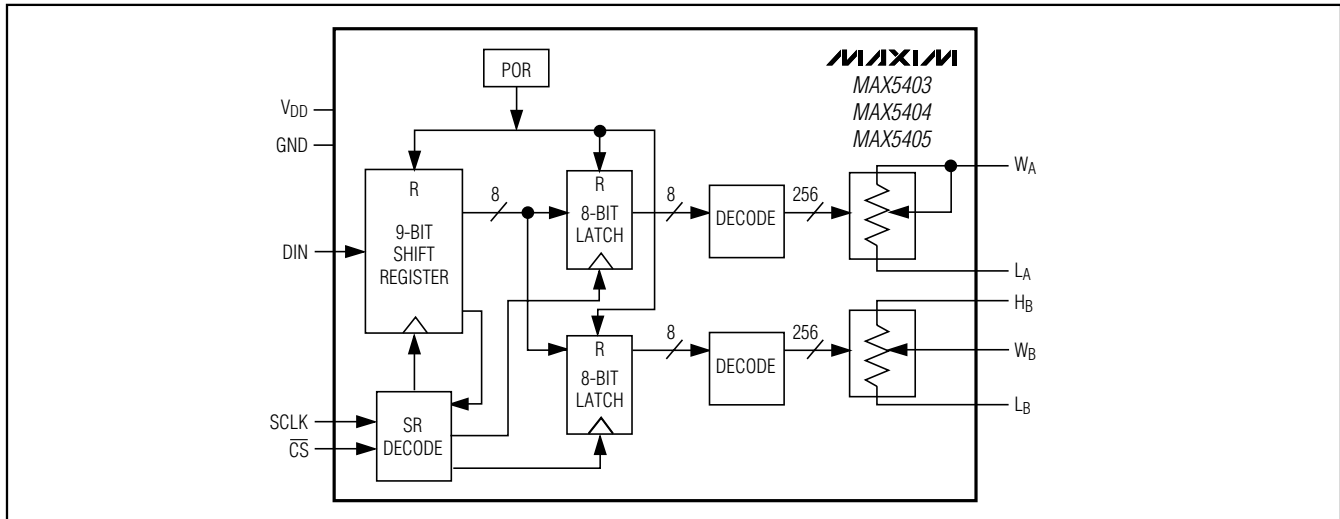


Figure 1. MAX5403/MAX5404/MAX5405 Functional Diagram: 2-Terminal Variable Resistor and 3-Terminal Potentiometers in 10- $\mu$ MAX Configuration

## Detailed Description

Each potentiometer consists of 255 fixed resistors in series between pins H<sub>B</sub> and L<sub>B</sub> for the 3-terminal potentiometer and between W<sub>A</sub> and L<sub>A</sub> for the 2-terminal variable resistor (Figure 1). The potentiometer wiper (pin W<sub>x</sub>) can be programmed to access any one of the 256 different tap points on the resistor string. The MAX5403/MAX5404/MAX5405 require nine bits to program the wiper position. The 1st bit is an address code,

allowing one or the other potentiometers to be selected for programming. The potentiometers are programmed independently of each other.

The MAX5403/MAX5404/MAX5405 use a 3-wire serial data interface to control the wiper tap position. This write-only interface contains three inputs: Chip Select ( $\overline{\text{CS}}$ ), Data In (DIN), and Data Clock (SCLK). When  $\overline{\text{CS}}$  is taken low, data from the DIN pin is synchronously loaded into the serial shift register on each rising edge

# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10- $\mu$ MAX

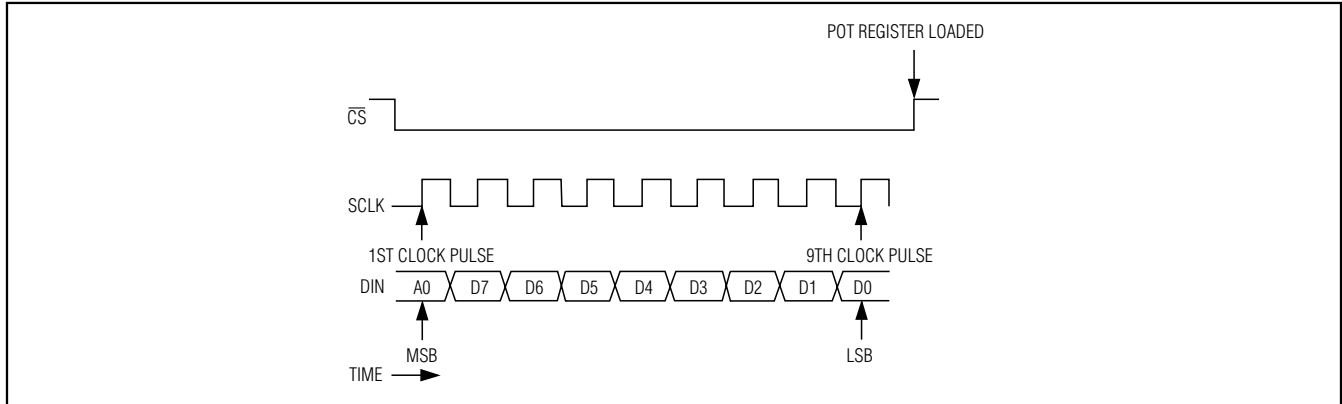


Figure 2. Potentiometer Serial Data Timing Circuit

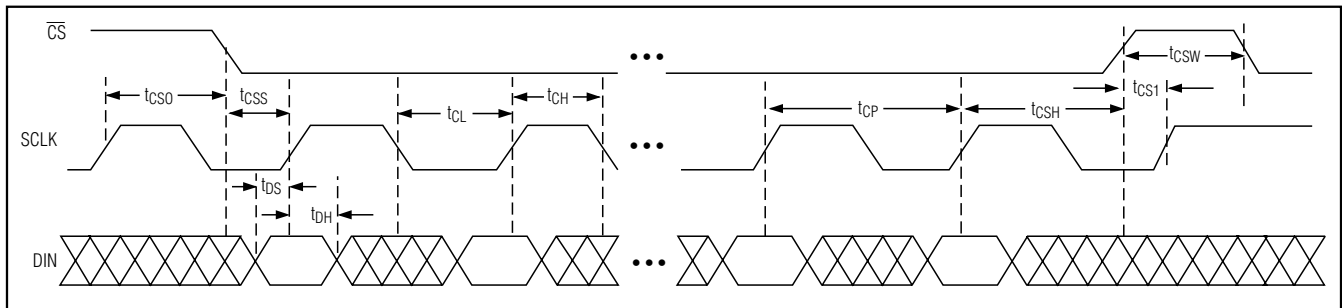


Figure 3. Detailed Serial Interface Timing Diagram

of each SCLK pulse (Figure 2). After all the data bits have been shifted in, they are latched into the appropriate potentiometer control register when  $\overline{CS}$  transitions from low to high. Note that if  $\overline{CS}$  is not kept low during the entire data stream, the data will be corrupted and the device will need to be reloaded.

The first bit A0 (address bit) is used to address one or the other of the potentiometers for programming. Potentiometer control register A is selected for writing when A0 is 'zero', and potentiometer control register B is selected when A0 is one.

The MAX5403/MAX5404/MAX5405 feature POR circuitry that sets the wiper to the midscale position at power-up.

## Applications Information

The MAX5403/MAX5404/MAX5405 are intended for a variety of circuits where accurate, fine-tuning adjustable resistance is required, such as in adjustable voltage or adjustable gain circuit configurations. It is primarily used in either a potentiometer divider or a variable resistor configuration.

### Adjustable Current to Voltage Converter

Figure 5 shows the MAX5403/MAX5404/MAX5405 being used with a MAX4250 low-noise op amp to fine tune a current to voltage converter. Pins H<sub>B</sub> and W<sub>B</sub> of the MAX5403/MAX5404/MAX5405 3-terminal potentiometer (only pin W<sub>A</sub> of the 2-terminal variable resistor) are connected to the node between R<sub>3</sub> and R<sub>2</sub> (pin L<sub>x</sub> is connected to ground). Circuit space is minimized due to both devices' packaging.

### Adjustable Gain Amplifier

Figure 6 shows how to use the MAX5403/MAX5404/MAX5405 to digitally adjust the gain of a noninverting op amp configuration. In Figure 6a, connect the MAX5403/MAX5404/MAX5405 as a 2-terminal variable resistor in series with a resistor to ground to form the adjustable gain control of a noninverting amplifier.

Similarly, Figure 6b shows how to use the MAX5403/MAX5404/MAX5405 as a 3-terminal potentiometer. In this application the MAX5403/MAX5404/MAX5405 low 5ppm/ $^{\circ}$ C ratiometric tempco allows for a very stable adjustable gain-configuration overtemperature.



# Dual 256-Tap, Low-Drift, Digital Potentiometers in 10-μMAX

| ADDRESS               | DATA WORD      |                |                |                |                |                |                |                      |
|-----------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------------|
| <b>B0</b> (A0)        | <b>B1</b> (D7) | <b>B2</b> (D6) | <b>B3</b> (D5) | <b>B4</b> (D4) | <b>B5</b> (D3) | <b>B6</b> (D2) | <b>B7</b> (D1) | <b>B8</b> (D0)       |
| (MSB)<br>First Bit In |                |                |                |                |                |                |                | (LSB)<br>Last Bit In |

Figure 4. Serial Data Format

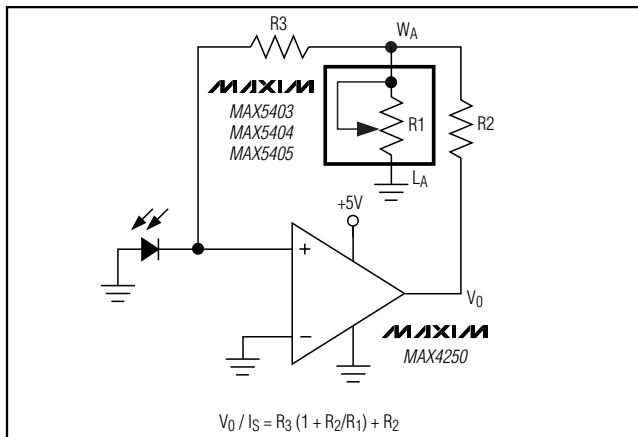


Figure 5. I to V Converter

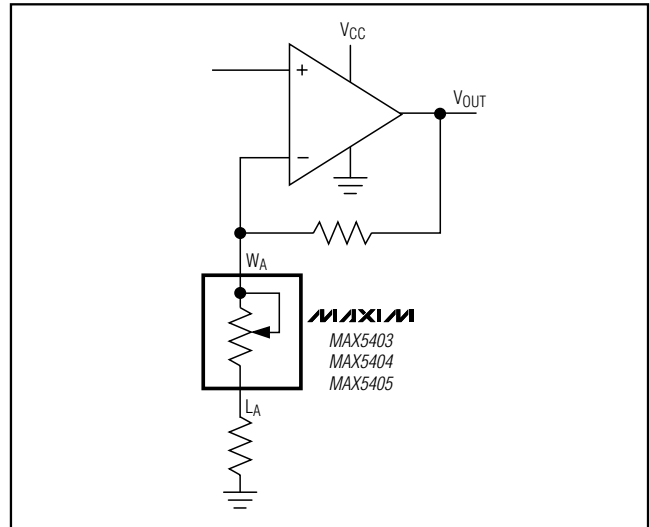


Figure 6a. Adjustable Gain Circuit Using: 2-Terminal Variable Resistor

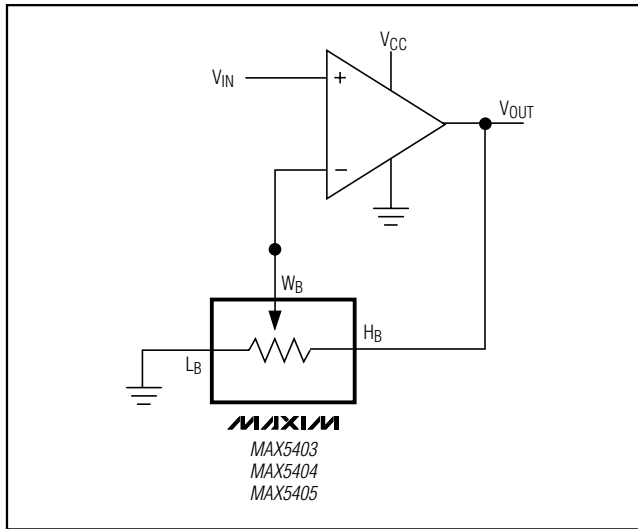


Figure 6b. Adjustable Gain Circuit Using: 3-Terminal Potentiometer

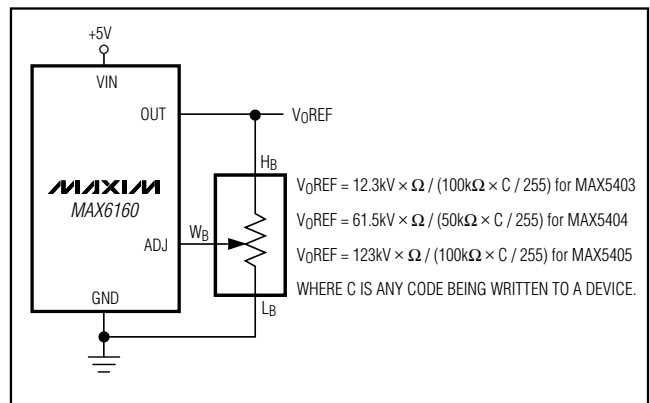


Figure 7a. Adjustable Voltage Reference Using: 3-Terminal Potentiometer

## Adjustable Voltage Reference

In Figure 7a, the MAX5403/MAX5404/MAX5405 is shown with the MAX6160 to make an adjustable voltage reference. In this circuit, the H<sub>x</sub> pin of the MAX5403/MAX5404/MAX5405 is connected to the OUT pin of the MAX6160, the L<sub>x</sub> pin of the MAX5403/MAX5404/MAX5405 is connected to GND, and the W<sub>x</sub>

pin of the MAX5403/MAX5404/MAX5405 is connected to the ADJ pin of the MAX6160. The MAX5403/MAX5404/MAX5405 allow precise setting of the voltage reference output. A low 5ppm/°C ratiometric tempco allows a very stable, adjustable voltage over temperature.