**MAX5387**

**Dual, 256-Tap, Volatile, Low-Voltage Linear Taper Digital Potentiometer**

**General Description**

The MAX5387 dual, 256-tap, volatile, low-voltage linear taper digital potentiometer offers three end-to-end resistance values of 10kΩ, 50kΩ, and 100kΩ. Operating from a single +2.6V to +5.5V power supply, the device provides a low 35ppm/ºC end-to-end temperature coefficient. The device features an I²C interface.

The small package size, low supply operating voltage, low supply current, and automotive temperature range of the MAX5387 make the device uniquely suitable for the portable consumer market and battery-backup industrial applications.

The MAX5387 is specified over the automotive -40ºC to +125ºC temperature range and is available in a 14-pin TSSOP package.

**Applications**

- Low-Voltage Battery Applications
- Portable Electronics
- Mechanical Potentiometer Replacement
- Offset and Gain Control
- Adjustable Voltage References/Linear Regulators

**Features**

- Dual, 256-Tap Linear Taper Positions
- Single +2.6V to +5.5V Supply Operation
- Low < 1μA Quiescent Supply Current
- 10kΩ, 50kΩ, 100kΩ End-to-End Resistance Values
- I²C-Compatible Interface
- Power-On Sets Wiper to Midscale
- -40ºC to +125ºC Operating Temperature Range

**Ordering Information**

<table>
<thead>
<tr>
<th>PART</th>
<th>PIN-PACKAGE</th>
<th>END-TO-END RESISTANCE (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX5387LAUD+</td>
<td>14 TSSOP</td>
<td>10</td>
</tr>
<tr>
<td>MAX5387MAUD+</td>
<td>14 TSSOP</td>
<td>50</td>
</tr>
<tr>
<td>MAX5387NAUD+</td>
<td>14 TSSOP</td>
<td>100</td>
</tr>
</tbody>
</table>

**Note:** All devices are specified over the -40ºC to +125ºC operating temperature range.

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

**Functional Diagram**

![Functional Diagram](image-url)
### Absolute Maximum Ratings

- **V<sub>DD</sub> to GND**: -0.3V to +6V
- **H<sub>_</sub>, W<sub>_</sub>, L<sub>_</sub> to GND**: -0.3V to the lower of (V<sub>DD</sub> + 0.3V) and +6V
- **All Other Pins to GND**: -0.3V to +6V
- Continuous Current into H<sub>_</sub>, W<sub>_</sub>, and L<sub>_</sub>:
  - MAX5387L: ±5mA
  - MAX5387M: ±2mA
  - MAX5387N: ±1mA
- Continuous Power Dissipation (T<sub>A</sub> = +70ºC): 796.8mW
- Operating Temperature Range: -40ºC to +125ºC
- Junction Temperature: +150ºC
- Storage Temperature Range: -65ºC to +150ºC
- Lead Temperature (soldering, 10s): +300ºC
- Soldering Temperature (reflow): +260ºC

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> = +2.6V to +5.5V, V<sub>H</sub> = V<sub>DD</sub>, V<sub>L</sub> = GND, T<sub>A</sub> = -40ºC to +125ºC, unless otherwise noted. Typical values are at V<sub>DD</sub> = +5V, T<sub>A</sub> = +25ºC.) (Note 1)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>N</td>
<td>(Note 2)</td>
<td>256</td>
<td></td>
<td></td>
<td>Tap</td>
</tr>
</tbody>
</table>

#### DC PERFORMANCE (Voltage-Divider Mode)

- **Integral Nonlinearity**
  - INL: Code = FFH
  - MAX5387L: -3 ±2.5 LSB
  - MAX5387M: -1 ±0.5 LSB
  - MAX5387N: -0.5 ±0.25 LSB

- **Differential Nonlinearity**
  - DNL: V<sub>DD</sub> = +2.6V
  - MAX5387L: ±1.0 ±2.5 LSB
  - MAX5387M: ±0.5 ±1.0 LSB
  - MAX5387N: ±0.25 ±0.8 LSB

- **Dual Code Matching**
  - Register A = register B
  - MAX5387L: +2.5 ±3 LSB
  - MAX5387M: +0.5 ±1.0 LSB
  - MAX5387N: +0.25 ±0.5 LSB

#### DC PERFORMANCE (Variable-Resistor Mode)

- **Integral Nonlinearity**
  - R-INL: V<sub>DD</sub> > +2.6V
  - MAX5387L: ±2.5 ±1.0 LSB
  - MAX5387M: ±1.0 ±0.5 LSB
  - MAX5387N: ±0.8 ±0.25 LSB

- **Differential Nonlinearity**
  - R-DNL: V<sub>DD</sub> > +4.75V
  - MAX5387L: ±1.5 ±0.4 LSB
  - MAX5387M: ±0.75 ±0.3 LSB
  - MAX5387N: ±0.5 ±0.25 LSB

#### DC PERFORMANCE (Resistor Characteristics)

- **Wiper Resistance**
  - R<sub>WL</sub>: V<sub>DD</sub> > 2.6V
  - MAX5387L: 250 ±600 Ω
  - MAX5387M: 150 ±300 Ω

- **Terminal Capacitance**
  - C<sub>H</sub>, C<sub>L</sub>: Measured to GND
  - 10 pF

- **Wiper Capacitance**
  - C<sub>W</sub>: Measured to GND
  - 50 pF

- **End-to-End Resistor Tempco**
  - T<sub>CR</sub>: No load
  - 35 ppm/ºC

- **End-to-End Resistor Tolerance**
  - ∆R<sub>HL</sub>: Wiper not connected
  - -25 ±25 %
Electrical Characteristics (continued)

(V_{DD} = +2.6V to +5.5V, V_{H_} = V_{DD}, V_{L_} = GND, T_{A} = -40ºC to +125ºC, unless otherwise noted. Typical values are at V_{DD} = +5V, T_{A} = +25ºC.) (Note 1)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosstalk (Note 5)</td>
<td></td>
<td></td>
<td>-90</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>-3dB Bandwidth</td>
<td>BW</td>
<td>Code = 80H, 10pF load,</td>
<td>MAX5387L</td>
<td>600</td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V_{DD} = +2.6V</td>
<td>MAX5387M</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAX5387N</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Harmonic Distortion Plus</td>
<td>THD+N</td>
<td>Noise Measured at W; V_{H_} = 1V RMS at 1kHz</td>
<td></td>
<td>0.015</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Wiper Settling Time (Note 6)</td>
<td>t_{S}</td>
<td>MAX5387L</td>
<td>300</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX5387M</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX5387N</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

POWER SUPPLIES

Supply-Voltage Range | V_{DD} | 2.6   | 5.5   | V     |
Standby Current      |        | Digital inputs = V_{DD} or GND | 1     | µA    |

DIGITAL INPUTS

Minimum Input High Voltage | V_{IH} | 70    | % x V_{DD} |
Maximum Input Low Voltage | V_{IL} | 30    | % x V_{DD} |
Input Leakage Current    |        | -1    | +1 µA      |
Input Capacitance        |        | 5     | pF         |

TIMING CHARACTERISTICS (Notes 7, 8)

Maximum SCL Frequency | f_{SCL} | 400   | kHz     |
Setup Time for START Condition | t_{SU:STA} | 0.6   | µs     |
Hold Time for START Condition | t_{HD:STA} | 0.6   | µs     |
SCL High Time | t_{HIGH} | 0.6   | µs     |
SCL Low Time | t_{LOW} | 1.3   | µs     |
Data Setup Time | t_{SU:DAT} | 100   | ns     |
Data Hold Time | t_{HD:DAT} | 0     | µs     |
SDA, SCL Rise Time | t_{R} | 0.3   | µs     |
SDA, SCL Fall | t_{F} | 0.3   | µs     |
Setup Time for STOP Condition | t_{SU:STO} | 0.6   | µs     |
Bus Free Time Between STOP and START Conditions | t_{BUF} | Minimum power-up rate = 0.2V/µs | 1.3   | µs     |
Pulse-Suppressed Spike Width | t_{SP} | 50    | ns     |
Capacitive Load for Each Bus | C_{B} | 400   | pF     |

Note 1: All devices are 100% production tested at T_{A} = +25ºC. Specifications overtemperatures limits are guaranteed by design and characterization.

Note 2: DNL and INL are measured with the potentiometer configured as a voltage-divider (Figure 1) with H_ = V_{DD} and L_ = 0V. The wiper terminal is unloaded and measured with an ideal voltmeter.

Note 3: R-DNL and R-INL are measured with the potentiometer configured as a variable resistor (Figure 1). DNL and INL are measured with the potentiometer configured as a variable resistor. H_ is unconnected and L_ = GND. For V_{DD} = +5V, the wiper terminal is driven with a source current of 400µA for the 10kΩ configuration, 80µA for the 50kΩ configuration, and 40µA for the 100kΩ configuration. For V_{DD} = +2.6V, the wiper terminal is driven with a source current of 200µA for the 10kΩ configuration, 40µA for the 50kΩ configuration, and 20µA for the 100kΩ configuration.

Note 4: The wiper resistance is the worst value measured by injecting the currents given in Note 3 into W_ with L_ = GND. R_{W} = (V_{W} - V_{H})/I_{W}.
Notes:

**Note 5:** Drive HA with a 1kHz GND to VDD amplitude tone. LA = LB = GND. No load. WB is at midscale with a 10pF load. Measure WB.

**Note 6:** The wiper settling time is the worst-case 0 to 50% rise time, measured between tap 0 and tap 127. H_ = VDD, L_ = GND, and the wiper terminal is loaded with 10pF capacitance to ground.

**Note 7:** Digital timing is guaranteed by design and characterization, not production tested.

**Note 8:** The SCL clock period includes rise and fall times (tR = fF). All digital input signals are specified with tR = fF = 2ns and timed from a voltage level of (VIL + VIH)/2.

**Typical Operating Characteristics**

(VDD = 5V, TA = +25°C, unless otherwise noted.)

Figure 1. Voltage-Divider and Variable Resistor Configurations

<table>
<thead>
<tr>
<th>SUPPLY CURRENT vs. TEMPERATURE</th>
<th>SUPPLY CURRENT vs. DIGITAL INPUT VOLTAGE</th>
<th>SUPPLY CURRENT vs. SUPPLY VOLTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESISTANCE (W-TO-L) vs. TAP POSITION (10kΩ)</th>
<th>RESISTANCE (W-TO-L) vs. TAP POSITION (50kΩ)</th>
<th>RESISTANCE (W-TO-L) vs. TAP POSITION (100kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4.png" alt="Graph" /></td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

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Typical Operating Characteristics (continued)

(V_{DD} = 5V, T_A = +25°C, unless otherwise noted.)
Typical Operating Characteristics (continued)

(V_{DD} = 5V, T_A = +25°C, unless otherwise noted.)
Typical Operating Characteristics (continued)

(V_{DD} = 5V, T_{A} = +25°C, unless otherwise noted.)

**MAX5387 POWER-ON WIPER TRANSIENT**

(Code 0 to 128)

**MIDSCALE FREQUENCY RESPONSE**

(V_{IN} = 1Vp-p, C_{W} = 10pF)

**CROSSTALK vs. FREQUENCY**

**TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY**
**Pin Description**

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HA</td>
<td>Resistor A High Terminal. The voltage at HA can be higher or lower than the voltage at LA. Current can flow into or out of HA.</td>
</tr>
<tr>
<td>2</td>
<td>WA</td>
<td>Resistor A Wiper Terminal</td>
</tr>
<tr>
<td>3</td>
<td>LA</td>
<td>Resistor A Low Terminal. The voltage at LA can be higher or lower than the voltage at HA. Current can flow into or out of LA.</td>
</tr>
<tr>
<td>4</td>
<td>HB</td>
<td>Resistor B High Terminal. The voltage at HB can be higher or lower than the voltage at LB. Current can flow into or out of HB.</td>
</tr>
<tr>
<td>5</td>
<td>WB</td>
<td>Resistor B Wiper Terminal</td>
</tr>
<tr>
<td>6</td>
<td>LB</td>
<td>Resistor B Low Terminal. The voltage at LB can be higher or lower than the voltage at HB. Current can flow into or out of LB.</td>
</tr>
<tr>
<td>7</td>
<td>I.C.</td>
<td>Internally Connected. Connect to GND.</td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>9</td>
<td>A2</td>
<td>Address Input 2. Connect to V_DD or GND.</td>
</tr>
<tr>
<td>10</td>
<td>A1</td>
<td>Address Input 1. Connect to V_DD or GND.</td>
</tr>
<tr>
<td>11</td>
<td>A0</td>
<td>Address Input 0. Connect to V_DD or GND.</td>
</tr>
<tr>
<td>12</td>
<td>SDA</td>
<td>I^2C-Compatible Serial-Data Input/Output. A pullup resistor is required.</td>
</tr>
<tr>
<td>13</td>
<td>SCL</td>
<td>I^2C-Compatible Serial-Clock Input. A pullup resistor is required.</td>
</tr>
<tr>
<td>14</td>
<td>V_DD</td>
<td>Power-Supply Input. Bypass V_DD to GND with a 0.1µF capacitor close to the device.</td>
</tr>
</tbody>
</table>
Detailed Description
The MAX5387 dual, 256-tap, volatile, low-voltage linear taper digital potentiometer offers three end-to-end resistance values of 10kΩ, 50kΩ, and 100kΩ. The potentiometer consists of 255 fixed resistors in series between terminals H_ and L_. The potentiometer wiper, W_, is programmable to access any one of the 256 tap points on the resistor string.

The potentiometers are programmable independently of each other. The MAX5387 features an I²C interface.

I²C Digital Interface
The I²C interface contains a shift register that decodes the command and address bytes, routing the data to the appropriate control registers. Data written to a control register immediately updates the wiper position. Wipers A and B power up in midposition, D[7:0] = 80H.

Serial Addressing
The MAX5387 operates as a slave device that receives data through an I²C-/SMBus™-compatible 2-wire serial interface. The interface uses a serial-data access (SDA) line and a serial-clock line (SCL) to achieve bidirectional communication between master(s) and slave(s). A master, typically a microcontroller, initiates all data transfers to the MAX5387, and generates the SCL clock that synchronizes the data transfer (Figure 2).

Each transmission consists of a START (S) condition (Figure 3) sent by a master, followed by the MAX5387 7-bit slave address plus the NOP/W bit (Figure 6), 1 command byte and 1 data byte, and finally a STOP (P) condition (Figure 3).

START and STOP Conditions
SCL and SDA remain high when the interface is inactive. A master controller signals the beginning of a transmission with a START condition by transitioning SDA from high to low while SCL is high. The master controller issues a STOP condition by transitioning the SDA from low to high while SCL is high, after finishing communicating with the slave. The bus is then free for another transmission.

![Figure 2. I²C Serial Interface Timing Diagram](image)

SMBus is a trademark of Intel Corp.
Bit Transfer
One data bit is transferred during each clock pulse. The data on the SDA line must remain stable while SCL is high. See Figure 4.

Acknowledge
The acknowledge bit is a clocked 9th bit that the recipient uses to handshake receipt of each byte of data. See Figure 5. Each byte transferred requires a total of nine bits. The master controller generates the 9th clock pulse, and the recipient pulls down SDA during the acknowledge clock pulse, so the SDA line remains stable low during the high period of the clock pulse.

Slave Address
The MAX5387 includes a 7-bit slave address (Figure 6). The 8th bit following the 7th bit of the slave address is the NOP/W bit. Set the NOP/W bit low for a write command and high for a no-operation command. The device does not support readback.

The device provides three address inputs (A0, A1, and A2), allowing up to eight devices to share a common bus (Table 1). The first 4 bits (MSBs) of the factory-set slave addresses are always 0101. A2, A1, and A0 set the next 3 bits of the slave address. Connect each address input to VDD or GND. Each device must have a unique address to share a common bus.

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Figure 3. START and STOP Conditions

Figure 4. Bit Transfer

Figure 5. Acknowledge
Message Format for Writing
Write to the devices by transmitting the device’s slave address with NOP/W (eighth bit) set to zero, followed by at least 2 bytes of information. The first byte of information is the command byte. The second byte is the data byte. The data byte goes into the internal register of the device as selected by the command byte (Figure 7 and Table 2).

Command Byte
Use the command byte to select the destination of the wiper data. See Table 2.

Command Descriptions
REG A: The data byte writes to register A and the wiper of potentiometer A moves to the appropriate position. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wiper to the position closest to LA. D[7:0] = FFh moves the wiper to the position closest to HA. D[7:0] is 80h following power-on.

Table 1. Slave Addresses

<table>
<thead>
<tr>
<th>ADDRESS INPUTS</th>
<th>SLAVE ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2 A1 A0</td>
<td>0101000</td>
</tr>
<tr>
<td>GND GND GND</td>
<td>0010001</td>
</tr>
<tr>
<td>GND GND VDD</td>
<td>0010011</td>
</tr>
<tr>
<td>GND VDD GND</td>
<td>0011100</td>
</tr>
<tr>
<td>GND VDD VDD</td>
<td>0011110</td>
</tr>
<tr>
<td>VDD GND GND</td>
<td>0011111</td>
</tr>
<tr>
<td>VDD VDD GND</td>
<td>0011111</td>
</tr>
<tr>
<td>VDD VDD VDD</td>
<td>0011111</td>
</tr>
</tbody>
</table>
REG B: The data byte writes to register B and the wiper of potentiometer B moves to the appropriate position. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wiper to the position closest to LB. D[7:0] = FFh moves the wiper to the position closest to HB. D[7:0] is 80h following power-on.

REGS A and B: The data byte writes to registers A and B and the wipers of potentiometers A and B move to the appropriate position. D[7:0] indicates the position of the wiper. D[7:0] = 00h moves the wipers to the position closest to L_. D[7:0] = FFh moves the wipers to the position closest to H_. D[7:0] is 80h following power-on.

Applications Information

Variable Gain Amplifier

Figure 8 shows a potentiometer adjusting the gain of a noninverting amplifier. Figure 9 shows a potentiometer adjusting the gain of an inverting amplifier.

Adjustable Dual Regulator

Figure 10 shows an adjustable dual linear regulator using a dual potentiometer as two variable resistors.

Adjustable Voltage Reference

Figure 11 shows an adjustable voltage reference circuit using a potentiometer as a voltage-divider.

<table>
<thead>
<tr>
<th>ADDRESS BYTE</th>
<th>COMMAND BYTE</th>
<th>DATA BYTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCL CYCLE NO.</td>
<td>START (S)</td>
<td>COMMAND</td>
</tr>
<tr>
<td>A6</td>
<td>A5</td>
<td>A4</td>
</tr>
<tr>
<td>REG A</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. I2C Command Byte Summary

Figure 8. Variable Gain Noninverting Amplifier

Figure 9. Variable Gain Inverting Amplifier

Figure 10. Adjustable Dual Linear Regulator
Variable Gain Current to Voltage Converter
Figure 12 shows a variable gain current to voltage converter using a potentiometer as a variable resistor.

LCD Bias Control
Figure 13 shows a positive LCD bias control circuit using a potentiometer as a voltage-divider.
Figure 14 shows a positive LCD bias control circuit using a potentiometer as a variable resistor.

Programmable Filter
Figure 15 shows a programmable filter using a dual potentiometer.

Offset-Voltage Adjustment Circuit
Figure 16 shows an offset-voltage adjustment circuit using a dual potentiometer.
MAX5387

Dual, 256-Tap, Volatile, Low-Voltage
Linear Taper Digital Potentiometer

Chip Information
PROCESS: BiCMOS

Package Information
For the latest package outline information and land patterns (footprints), go to 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.

<table>
<thead>
<tr>
<th>PACKAGE TYPE</th>
<th>PACKAGE CODE</th>
<th>OUTLINE NO.</th>
<th>LAND PATTERN NO.</th>
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<tbody>
<tr>
<td>14 TSSOP</td>
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<td>21-0066</td>
<td>90-0113</td>
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**Revision History**

<table>
<thead>
<tr>
<th>REVISION NUMBER</th>
<th>REVISION DATE</th>
<th>DESCRIPTION</th>
<th>PAGES CHANGED</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1/10</td>
<td>Initial release</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>4/10</td>
<td>Added Soldering Temperature in <em>Absolute Maximum Ratings</em>; corrected code in Conditions of -3dB Bandwidth specification in <em>Electrical Characteristics</em></td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>11/10</td>
<td>Updated figures for optimal circuit operation</td>
<td>12, 13, 14</td>
</tr>
<tr>
<td>3</td>
<td>9/14</td>
<td>Removed automotive references from data sheet</td>
<td>1</td>
</tr>
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</table>

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For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim Integrated’s website at www.maximintegrated.com.