

## TPL0102 具有非易失性存储器的 256 抽头双通道数字电位计

### 1 特性

- 两个分辨率为 256 个位置的电位计
- 非易失性存储器存储抽头设置
- 100kΩ 端到端电阻 (TPL0102-100)
- 短暂的抽头设置上电响应时间: < 100μs
- ±0.5 最低有效位 (LSB) 积分非线性 (INL), ±0.25 LSB 微分非线性 (DNL) (分压模式)
- 4ppm/°C 比例温度系数
- 兼容 I<sup>2</sup>C 的串行接口
- 2.7V 至 5.5V 单电源运行
- ±2.25V 至 ±2.75V 双电源运行
- 工作温度范围: -40°C 至 85°C
- 关断模式
- 静电放电 (ESD) 性能测试符合 JESD 22 标准
  - 2000V 人体模型 (A114-B, II 类)
  - 1000V 充电器件模型 (C101)

### 2 应用

- 可调节增益放大器和偏移修整
- 可调节电源
- 设定点阈值的精度校准
- 传感器微调和校准
- 机械电位器的替代产品

### 3 说明

TPL0102 配有两个具备 256 个抽头位置的线性抽头数字电位计 (DPOT)。每个分压器可用作三端分压器或者两端变阻器。TPL0102-100 具有一个 100kΩ 端到端电阻。

TPL0102 配有非易失性存储器 (EEPROM)，可用于存储抽头位置。这一点的优势是即使在掉电期间也可存储抽头位置。因此，再次上电时便可自动恢复抽头位置。TPL0102 的内部寄存器可以使用 I<sup>2</sup>C 接口进行访问。

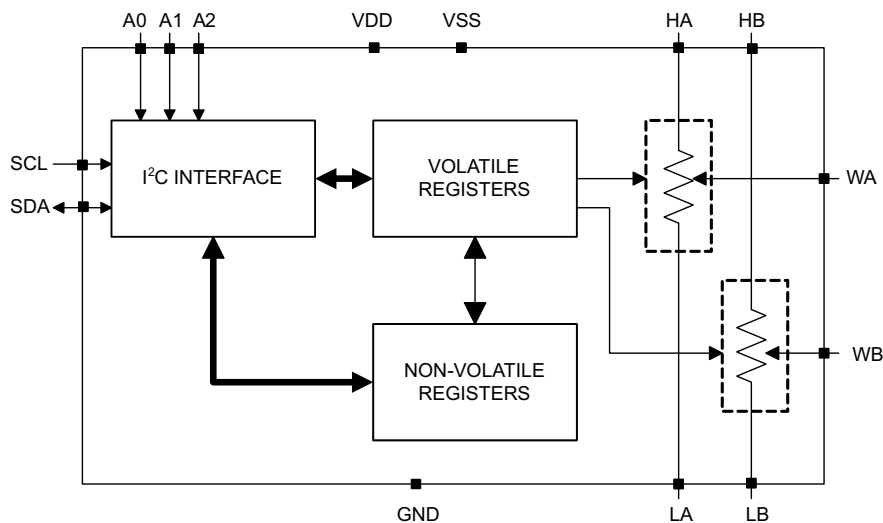
TPL0102 采用 14 引脚 MicroQFN 和 14 引脚薄型小外形尺寸 (TSSOP) 封装，额定温度范围为 -40°C 至 85°C。

器件信息(1)

| 器件型号    | 封装         | 封装尺寸 (标称值)      |
|---------|------------|-----------------|
| TPL0102 | X2QFN (14) | 2.00mm x 2.00mm |
|         | TSSOP (14) | 5.00mm x 4.40mm |

(1) 要了解所有可用封装，请见数据表末尾的可订购产品附录。

简化电路原理图



## 目录

|          |  |           |           |   |           |
|----------|--|-----------|-----------|---|-----------|
| 1        | 特性 .....                                     | 1         | 7.5       | Programming with I <sup>2</sup> C .....     | 20        |
| 2        | 应用 .....                                     | 1         | 7.6       | Register Maps .....                         | 25        |
| 3        | 说明 .....                                     | 1         | <b>8</b>  | <b>Application and Implementation</b> ..... | <b>28</b> |
| 4        | 修订历史记录 .....                                 | 2         | 8.1       | Application Information .....               | 28        |
| <b>5</b> | <b>Pin Configuration and Functions</b> ..... | <b>3</b>  | 8.2       | Typical Applications .....                  | 28        |
| <b>6</b> | <b>Specifications</b> .....                  | <b>4</b>  | <b>9</b>  | <b>Power Supply Recommendations</b> .....   | <b>34</b> |
| 6.1      | Absolute Maximum Ratings .....               | 4         | 9.1       | Power Sequence .....                        | 34        |
| 6.2      | ESD Ratings .....                            | 4         | 9.2       | Wiper Position Upon Power Up .....          | 34        |
| 6.3      | Recommended Operating Conditions .....       | 4         | 9.3       | Dual-Supply vs Single-Supply .....          | 34        |
| 6.4      | Thermal Information .....                    | 4         | <b>10</b> | <b>Layout</b> .....                         | <b>35</b> |
| 6.5      | Electrical Characteristics .....             | 5         | 10.1      | Layout Guidelines .....                     | 35        |
| 6.6      | Operating Characteristics .....              | 6         | 10.2      | Layout Example .....                        | 35        |
| 6.7      | Timing Requirements .....                    | 7         | <b>11</b> | <b>器件和文档支持</b> .....                        | <b>36</b> |
| 6.8      | Typical Characteristics .....                | 8         | 11.1      | 社区资源 .....                                  | 36        |
| <b>7</b> | <b>Detailed Description</b> .....            | <b>11</b> | 11.2      | 商标 .....                                    | 36        |
| 7.1      | Overview .....                               | 11        | 11.3      | 静电放电警告 .....                                | 36        |
| 7.2      | Functional Block Diagram .....               | 12        | 11.4      | Glossary .....                              | 36        |
| 7.3      | Feature Description .....                    | 12        | <b>12</b> | <b>机械、封装和可订购信息</b> .....                    | <b>36</b> |
| 7.4      | Device Functional Modes .....                | 13        |           |   |           |

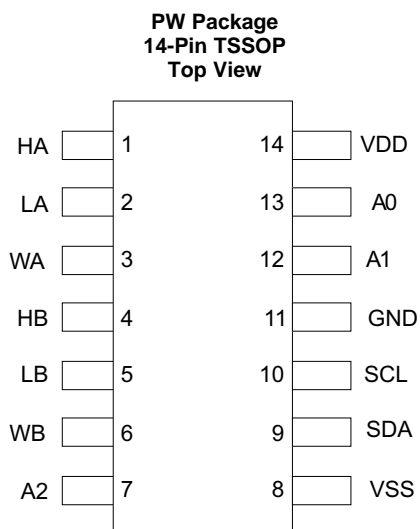
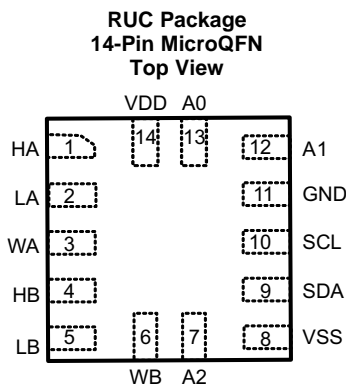
## 4 修订历史记录

注：之前版本的页码可能与当前版本有所不同。

| <b>Changes from Revision B (August 2011) to Revision C</b>                                | <b>Page</b> |
|---|-------------|
| • 已添加 <i>ESD</i> 额定值表，特性 描述部分，器件功能模式，应用和实施部分，电源相关建议部分，布局部分，器件和文档支持部分以及机械、封装和可订购信息部分 ..... | 1           |

| <b>Changes from Revision A (March 2011) to Revision B</b>   | <b>Page</b> |
|---|-------------|
| • Added <i>Recommended Operating Conditions</i> table. .... | 4           |

## 5 Pin Configuration and Functions



### Pin Functions

| PIN  |     | I/O | DESCRIPTION  |
|------|-----|-----|--|
| NAME | NO. |     |  |
| HA   | 1   | I/O | High terminal of potentiometer A   |
| LA   | 2   | I/O | Low terminal of potentiometer A  |
| WA   | 3   | I/O | Wiper terminal of potentiometer A  |
| HB   | 4   | I/O | High terminal of potentiometer B   |
| LB   | 5   | I/O | Low terminal of potentiometer B  |
| WB   | 6   | I/O | Wiper terminal of potentiometer B  |
| A2   | 7   | I   | I <sup>2</sup> C address bit 2   |
| VSS  | 8   | –   | Negative power supply pin (Dual-Supply Operation) or tied to GND (Single-Supply Operation) |
| SDA  | 9   | I/O | I <sup>2</sup> C data I/O  |
| SCL  | 10  | I   | I <sup>2</sup> C clock Input   |
| GND  | 11  | –   | Ground   |
| A1   | 12  | I   | I <sup>2</sup> C address bit 1   |
| A0   | 13  | I   | I <sup>2</sup> C address bit 0   |
| VDD  | 14  | –   | Positive power supply pin  |

## 6 Specifications

### 6.1 Absolute Maximum Ratings<sup>(1)(2)(3)</sup>

|  |                               | MIN                   | MAX                   | UNIT |
|--|-------------------------------|-----------------------|-----------------------|------|
| V <sub>DD</sub> to GND                           | Supply voltage                | -0.3                  | 7                     | V    |
| V <sub>SS</sub> to GND                           |                               | -7                    | 0.3                   | V    |
| V <sub>DD</sub> to V <sub>SS</sub>               |                               |                       | 7                     | V    |
| V <sub>H</sub> , V <sub>L</sub> , V <sub>W</sub> | Voltage at resistor terminals | V <sub>SS</sub> - 0.3 | V <sub>DD</sub> + 0.3 | V    |
| V <sub>I</sub>                                   | Digital input voltage         | -0.3                  | V <sub>DD</sub> + 0.3 | V    |
| I <sub>H</sub> , I <sub>L</sub> , I <sub>W</sub> | Pulse current                 |                       | ±20                   | mA   |
|  | Continuous current            |                       | ±2                    | mA   |
| T <sub>stg</sub>                                 | Storage temperature           | -65                   | 150                   | °C   |

- (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
- (2) The algebraic convention, whereby the most negative value is a minimum and the most positive value is a maximum.
- (3) All voltages are with respect to ground, unless otherwise specified.

### 6.2 ESD Ratings

|  |  | VALUE | UNIT |
|--|--|-------|------|
| V <sub>(ESD)</sub> Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±2000 | V    |
|  | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±1000 |      |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 500-V HBM is possible with the necessary precautions.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 250-V CDM is possible with the necessary precautions.

### 6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

|                                 |   | MIN                   | MAX                   | UNIT |
|---------------------------------|---|-----------------------|-----------------------|------|
| V <sub>DD</sub>                 | Single supply operation (V <sub>SS</sub> = 0 V)             | 2.7                   | 5.5                   | V    |
|                                 | Dual supply operation (V <sub>SS</sub> = -V <sub>DD</sub> ) | 2.25                  | 2.75                  |      |
| V <sub>H</sub> , V <sub>L</sub> | Terminal voltage range                                      | V <sub>SS</sub>       | V <sub>DD</sub>       | V    |
| V <sub>IH</sub>                 | Digital input voltage high (SCL, SDA, A0, A1, A2)           | 0.7 × V <sub>DD</sub> | 5.5                   | V    |
| V <sub>IL</sub>                 | Digital input voltage low (SCL, SDA, A0, A1, A2)            | 0                     | 0.3 × V <sub>DD</sub> | V    |
| I <sub>W</sub>                  | Wiper current   |                       | ±2                    | mA   |
| T <sub>A</sub>                  | Ambient temperature   | -40                   | 85                    | °C   |

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |  | TPL0102    |             | UNIT |
|-------------------------------|--|------------|-------------|------|
|                               |  | PW (TSSOP) | RUC (X2QFN) |      |
|                               |  | 14 PINS    | 14 PINS     |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 112.9      | 119.4       | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 39.9       | 51.3        | °C/W |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 55.9       | 59.0        | °C/W |
| Ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 3.5        | 1.2         | °C/W |
| Ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 55.2       | 59.0        | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

## 6.5 Electrical Characteristics

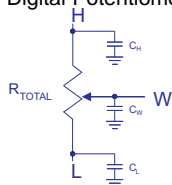
$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $V_{SS} = 0\text{ V}$ ,  $V_H = V_{DD}$ ,  $V_L = \text{GND}$ ,  $T_A = -40^\circ\text{C to }85^\circ\text{C}$  (unless otherwise noted). Typical values are at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted).

| PARAMETER                       |   | TEST CONDITIONS  | MIN   | TYP  | MAX  | UNIT                  |
|---------------------------------|---|--|-------|------|------|-----------------------|
| $R_{TOT}$                       | End-to-End resistance (Between H and L Terminals) |  | 80    | 100  | 120  | k $\Omega$            |
| $R_H, R_L$                      | Terminal resistance                               |  |       | 60   | 200  | $\Omega$              |
| $R_W$                           | Wiper resistance                                  |  |       | 25   | 100  | $\Omega$              |
| $C_H, C_L$ <sup>(1) (2)</sup>   | Terminal capacitance                              |  |       | 22   |      | pF                    |
| $C_W$ <sup>(1) (2)</sup>        | Wiper capacitance                                 |  |       | 16   |      | pF                    |
| $I_{LKG}$                       | Terminal leakage current                          | $V_H = V_{SS}$ to $V_{DD}$ , $V_L = \text{Floating}$<br>OR<br>$V_L = V_{SS}$ to $V_{DD}$ , $V_H = \text{Floating}$ |       | 0.1  | 1    | $\mu\text{A}$         |
| $TC_R$                          | Resistance temperature coefficient                | Input Code = 0x80h   |       | 92   |      | ppm/ $^\circ\text{C}$ |
| $R_{TOT, MATCH}$                | Channel-to-channel resistance match               |  |       | 0.1  |      | %                     |
| <b>Voltage Divider Mode</b>     |   |  |       |      |      |                       |
| $INL$ <sup>(3)(4)</sup>         | Integral non-linearity                            |  | -0.5  |      | 0.5  | LSB                   |
| $DNL$ <sup>(3)(5)</sup>         | Differential non-linearity                        |  | -0.25 |      | 0.25 | LSB                   |
| $ZS_{ERROR}$ <sup>(6)(7)</sup>  | Zero-scale error                                  |  | 0     | 0.1  | 2    | LSB                   |
| $FS_{ERROR}$ <sup>(6)(8)</sup>  | Full-scale error                                  |  | -2    | -0.1 | 0    | LSB                   |
| $MATCH_{VDM}$ <sup>(6)(9)</sup> | Channel-to-Channel matching                       | Wiper at the same tap position, same voltage at all H and same voltage at all L terminals                          | -2    |      | 2    | LSB                   |
| $TC_{VDM}$                      | Ratiometric temperature coefficient               | Wiper set at mid-scale   |       | 4    |      | ppm/ $^\circ\text{C}$ |
| BW                              | Bandwidth   | Wiper set at mid-scale<br>$C_{LOAD} = 10\text{ pF}$  |       | 229  |      | kHz                   |
| $t_{SW}$                        | Wiper setting time                                |  |       | 3.6  |      | $\mu\text{s}$         |
| THD                             | Total harmonic distortion                         | $V_H = 1\text{ V}_{RMS}$ at 1 kHz,<br>$V_L = (V_{DD} - V_{SS})/2$ ,<br>Measurement at pin W                        |       | 0.03 |      | %                     |
| $X_{TALK}$                      | Cross talk  | $f_H = 1\text{ kHz}$ ,<br>$V_L = \text{GND}$ ,<br>Measurement at pin W   |       | -82  |      | dB                    |

- (1) Terminal and Wiper Capacitance extracted from self admittance of three port network measurement

$$Y_{ii} = \frac{I_i}{V_i} \Big|_{V_k=0 \text{ for } k \neq i}$$

- (2) Digital Potentiometer Macromodel



- (3)  $LSB = (V_{MEAS[\text{code } 255]} - V_{MEAS[\text{code } 0]}) / 255$   
(4)  $INL = ((V_{MEAS[\text{code } x]} - V_{MEAS[\text{code } 0]}) / LSB) - [\text{code } x]$   
(5)  $DNL = ((V_{MEAS[\text{code } x]} - V_{MEAS[\text{code } x-1]}) / LSB) - 1$   
(6)  $IDEAL\_LSB = (V_H - V_L) / 256$   
(7)  $ZS_{ERROR} = V_{MEAS[\text{code } 0]} / IDEAL\_LSB$   
(8)  $FS_{ERROR} = ((V_{MEAS[\text{code } 255]} - (V_H - V_L)) / IDEAL\_LSB) + 1$   
(9)  $MATCH_{VDM} = (V_{MEAS\_A[\text{code } x]} - V_{MEAS\_B[\text{code } x]}) / IDEAL\_LSB$

### Electrical Characteristics (continued)

$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $V_{SS} = 0\text{ V}$ ,  $V_H = V_{DD}$ ,  $V_L = \text{GND}$ ,  $T_A = -40^\circ\text{C to }85^\circ\text{C}$  (unless otherwise noted). Typical values are at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted).

| PARAMETER   | TEST CONDITIONS             | MIN   | TYP | MAX | UNIT |
|---|-----------------------------|---|-----|-----|------|
| <b>RHEOSTAT MODE (Measurements between W and L with H not connected, or between W and H with L not connected)</b> |                             |   |     |     |      |
| RINL <sup>(10)(11)</sup>  | Integral non-linearity      | -1  |     | 1   | LSB  |
| RDNL <sup>(10)(12)</sup>  | Differential non-linearity  | -0.5  |     | 0.5 | LSB  |
| OFFSET <sub>RM</sub> <sup>(13)(14)</sup>  | Offset                      | 0   | 0.2 | 2   | LSB  |
| MATCH <sub>RM</sub> <sup>(13)(15)</sup>   | Channel-to-Channel matching | -2  |     | 2   | LSB  |
| BW  | Bandwidth                   | Code = 0x00h,<br>L Floating,<br>Input applied to W, Measure at H, C <sub>LOAD</sub> = 10 pF |     | 54  | kHz  |

- (10)  $RLSB = (R_{MEAS[code\ 255]} - R_{MEAS[code\ 0]}) / 255$
- (11)  $RINL = ((R_{MEAS[code\ x]} - R_{MEAS[code\ 0]}) / RLSB) - [code\ x]$
- (12)  $RDNL = ((R_{MEAS[code\ x]} - R_{MEAS[code\ x-1]}) / RLSB) - 1$
- (13)  $IDEAL\_RLSB = R_{TOT} / 256$
- (14)  $OFFSET_{RM} = R_{MEAS[code\ 0]} / IDEAL\_RLSB$
- (15)  $MATCH_{RM} = (R_{MEAS\_A[code\ x]} - R_{MEAS\_B[code\ x]}) / IDEAL\_RLSB$

### 6.6 Operating Characteristics

$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $V_{SS} = 0\text{ V}$ ,  $V_H = V_{DD}$ ,  $V_L = \text{GND}$ ,  $T_A = -40^\circ\text{C to }85^\circ\text{C}$  (unless otherwise noted). Typical values are at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted).

| PARAMETER                           | TEST CONDITIONS   | MIN   | TYP     | MAX | UNIT   |
|-------------------------------------|---|---|---------|-----|--------|
| I <sub>DD(STBY)</sub>               | V <sub>DD</sub> standby current                         |   | 0.2     | 1   | μA     |
| I <sub>SS(STBY)</sub>               | V <sub>SS</sub> standby current                         | -1  | -0.2    |     | μA     |
| I <sub>DD(SHUTDOWN)</sub>           | V <sub>DD</sub> shutdown current                        |   | 0.2     | 1   | μA     |
| I <sub>SS(SHUTDOWN)</sub>           | V <sub>SS</sub> shutdown current                        | -1  | -0.2    |     | μA     |
| I <sub>DD</sub>                     | V <sub>DD</sub> current during non-volatile write       |   | 200     |     | μA     |
| I <sub>SS</sub>                     | V <sub>SS</sub> current during non-volatile write       | -200  |         |     | μA     |
| I <sub>LKG(DIG)</sub>               | Digital pins leakage current (A0, A1, A2, SDA, and SCL) | -1  |         | 1   | μA     |
| V <sub>POR</sub>                    | Power-on recall voltage                                 |   | 23      |     | V      |
| <b>EEPROM Specification</b>         |   |   |         |     |        |
|                                     | EEPROM endurance  |   | 100 000 |     | Cycles |
|                                     | EEPROM retention  | T <sub>A</sub> = 85°C   | 100     |     | Years  |
| t <sub>WC</sub>                     | Non-volatile write cycle time                           |   | 20      |     | ms     |
| <b>Wiper Timing Characteristics</b> |   |   |         |     |        |
| t <sub>(WRT)</sub>                  | Wiper response time                                     | SCL falling edge of last bit of wiper data byte to wiper new position   |         | 600 | ns     |
| t <sub>(SR)</sub>                   | Wiper position recall time from shut-down mode          | SCL falling edge of last bit of ACR data byte to wiper stored position and H connection   |         | 800 | ns     |
| t <sub>(D)</sub>                    | Power-up delay  | V <sub>DD</sub> above V <sub>POR</sub> , to wiper initial value register recall completed, and I <sup>2</sup> C interface in standby mode |         | 35  | 100    |
| C <sub>(PIN)</sub>                  | Pin capacitance   | A0, A1, A2, SDA, SCL pins   |         | 7   | pF     |

## Operating Characteristics (continued)

$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $V_{SS} = 0\text{ V}$ ,  $V_H = V_{DD}$ ,  $V_L = \text{GND}$ ,  $T_A = -40^\circ\text{C to }85^\circ\text{C}$  (unless otherwise noted). Typical values are at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted).

| PARAMETER                                      | TEST CONDITIONS    | MIN                             | TYP                 | MAX | UNIT |    |
|--|--------------------|---------------------------------|---------------------|-----|------|----|
| <b>I<sup>2</sup>C Interface Specifications</b> |                    |                                 |                     |     |      |    |
| $V_{IH}$                                       | Input high voltage | $0.7 \times V_{DD}$             |                     | 5.5 | V    |    |
| $V_{IL}$                                       | Input low voltage  | 0                               | $0.3 \times V_{DD}$ |     | V    |    |
| $V_{OL}$                                       | Output low voltage | SDA pin, $I_{OL} = 4\text{ mA}$ |                     |     | 0.4  | V  |
| $C_{IN}$                                       | Pin capacitance    | A0, A1, A2, SDA, SCL pins       |                     |     | 7    | pF |

## 6.7 Timing Requirements

$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $V_{SS} = 0\text{ V}$ ,  $V_H = V_{DD}$ ,  $V_L = \text{GND}$ ,  $T_A = -40^\circ\text{C to }85^\circ\text{C}$  (unless otherwise noted). Typical values are at  $V_{DD} = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted).

|   |  | STANDARD MODE I <sup>2</sup> C BUS |      | FAST MODE I <sup>2</sup> C BUS |     | UNIT |
|---|--|------------------------------------|------|--------------------------------|-----|------|
|   |  | MIN                                | MAX  | MIN                            | MAX |      |
| <b>I<sup>2</sup>C Interface Timing Requirements</b> |  |                                    |      |                                |     |      |
| $f_{SCL}$   | I <sup>2</sup> C clock frequency   | 0                                  | 100  | 0                              | 400 | kHz  |
| $t_{SCH}$   | I <sup>2</sup> C clock high time   | 4                                  |      | 0.6                            |     | μs   |
| $t_{SCL}$   | I <sup>2</sup> C clock low time  | 4.7                                |      | 1.3                            |     | μs   |
| $t_{sp}$  | I <sup>2</sup> C spike time  | 0                                  | 50   | 0                              | 50  | ns   |
| $t_{SDS}$   | I <sup>2</sup> C serial data setup time                                    | 250                                |      | 100                            |     | ns   |
| $t_{SDH}$   | I <sup>2</sup> C serial data hold time                                     | 0                                  |      | 0                              |     | ns   |
| $t_{ICR}$   | I <sup>2</sup> C input rise time   |                                    | 1000 | $20 + 0.1C_b^{(1)}$            | 300 | ns   |
| $t_{ICF}$   | I <sup>2</sup> C input fall time   |                                    | 300  | $20 + 0.1C_b^{(1)}$            | 300 | ns   |
| $t_{ICF}$   | I <sup>2</sup> C output fall time, 10 pF to 400 pF bus                     |                                    | 300  | $20 + 0.1C_b^{(1)}$            | 300 | ns   |
| $t_{BUF}$   | I <sup>2</sup> C bus free time between stop and start                      | 4.7                                |      | 1.3                            |     | μs   |
| $t_{STS}$   | I <sup>2</sup> C start or repeater start condition setup time              | 4.7                                |      | 1.3                            |     | μs   |
| $t_{STH}$   | I <sup>2</sup> C start or repeater start condition hold time               | 4                                  |      | 0.6                            |     | μs   |
| $t_{SPS}$   | I <sup>2</sup> C stop condition setup time                                 | 4                                  |      | 0.6                            |     | μs   |
| $t_{VD(DATA)}$                                      | Valid data time, SCL low to SDA output valid                               |                                    | 1    |                                | 1   | μs   |
| $3t_{VD(ACK)}$                                      | Valid data time of ACK condition, ACK signal from SCL low to SDA (out) low |                                    | 1    |                                | 1   | μs   |

(1)  $C_b$  = total capacitance of one bus line in pF

### 6.8 Typical Characteristics

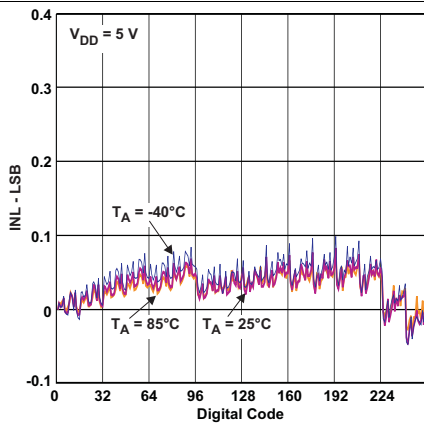


Figure 1. Voltage Divider Mode INL vs Digital Code ( $V_{DD} = 5$  V)

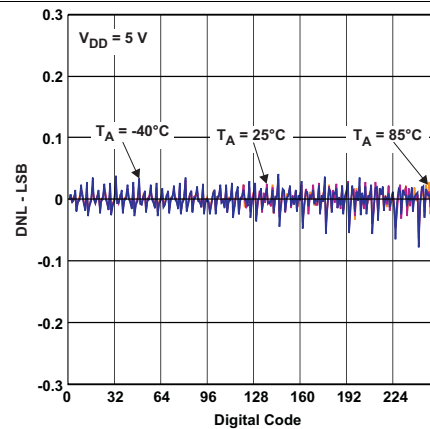


Figure 2. Voltage Divider Mode DNL vs Digital Code ( $V_{DD} = 5$  V)

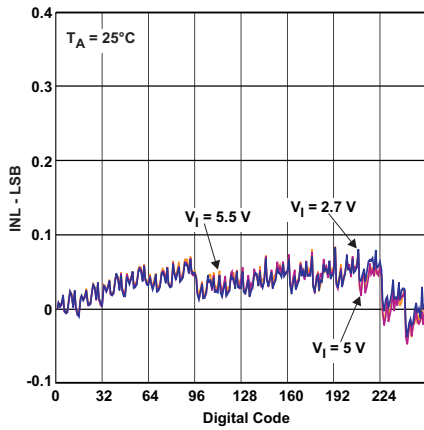


Figure 3. Voltage Divider Mode INL vs Digital Code (25°C)

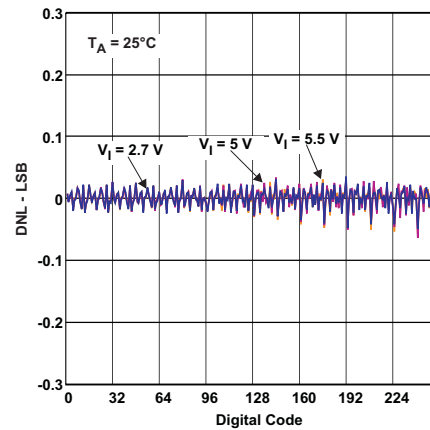


Figure 4. Voltage Divider Mode DNL vs Digital Code (25°C)

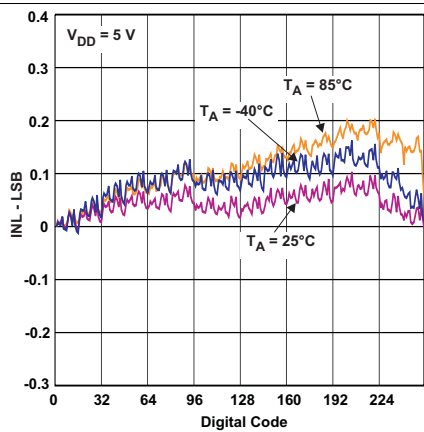


Figure 5. Rheostat Mode RINL vs Digital Code ( $V_{DD} = 5$  V)

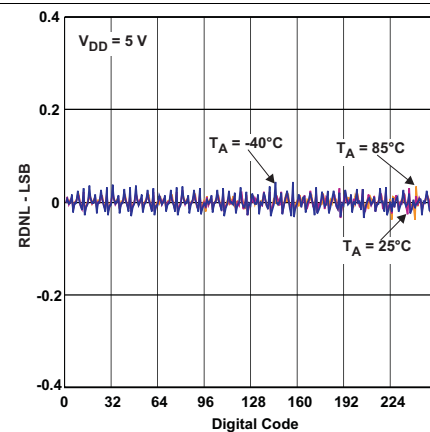


Figure 6. Rheostat Mode RDNL vs Digital Code ( $V_{DD} = 5$  V)



Typical Characteristics (continued)

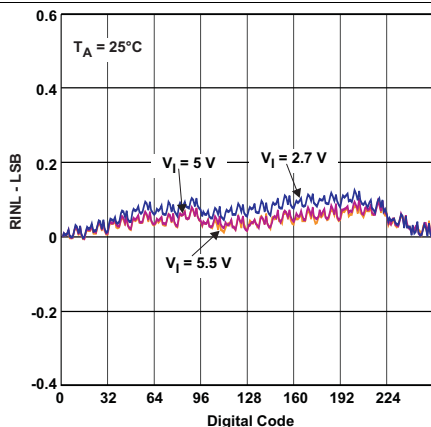


Figure 7. Rheostat Mode RINL vs Digital Code (25°C)

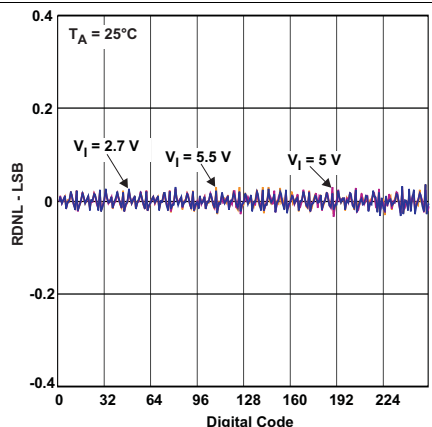


Figure 8. Rheostat Mode RDNL vs Digital Code (25°C)

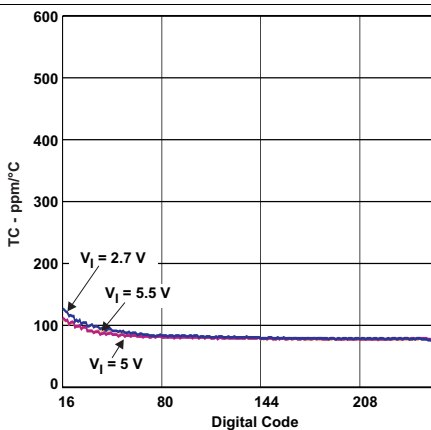


Figure 9. Rheostat Mode TC<sub>R</sub> vs Digital Code

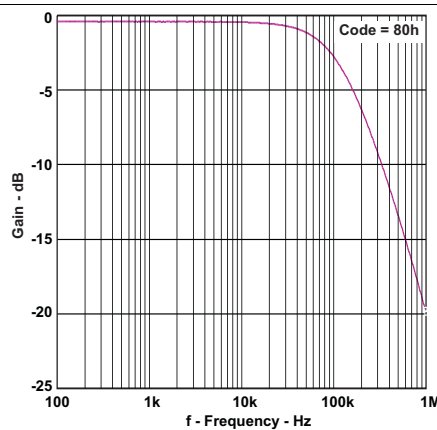


Figure 10. Rheostat Mode Gain vs Frequency

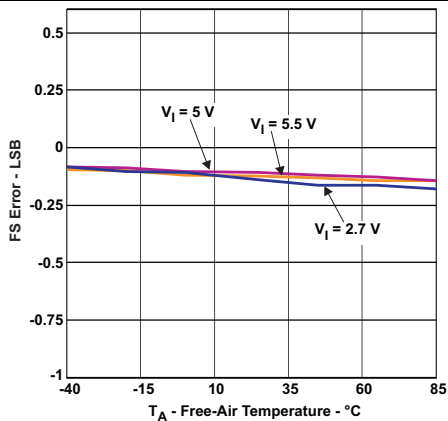


Figure 11. Voltage Divider Mode FS Error vs Temperature

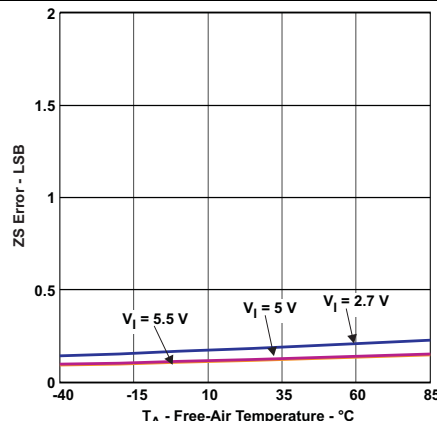


Figure 12. Voltage Divider Mode ZS Error vs Temperature

Typical Characteristics (continued)

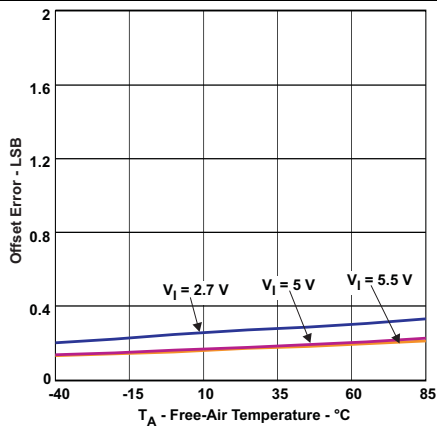


Figure 13. Rheostat Mode Offset Error vs Temperature

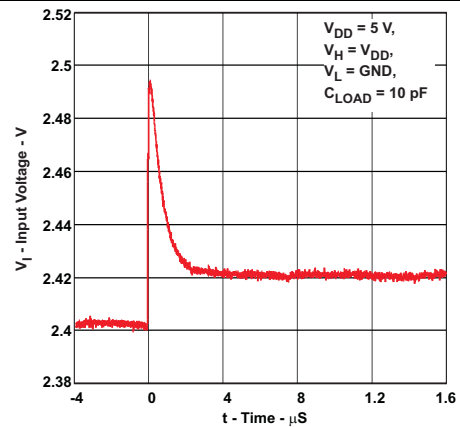


Figure 14. Midscale Wiper Glitch (0x7Fh to 0x80h)

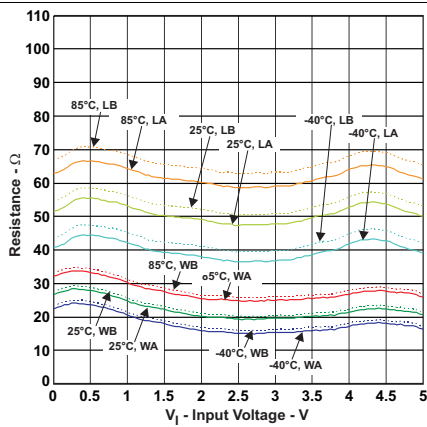


Figure 15. Wiper to Low Terminal Resistance ( $V_{DD} = 5 V$ )

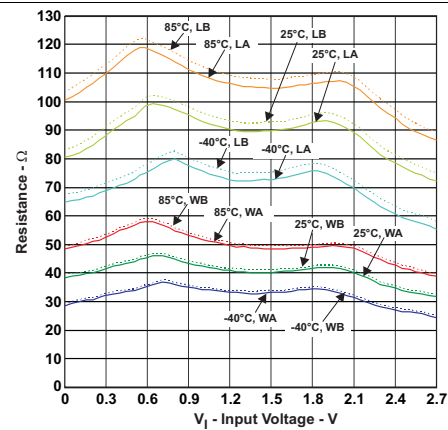


Figure 16. Wiper to Low Terminal Resistance ( $V_{DD} = 2.7 V$ )

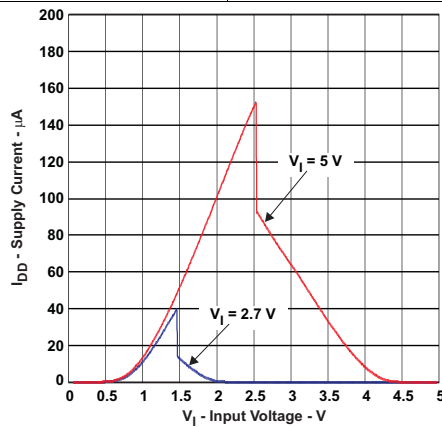


Figure 17. Supply Current vs Digital Input Voltage

## 7 Detailed Description

### 7.1 Overview

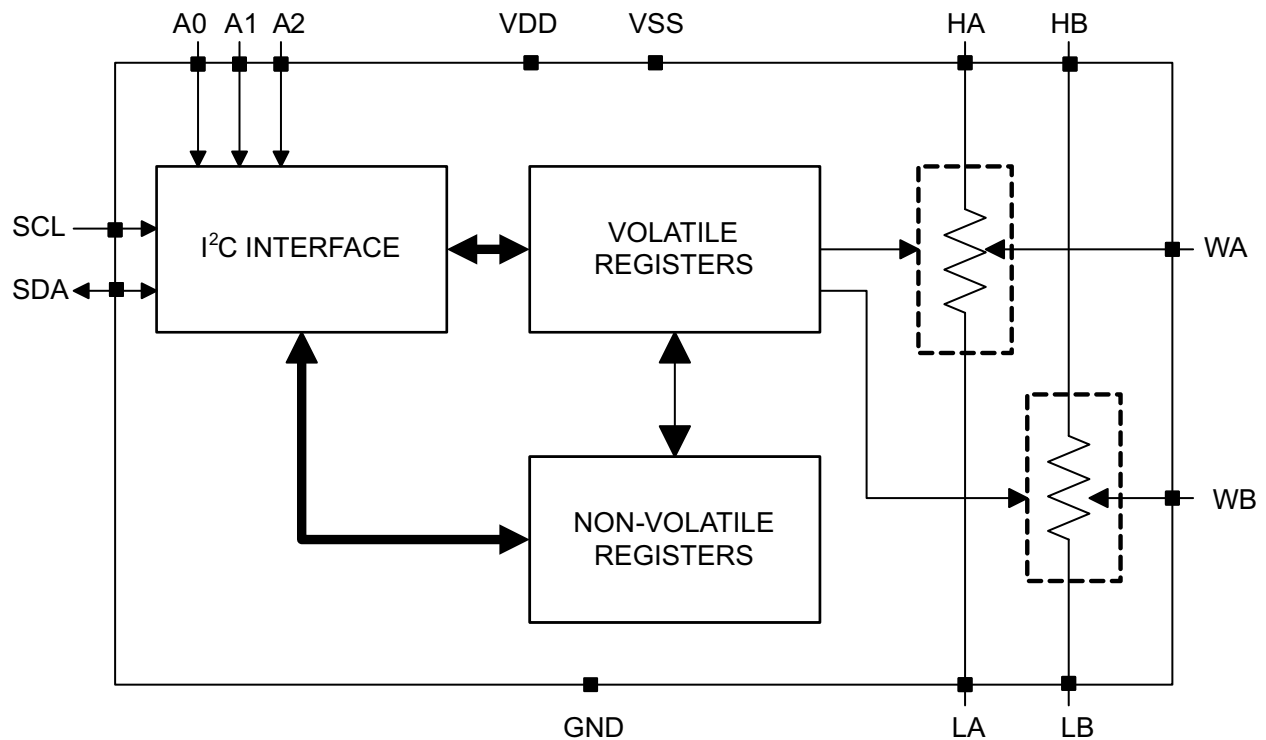
The TPL0102 has two linear-taper digital potentiometers with 256 wiper positions and an end-to-end resistance of 100 k $\Omega$ . Each potentiometer can be used as a three-terminal potentiometer or as a two-terminal rheostat. The two potentiometers can both be used in Voltage Divider Mode, Rheostat Mode, or Shutdown Mode at the same time, or any combination of those modes. For example, potentiometer A can be used in Voltage Divider Mode and potentiometer B can be used in Voltage Divider Mode, or potentiometer A can be used in Voltage Divider Mode and potentiometer B can be used in Rheostat Mode. The two potentiometers are functionally independent of one another.

The High (H) and Low (L) terminals of the TPL0102 are equivalent to the fixed terminals of a mechanical potentiometer. The H and L terminals do not have any polarity restrictions (H can be at a higher voltage than L, or L can be at a higher voltage than H). The position of the wiper (W) terminal is controlled by the value in the Wiper Resistance (WR) 8-bit register. When the WR register contains all zeroes (zero-scale), the wiper terminal is closest to its L terminal. As the value of the WR register increases from all zeroes to all ones (full-scale), the wiper moves monotonically from the position closest to L terminal to the position closest to the H terminal. At the same time, the resistance between W and L increases monotonically, whereas the resistance between W and H decreases monotonically.

The TPL0102 has non-volatile memory (EEPROM) which can be used to store the wiper position. When the device is powered down, the last value stored in the Initial Value Register (IVR) will be maintained in the non-volatile memory. When power is restored, the contents of the IVR are automatically recalled and loaded into the corresponding WR register to set the wipers. The internal registers of the TPL0102 can be accessed using the I<sup>2</sup>C interface. The factory-programmed default value for the IVR upon power up is 0x80h (1000 0000). The WR register can be written to directly without first writing to the IVR, depending upon the setting of the volatile memory (VOL) in the [ACR \(Access Control Register\)](#). If the WR register is written to directly without writing to the IVR as well, this results in the wiper position changing to a desired position, but the position will not be stored in memory and will not be reloaded upon powering up the device.

With one TPL0102, a variable resistor with 512 settings can be used since there are two potentiometers in one TPL0102. In order to achieve this, the two potentiometers should be in Rheostat Mode and wired so that terminal L of potentiometer B is tied to terminal W of potentiometer A. This will provide 512 settings between terminal L of potentiometer A and terminal W of potentiometer B.

## 7.2 Functional Block Diagram



## 7.3 Feature Description

The TPL0102 has two linear-taper digital potentiometers (DPOTs) with 256 wiper positions. Each potentiometer can be used as a three-terminal potentiometer or a two-terminal rheostat. The TPL0102-100 has an end-to-end resistance of 100 k $\Omega$  with a 20% end-to-end resistance tolerance. Non-volatile memory (EEPROM) can be used to store the wiper position allowing the wiper position to be stored even during power-off and automatically reinstated after power-on. The internal registers of the TPL0102 can be accessed using the I<sup>2</sup>C digital interface. The TPL0102 is available in a 14-pin MicroQFN (2.00 mm x 2.00 mm) and 14-pin TSSOP package.

## 7.4 Device Functional Modes

### 7.4.1 Shutdown Mode

The TPL0102 can be put in Shutdown Mode by executing the proper command in the *ACR (Access Control Register)*. Please see the *TPL0102 Register Map* for more details. When active, this feature causes terminal H to become high impedance.

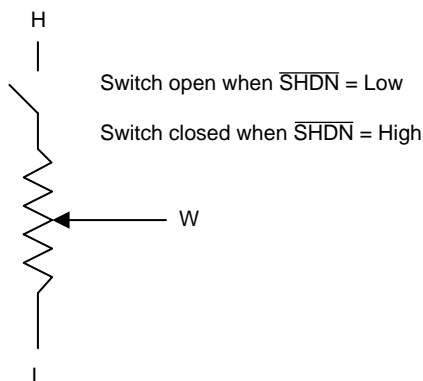


Figure 18. Equivalent Circuit for Shutdown Mode

### 7.4.2 Voltage Divider Mode

The digital potentiometer generates a voltage divider when all three terminals are used. The voltage divider at wiper-to-H and wiper-to-L is proportional to the input voltage at H to L.

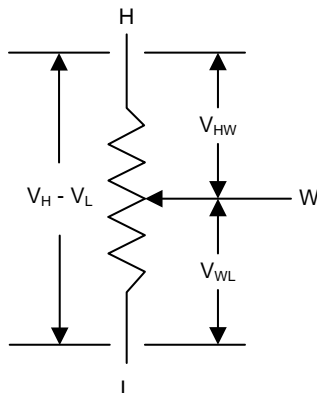


Figure 19. Equivalent Circuit for Voltage Divider Mode

For example, connecting terminal H to 5 V and terminal L to ground, the output voltage at terminal W can range from 0 V to 5 V. The general equation defining the output voltage at terminal W for any valid input voltage applied to terminal H and terminal L is

$$V_W = V_{WL} = (V_H - V_L) \times \frac{D}{256} \quad (1)$$

The voltage difference between terminal H and terminal W can also be calculated

$$V_{HW} = (V_H - V_L) \times \left(1 - \left(\frac{D}{256}\right)\right)$$

where

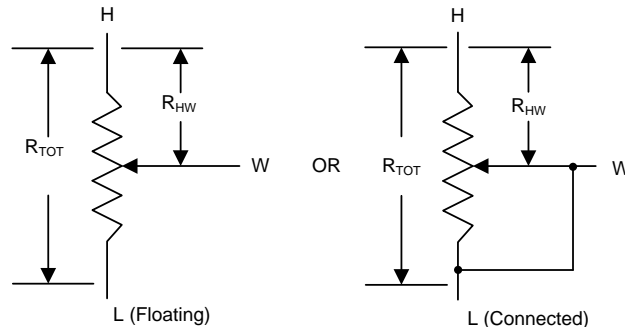
- D is the decimal value of the wiper code. (2)

## Device Functional Modes (continued)

### 7.4.3 Rheostat Mode

The TPL0102 operates in rheostat mode when only two terminals are used as a variable resistor. The variable resistance can either be between terminal H and terminal W or between terminal L and terminal W. The unused terminal can be left floating or it can be tied to terminal W. The nominal resistance between terminal H and terminal L is 100 kΩ and has 256 tap points accessed by the wiper terminal. The 8-bit volatile register value is used to determine one of the 256 possible wiper positions.

In rheostat mode, to set the resistance between terminal H and terminal W, the potentiometer can be configured in two possible ways.



**Figure 20. Equivalent Circuit for Rheostat Mode with Terminal H to Terminal W Resistance**

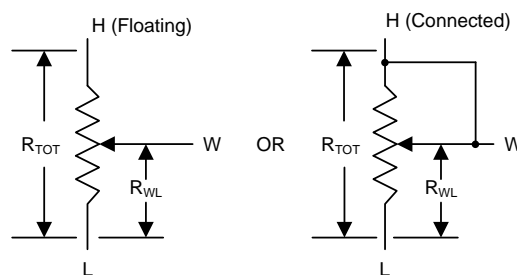
The general equation for determining the digitally programmed output resistance between Terminal H and Terminal W is:

$$R_{HW} = R_{TOT} \times \left( 1 - \left( \frac{D}{256} \right) \right)$$

where

- $R_{TOT}$  is the end-to-end resistance between terminal H and terminal L.
- D is the decimal value of the wiper code. (3)

Similarly, to set the resistance between terminal L and terminal W, the potentiometer can be configured in two possible ways.



**Figure 21. Equivalent Circuit for Rheostat Mode with Terminal L to Terminal W Resistance**

The general equation for determining the digitally programmed output resistance between terminal L and terminal W is

$$R_{WL} = R_{TOT} \times \frac{D}{256}$$

where

- $R_{TOT}$  is the end-to-end resistance between terminal H and terminal L.
- D is the decimal value of the wiper code. (4)

## Device Functional Modes (continued)

The following table shows the ideal values for DPOT with End-to End resistance of 100 kΩ. The absolute values of resistance can vary significantly but the Ratio ( $R_{WL}/R_{HW}$ ) is extremely accurate.

The linearity values are "relative" linearity values (i.e. linearity after zero-scale and full-scale offset errors are removed). Please take this into account when expecting a certain absolute accuracy since some error will be introduced once you get close in magnitude to the offset errors.

| Step           | Hex   | Binary    | $R_{WL}$ (kΩ) | $R_{HW}$ (kΩ) | $R_{WL}/R_{HW}$ |
|----------------|-------|-----------|---------------|---------------|-----------------|
| 0 (zero-scale) | 0x00h | 0000 0000 | 0.00          | 100.00        | 0.00            |
| 1              | 0x01h | 0000 0001 | 0.39          | 99.61         | 0.00            |
| 2              | 0x02h | 0000 0010 | 0.78          | 99.22         | 0.01            |
| 3              | 0x03h | 0000 0011 | 1.17          | 98.83         | 0.01            |
| 4              | 0x04h | 0000 0100 | 1.56          | 98.44         | 0.02            |
| 5              | 0x05h | 0000 0101 | 1.95          | 98.05         | 0.02            |
| 6              | 0x06h | 0000 0110 | 2.34          | 97.66         | 0.02            |
| 7              | 0x07h | 0000 0111 | 2.73          | 97.27         | 0.03            |
| 8              | 0x08h | 0000 1000 | 3.13          | 96.88         | 0.03            |
| 9              | 0x09h | 0000 1001 | 3.52          | 96.48         | 0.04            |
| 10             | 0x0Ah | 0000 1010 | 3.91          | 96.09         | 0.04            |
| 11             | 0x0Bh | 0000 1011 | 4.30          | 95.70         | 0.04            |
| 12             | 0x0Ch | 0000 1100 | 4.69          | 95.31         | 0.05            |
| 13             | 0x0Dh | 0000 1101 | 5.08          | 94.92         | 0.05            |
| 14             | 0x0Eh | 0000 1110 | 5.47          | 94.53         | 0.06            |
| 15             | 0x0Fh | 0000 1111 | 5.86          | 94.14         | 0.06            |
| 16             | 0x10h | 0001 0000 | 6.25          | 93.75         | 0.07            |
| 17             | 0x11h | 0001 0001 | 6.64          | 93.36         | 0.07            |
| 18             | 0x12h | 0001 0010 | 7.03          | 92.97         | 0.08            |
| 19             | 0x13h | 0001 0011 | 7.42          | 92.58         | 0.08            |
| 20             | 0x14h | 0001 0100 | 7.81          | 92.19         | 0.08            |
| 21             | 0x15h | 0001 0101 | 8.20          | 91.80         | 0.09            |
| 22             | 0x16h | 0001 0110 | 8.59          | 91.41         | 0.09            |
| 23             | 0x17h | 0001 0111 | 8.98          | 91.02         | 0.10            |
| 24             | 0x18h | 0001 1000 | 9.38          | 90.63         | 0.10            |
| 25             | 0x19h | 0001 1001 | 9.77          | 90.23         | 0.11            |
| 26             | 0x1Ah | 0001 1010 | 10.16         | 89.84         | 0.11            |
| 27             | 0x1Bh | 0001 1011 | 10.55         | 89.45         | 0.12            |
| 28             | 0x1Ch | 0001 1100 | 10.94         | 89.06         | 0.12            |
| 29             | 0x1Dh | 0001 1101 | 11.33         | 88.67         | 0.13            |
| 30             | 0x1Eh | 0001 1110 | 11.72         | 88.28         | 0.13            |
| 31             | 0x1Fh | 0001 1111 | 12.11         | 87.89         | 0.14            |
| 32             | 0x20h | 0010 0000 | 12.50         | 87.50         | 0.14            |
| 33             | 0x21h | 0010 0001 | 12.89         | 87.11         | 0.15            |
| 34             | 0x22h | 0010 0010 | 13.28         | 86.72         | 0.15            |
| 35             | 0x23h | 0010 0011 | 13.67         | 86.33         | 0.16            |
| 36             | 0x24h | 0010 0100 | 14.06         | 85.94         | 0.16            |
| 37             | 0x25h | 0010 0101 | 14.45         | 85.55         | 0.17            |
| 38             | 0x26h | 0010 0110 | 14.84         | 85.16         | 0.17            |
| 39             | 0x27h | 0010 0111 | 15.23         | 84.77         | 0.18            |
| 40             | 0x28h | 0010 1000 | 15.63         | 84.38         | 0.19            |
| 41             | 0x29h | 0010 1001 | 16.02         | 83.98         | 0.19            |

**TPL0102**

ZHCSE79C – MARCH 2011 – REVISED SEPTEMBER 2015

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| Step | Hex   | Binary    | R <sub>WL</sub> (kΩ) | R <sub>HW</sub> (kΩ) | R <sub>WL</sub> /R <sub>HW</sub> |
|------|-------|-----------|----------------------|----------------------|----------------------------------|
| 42   | 0x2Ah | 0010 1010 | 16.41                | 83.59                | 0.20                             |
| 43   | 0x2Bh | 0010 1011 | 16.80                | 83.20                | 0.20                             |
| 44   | 0x2Ch | 0010 1100 | 17.19                | 82.81                | 0.21                             |
| 45   | 0x2Dh | 0010 1101 | 17.58                | 82.42                | 0.21                             |
| 46   | 0x2Eh | 0010 1110 | 17.97                | 82.03                | 0.22                             |
| 47   | 0x2Fh | 0010 1111 | 18.36                | 81.64                | 0.22                             |
| 48   | 0x30h | 0011 0000 | 18.75                | 81.25                | 0.23                             |
| 49   | 0x31h | 0011 0001 | 19.14                | 80.86                | 0.24                             |
| 50   | 0x32h | 0011 0010 | 19.53                | 80.47                | 0.24                             |
| 51   | 0x33h | 0011 0011 | 19.92                | 80.08                | 0.25                             |
| 52   | 0x34h | 0011 0100 | 20.31                | 79.69                | 0.25                             |
| 53   | 0x35h | 0011 0101 | 20.70                | 79.30                | 0.26                             |
| 54   | 0x36h | 0011 0110 | 21.09                | 78.91                | 0.27                             |
| 55   | 0x37h | 0011 0111 | 21.48                | 78.52                | 0.27                             |
| 56   | 0x38h | 0011 1000 | 21.88                | 78.13                | 0.28                             |
| 57   | 0x39h | 0011 1001 | 22.27                | 77.73                | 0.29                             |
| 58   | 0x3Ah | 0011 1010 | 22.66                | 77.34                | 0.29                             |
| 59   | 0x3Bh | 0011 1011 | 23.05                | 76.95                | 0.30                             |
| 60   | 0x3Ch | 0011 1100 | 23.44                | 76.56                | 0.31                             |
| 61   | 0x3Dh | 0011 1101 | 23.83                | 76.17                | 0.31                             |
| 62   | 0x3Eh | 0011 1110 | 24.22                | 75.78                | 0.32                             |
| 63   | 0x3Fh | 0011 1111 | 24.61                | 75.39                | 0.33                             |
| 64   | 0x40h | 0100 0000 | 25.00                | 75.00                | 0.33                             |
| 65   | 0x41h | 0100 0001 | 25.39                | 74.61                | 0.34                             |
| 66   | 0x42h | 0100 0010 | 25.78                | 74.22                | 0.35                             |
| 67   | 0x43h | 0100 0011 | 26.17                | 73.83                | 0.35                             |
| 68   | 0x44h | 0100 0100 | 26.56                | 73.44                | 0.36                             |
| 69   | 0x45h | 0100 0101 | 26.95                | 73.05                | 0.37                             |
| 70   | 0x46h | 0100 0110 | 27.34                | 72.66                | 0.38                             |
| 71   | 0x47h | 0100 0111 | 27.73                | 72.27                | 0.38                             |
| 72   | 0x48h | 0100 1000 | 28.13                | 71.88                | 0.39                             |
| 73   | 0x49h | 0100 1001 | 28.52                | 71.48                | 0.40                             |
| 74   | 0x4Ah | 0100 1010 | 28.91                | 71.09                | 0.41                             |
| 75   | 0x4Bh | 0100 1011 | 29.30                | 70.70                | 0.41                             |
| 76   | 0x4Ch | 0100 1100 | 29.69                | 70.31                | 0.42                             |
| 77   | 0x4Dh | 0100 1101 | 30.08                | 69.92                | 0.43                             |
| 78   | 0x4Eh | 0100 1110 | 30.47                | 69.53                | 0.44                             |
| 79   | 0x4Fh | 0100 1111 | 30.86                | 69.14                | 0.45                             |
| 80   | 0x50h | 0101 0000 | 31.25                | 68.75                | 0.45                             |
| 81   | 0x51h | 0101 0001 | 31.64                | 68.36                | 0.46                             |
| 82   | 0x52h | 0101 0010 | 32.03                | 67.97                | 0.47                             |
| 83   | 0x53h | 0101 0011 | 32.42                | 67.58                | 0.48                             |
| 84   | 0x54h | 0101 0100 | 32.81                | 67.19                | 0.49                             |
| 85   | 0x55h | 0101 0101 | 33.20                | 66.80                | 0.50                             |
| 86   | 0x56h | 0101 0110 | 33.59                | 66.41                | 0.51                             |
| 87   | 0x57h | 0101 0111 | 33.98                | 66.02                | 0.51                             |
| 88   | 0x58h | 0101 1000 | 34.38                | 65.63                | 0.52                             |
| 89   | 0x59h | 0101 1001 | 34.77                | 65.23                | 0.53                             |
| 90   | 0x5Ah | 0101 1010 | 35.16                | 64.84                | 0.54                             |



| Step | Hex   | Binary    | R <sub>WL</sub> (kΩ) | R <sub>HW</sub> (kΩ) | R <sub>WL</sub> /R <sub>HW</sub> |
|------|-------|-----------|----------------------|----------------------|----------------------------------|
| 91   | 0x5Bh | 0101 1011 | 35.55                | 64.45                | 0.55                             |
| 92   | 0x5Ch | 0101 1100 | 35.94                | 64.06                | 0.56                             |
| 93   | 0x5Dh | 0101 1101 | 36.33                | 63.67                | 0.57                             |
| 94   | 0x5Eh | 0101 1110 | 36.72                | 63.28                | 0.58                             |
| 95   | 0x5Fh | 0101 1111 | 37.11                | 62.89                | 0.59                             |
| 96   | 0x60h | 0110 0000 | 37.50                | 62.50                | 0.60                             |
| 97   | 0x61h | 0110 0001 | 37.89                | 62.11                | 0.61                             |
| 98   | 0x62h | 0110 0010 | 38.28                | 61.72                | 0.62                             |
| 99   | 0x63h | 0110 0011 | 38.67                | 61.33                | 0.63                             |
| 100  | 0x64h | 0110 0100 | 39.06                | 60.94                | 0.64                             |
| 101  | 0x65h | 0110 0101 | 39.45                | 60.55                | 0.65                             |
| 102  | 0x66h | 0110 0110 | 39.84                | 60.16                | 0.66                             |
| 103  | 0x67h | 0110 0111 | 40.23                | 59.77                | 0.67                             |
| 104  | 0x68h | 0110 1000 | 40.63                | 59.38                | 0.68                             |
| 105  | 0x69h | 0110 1001 | 41.02                | 58.98                | 0.70                             |
| 106  | 0x6Ah | 0110 1010 | 41.41                | 58.59                | 0.71                             |
| 107  | 0x6Bh | 0110 1011 | 41.80                | 58.20                | 0.72                             |
| 108  | 0x6Ch | 0110 1100 | 42.19                | 57.81                | 0.73                             |
| 109  | 0x6Dh | 0110 1101 | 42.58                | 57.42                | 0.74                             |
| 110  | 0x6Eh | 0110 1110 | 42.97                | 57.03                | 0.75                             |
| 111  | 0x6Fh | 0110 1111 | 43.36                | 56.64                | 0.77                             |
| 112  | 0x70h | 0111 0000 | 43.75                | 56.25                | 0.78                             |
| 113  | 0x71h | 0111 0001 | 44.14                | 55.86                | 0.79                             |
| 114  | 0x72h | 0111 0010 | 44.53                | 55.47                | 0.80                             |
| 115  | 0x73h | 0111 0011 | 44.92                | 55.08                | 0.82                             |
| 116  | 0x74h | 0111 0100 | 45.31                | 54.69                | 0.83                             |
| 117  | 0x75h | 0111 0101 | 45.70                | 54.30                | 0.84                             |
| 118  | 0x76h | 0111 0110 | 46.09                | 53.91                | 0.86                             |
| 119  | 0x77h | 0111 0111 | 46.48                | 53.52                | 0.87                             |
| 120  | 0x78h | 0111 1000 | 46.88                | 53.13                | 0.88                             |
| 121  | 0x79h | 0111 1001 | 47.27                | 52.73                | 0.90                             |
| 122  | 0x7Ah | 0111 1010 | 47.66                | 52.34                | 0.91                             |
| 123  | 0x7Bh | 0111 1011 | 48.05                | 51.95                | 0.92                             |
| 124  | 0x7Ch | 0111 1100 | 48.44                | 51.56                | 0.94                             |
| 125  | 0x7Dh | 0111 1101 | 48.83                | 51.17                | 0.95                             |
| 126  | 0x7Eh | 0111 1110 | 49.22                | 50.78                | 0.97                             |
| 127  | 0x7Fh | 0111 1111 | 49.61                | 50.39                | 0.98                             |
| 128  | 0x80h | 1000 0000 | 50.00                | 50.00                | 1.00                             |
| 129  | 0x81h | 1000 0001 | 50.39                | 49.61                | 1.02                             |
| 130  | 0x82h | 1000 0010 | 50.78                | 49.22                | 1.03                             |
| 131  | 0x83h | 1000 0011 | 51.17                | 48.83                | 1.05                             |
| 132  | 0x84h | 1000 0100 | 51.56                | 48.44                | 1.06                             |
| 133  | 0x85h | 1000 0101 | 51.95                | 48.05                | 1.08                             |
| 134  | 0x86h | 1000 0110 | 52.34                | 47.66                | 1.10                             |
| 135  | 0x87h | 1000 0111 | 52.73                | 47.27                | 1.12                             |
| 136  | 0x88h | 1000 1000 | 53.13                | 46.88                | 1.13                             |
| 137  | 0x89h | 1000 1001 | 53.52                | 46.48                | 1.15                             |
| 138  | 0x8Ah | 1000 1010 | 53.91                | 46.09                | 1.17                             |
| 139  | 0x8Bh | 1000 1011 | 54.30                | 45.70                | 1.19                             |

| Step | Hex   | Binary    | R <sub>WL</sub> (kΩ) | R <sub>HW</sub> (kΩ) | R <sub>WL</sub> /R <sub>HW</sub> |
|------|-------|-----------|----------------------|----------------------|----------------------------------|
| 140  | 0x8Ch | 1000 1100 | 54.69                | 45.31                | 1.21                             |
| 141  | 0x8Dh | 1000 1101 | 55.08                | 44.92                | 1.23                             |
| 142  | 0x8Eh | 1000 1110 | 55.47                | 44.53                | 1.25                             |
| 143  | 0x8Fh | 1000 1111 | 55.86                | 44.14                | 1.27                             |
| 144  | 0x90h | 1001 0000 | 56.25                | 43.75                | 1.29                             |
| 145  | 0x91h | 1001 0001 | 56.64                | 43.36                | 1.31                             |
| 146  | 0x92h | 1001 0010 | 57.03                | 42.97                | 1.33                             |
| 147  | 0x93h | 1001 0011 | 57.42                | 42.58                | 1.35                             |
| 148  | 0x94h | 1001 0100 | 57.81                | 42.19                | 1.37                             |
| 149  | 0x95h | 1001 0101 | 58.20                | 41.80                | 1.39                             |
| 150  | 0x96h | 1001 0110 | 58.59                | 41.41                | 1.42                             |
| 151  | 0x97h | 1001 0111 | 58.98                | 41.02                | 1.44                             |
| 152  | 0x98h | 1001 1000 | 59.38                | 40.63                | 1.46                             |
| 153  | 0x99h | 1001 1001 | 59.77                | 40.23                | 1.49                             |
| 154  | 0x9Ah | 1001 1010 | 60.16                | 39.84                | 1.51                             |
| 155  | 0x9Bh | 1001 1011 | 60.55                | 39.45                | 1.53                             |
| 156  | 0x9Ch | 1001 1100 | 60.94                | 39.06                | 1.56                             |
| 157  | 0x9Dh | 1001 1101 | 61.33                | 38.67                | 1.59                             |
| 158  | 0x9Eh | 1001 1110 | 61.72                | 38.28                | 1.61                             |
| 159  | 0x9Fh | 1001 1111 | 62.11                | 37.89                | 1.64                             |
| 160  | 0xA0h | 1010 0000 | 62.50                | 37.50                | 1.67                             |
| 161  | 0xA1h | 1010 0001 | 62.89                | 37.11                | 1.69                             |
| 162  | 0xA2h | 1010 0010 | 63.28                | 36.72                | 1.72                             |
| 163  | 0xA3h | 1010 0011 | 63.67                | 36.33                | 1.75                             |
| 164  | 0xA4h | 1010 0100 | 64.06                | 35.94                | 1.78                             |
| 165  | 0xA5h | 1010 0101 | 64.45                | 35.55                | 1.81                             |
| 166  | 0xA6h | 1010 0110 | 64.84                | 35.16                | 1.84                             |
| 167  | 0xA7h | 1010 0111 | 65.23                | 34.77                | 1.88                             |
| 168  | 0xA8h | 1010 1000 | 65.63                | 34.38                | 1.91                             |
| 169  | 0xA9h | 1010 1001 | 66.02                | 33.98                | 1.94                             |
| 170  | 0xAAh | 1010 1010 | 66.41                | 33.59                | 1.98                             |
| 171  | 0xABh | 1010 1011 | 66.80                | 33.20                | 2.01                             |
| 172  | 0xACh | 1010 1100 | 67.19                | 32.81                | 2.05                             |
| 173  | 0xADh | 1010 1101 | 67.58                | 32.42                | 2.08                             |
| 174  | 0xAEh | 1010 1110 | 67.97                | 32.03                | 2.12                             |
| 175  | 0xAFh | 1010 1111 | 68.36                | 31.64                | 2.16                             |
| 176  | 0xB0h | 1011 0000 | 68.75                | 31.25                | 2.20                             |
| 177  | 0xB1h | 1011 0001 | 69.14                | 30.86                | 2.24                             |
| 178  | 0xB2h | 1011 0010 | 69.53                | 30.47                | 2.28                             |
| 179  | 0xB3h | 1011 0011 | 69.92                | 30.08                | 2.32                             |
| 180  | 0xB4h | 1011 0100 | 70.31                | 29.69                | 2.37                             |
| 181  | 0xB5h | 1011 0101 | 70.70                | 29.30                | 2.41                             |
| 182  | 0xB6h | 1011 0110 | 71.09                | 28.91                | 2.46                             |
| 183  | 0xB7h | 1011 0111 | 71.48                | 28.52                | 2.51                             |
| 184  | 0xB8h | 1011 1000 | 71.88                | 28.13                | 2.56                             |
| 185  | 0xB9h | 1011 1001 | 72.27                | 27.73                | 2.61                             |
| 186  | 0xBAh | 1011 1010 | 72.66                | 27.34                | 2.66                             |
| 187  | 0xBBh | 1011 1011 | 73.05                | 26.95                | 2.71                             |
| 188  | 0xBC  | 1011 1100 | 73.44                | 26.56                | 2.76                             |

| Step | Hex   | Binary    | R <sub>WL</sub> (kΩ) | R <sub>HW</sub> (kΩ) | R <sub>WL</sub> /R <sub>HW</sub> |
|------|-------|-----------|----------------------|----------------------|----------------------------------|
| 189  | 0xBDh | 1011 1101 | 73.83                | 26.17                | 2.82                             |
| 190  | 0xBEh | 1011 1110 | 74.22                | 25.78                | 2.88                             |
| 191  | 0xBFh | 1011 1111 | 74.61                | 25.39                | 2.94                             |
| 192  | 0xC0h | 1100 0000 | 75.00                | 25.00                | 3.00                             |
| 193  | 0xC1h | 1100 0001 | 75.39                | 24.61                | 3.06                             |
| 194  | 0xC2h | 1100 0010 | 75.78                | 24.22                | 3.13                             |
| 195  | 0xC3h | 1100 0011 | 76.17                | 23.83                | 3.20                             |
| 196  | 0xC4h | 1100 0100 | 76.56                | 23.44                | 3.27                             |
| 197  | 0xC5h | 1100 0101 | 76.95                | 23.05                | 3.34                             |
| 198  | 0xC6h | 1100 0110 | 77.34                | 22.66                | 3.41                             |
| 199  | 0xC7h | 1100 0111 | 77.73                | 22.27                | 3.49                             |
| 200  | 0xC8h | 1100 1000 | 78.13                | 21.88                | 3.57                             |
| 201  | 0xC9h | 1100 1001 | 78.52                | 21.48                | 3.65                             |
| 202  | 0xCAh | 1100 1010 | 78.91                | 21.09                | 3.74                             |
| 203  | 0xCBh | 1100 1011 | 79.30                | 20.70                | 3.83                             |
| 204  | 0xCCh | 1100 1100 | 79.69                | 20.31                | 3.92                             |
| 205  | 0xCDh | 1100 1101 | 80.08                | 19.92                | 4.02                             |
| 206  | 0xCEh | 1100 1110 | 80.47                | 19.53                | 4.12                             |
| 207  | 0xCFh | 1100 1111 | 80.86                | 19.14                | 4.22                             |
| 208  | 0xD0h | 1101 0000 | 81.25                | 18.75                | 4.33                             |
| 209  | 0xD1h | 1101 0001 | 81.64                | 18.36                | 4.45                             |
| 210  | 0xD2h | 1101 0010 | 82.03                | 17.97                | 4.57                             |
| 211  | 0xD3h | 1101 0011 | 82.42                | 17.58                | 4.69                             |
| 212  | 0xD4h | 1101 0100 | 82.81                | 17.19                | 4.82                             |
| 213  | 0xD5h | 1101 0101 | 83.20                | 16.80                | 4.95                             |
| 214  | 0xD6h | 1101 0110 | 83.59                | 16.41                | 5.10                             |
| 215  | 0xD7h | 1101 0111 | 83.98                | 16.02                | 5.24                             |
| 216  | 0xD8h | 1101 1000 | 84.38                | 15.63                | 5.40                             |
| 217  | 0xD9h | 1101 1001 | 84.77                | 15.23                | 5.56                             |
| 218  | 0xDAh | 1101 1010 | 85.16                | 14.84                | 5.74                             |
| 219  | 0xDBh | 1101 1011 | 85.55                | 14.45                | 5.92                             |
| 220  | 0xDCh | 1101 1100 | 85.94                | 14.06                | 6.11                             |
| 221  | 0xDDh | 1101 1101 | 86.33                | 13.67                | 6.31                             |
| 222  | 0xDEh | 1101 1110 | 86.72                | 13.28                | 6.53                             |
| 223  | 0xDFh | 1101 1111 | 87.11                | 12.89                | 6.76                             |
| 224  | 0xE0h | 1110 0000 | 87.50                | 12.50                | 7.00                             |
| 225  | 0xE1h | 1110 0001 | 87.89                | 12.11                | 7.26                             |
| 226  | 0xE2h | 1110 0010 | 88.28                | 11.72                | 7.53                             |
| 227  | 0xE3h | 1110 0011 | 88.67                | 11.33                | 7.83                             |
| 228  | 0xE4h | 1110 0100 | 89.06                | 10.94                | 8.14                             |
| 229  | 0xE5h | 1110 0101 | 89.45                | 10.55                | 8.48                             |
| 230  | 0xE6h | 1110 0110 | 89.84                | 10.16                | 8.85                             |
| 231  | 0xE7h | 1110 0111 | 90.23                | 9.77                 | 9.24                             |
| 232  | 0xE8h | 1110 1000 | 90.63                | 9.38                 | 9.67                             |
| 233  | 0xE9h | 1110 1001 | 91.02                | 8.98                 | 10.13                            |
| 234  | 0xEAh | 1110 1010 | 91.41                | 8.59                 | 10.64                            |
| 235  | 0xEBh | 1110 1011 | 91.80                | 8.20                 | 11.19                            |
| 236  | 0xECh | 1110 1100 | 92.19                | 7.81                 | 11.80                            |
| 237  | 0xEDh | 1110 1101 | 92.58                | 7.42                 | 12.47                            |

| Step             | Hex   | Binary    | R <sub>WL</sub> (kΩ) | R <sub>HW</sub> (kΩ) | R <sub>WL</sub> /R <sub>HW</sub> |
|------------------|-------|-----------|----------------------|----------------------|----------------------------------|
| 238              | 0xEEh | 1110 1110 | 92.97                | 7.03                 | 13.22                            |
| 239              | 0xEFh | 1110 1111 | 93.36                | 6.64                 | 14.06                            |
| 240              | 0xF0h | 1111 0000 | 93.75                | 6.25                 | 15.00                            |
| 241              | 0xF1h | 1111 0001 | 94.14                | 5.86                 | 16.07                            |
| 242              | 0xF2h | 1111 0010 | 94.53                | 5.47                 | 17.29                            |
| 243              | 0xF3h | 1111 0011 | 94.92                | 5.08                 | 18.69                            |
| 244              | 0xF4h | 1111 0100 | 95.31                | 4.69                 | 20.33                            |
| 245              | 0xF5h | 1111 0101 | 95.70                | 4.30                 | 22.27                            |
| 246              | 0xF6h | 1111 0110 | 96.09                | 3.91                 | 24.60                            |
| 247              | 0xF7h | 1111 0111 | 96.48                | 3.52                 | 27.44                            |
| 248              | 0xF8h | 1111 1000 | 96.88                | 3.13                 | 31.00                            |
| 249              | 0xF9h | 1111 1001 | 97.27                | 2.73                 | 35.57                            |
| 250              | 0xFAh | 1111 1010 | 97.66                | 2.34                 | 41.67                            |
| 251              | 0xFBh | 1111 1011 | 98.05                | 1.95                 | 50.20                            |
| 252              | 0xFC  | 1111 1100 | 98.44                | 1.56                 | 63.00                            |
| 253              | 0xFDh | 1111 1101 | 98.83                | 1.17                 | 84.33                            |
| 254              | 0xFEh | 1111 1110 | 99.22                | 0.78                 | 127.00                           |
| 255 (full-scale) | 0xFFh | 1111 1111 | 99.61                | 0.3                  | 255.00                           |

## 7.5 Programming with I<sup>2</sup>C

### 7.5.1 I<sup>2</sup>C General Operation

#### 7.5.1.1 I<sup>2</sup>C Interface

The TPL0102 has a standard bidirectional I<sup>2</sup>C interface that is controlled by a microcontroller in order to configure the device and read the status of the device. Each device on the I<sup>2</sup>C bus, including this device, has a specific device address to differentiate between other devices that may be on the I<sup>2</sup>C bus. Configuration of the device is performed when the microcontroller addresses the device, then accesses the device's internal Register Maps, which have unique register addresses. The TPL0102 has multiple registers where data is stored, written, or read. Please refer to the Register Map for more details.

The physical I<sup>2</sup>C interface consists of the serial clock (SCL) and serial data (SDA) lines. Both SDA and SCL lines must be connected to VDD through a pull-up resistor. The size of the pull-up resistor is determined by the amount of capacitance on the I<sup>2</sup>C lines (for further details, please refer to the [I<sup>2</sup>C Bus Pullup Resistor Calculation](#) Application Report). Data transfer may be initiated only when the bus is not busy. For more detailed information on I<sup>2</sup>C, please refer to the [Understanding the I<sup>2</sup>C Bus](#) Application Report.

1. Suppose a master wants to send information to the TPL0102:

- Master addresses TPL0102 (slave)
- Master-transmitter sends data to TPL0102 (slave-receiver)
- Master terminates the transfer.

2. If a master wants to receive information from TPL0102:

- Master addresses TPL0102 (slave)
- Master-receiver receives data from TPL0102 (slave-transmitter)
- Master terminates the transfer.

The master generates the timing for the SCL.

#### 7.5.1.2 START and STOP Conditions

I<sup>2</sup>C communication with this device is initiated by the master sending a START condition and terminated by the master sending a STOP condition. A high-to-low transition on the SDA line while the SCL is high defines a START condition. A low-to-high transition on the SDA line while the SCL is high defines a STOP condition.

Programming with I<sup>2</sup>C (continued)

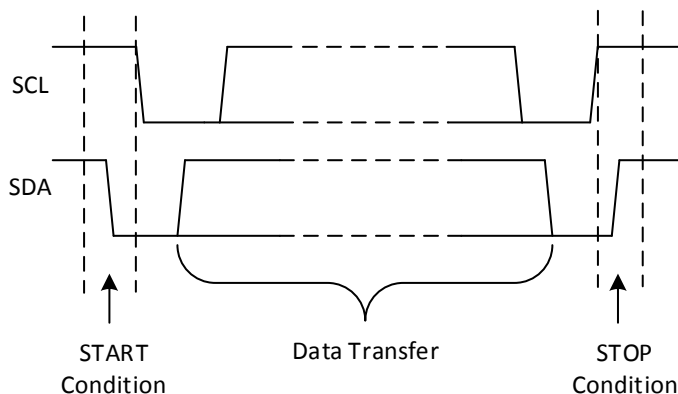


Figure 22. Definition of START and STOP Conditions

7.5.1.3 Data Validity and Byte Formation

One data bit is transferred during each clock pulse of the SCL. One byte is comprised of eight bits on the SDA line. A byte may either be a device address, register address, or data written to or read from a slave.

Data is transferred Most Significant Bit (MSB) first. Any number of data bytes can be transferred from the master to slave between the START and STOP conditions. Data on the SDA line must remain stable during the high phase of the clock period, as changes in the data line when the SCL is high are interpreted as control commands (START or STOP).

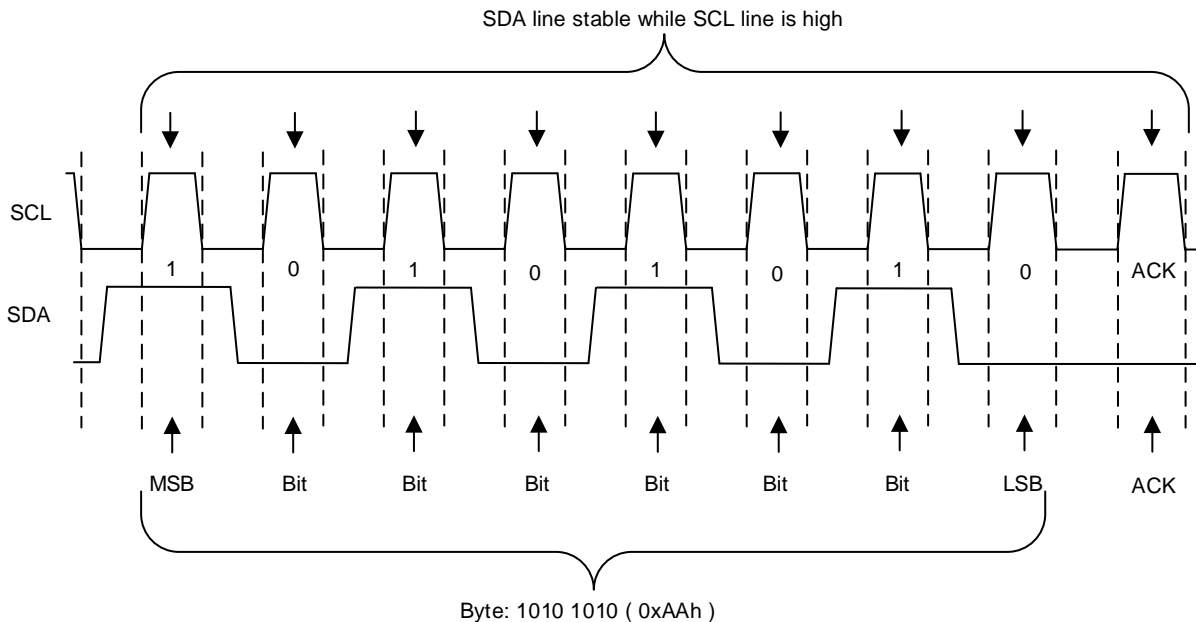
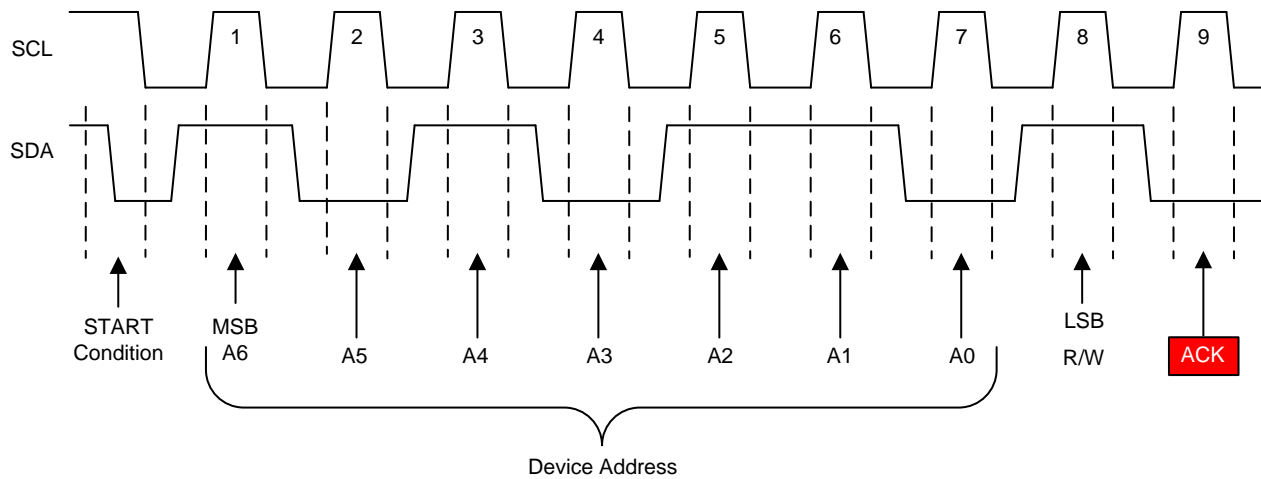


Figure 23. Definition of Byte Formation

7.5.1.4 Acknowledge (ACK) and Not Acknowledge (NACK)

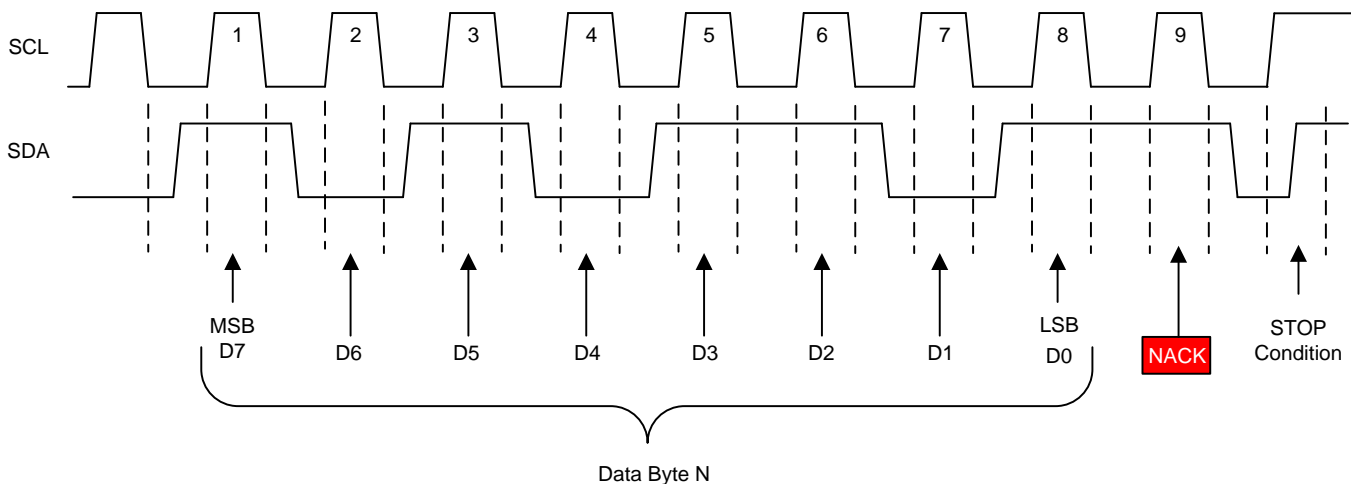
Each byte is followed by one ACK bit from the receiver. The ACK bit allows the receiver to communicate to the transmitter that the byte was successfully received and another byte may be sent.

The transmitter must release the SDA line before the receiver can send the ACK bit. To send an ACK bit, the receiver shall pull down the SDA line during the low phase of the ACK/NACK-related clock period (period 9), so that the SDA line is stable low during the high phase of the ACK/NACK-related clock period. Setup and hold times must be taken into account.

**Programming with I<sup>2</sup>C (continued)**

**Figure 24. Example use of ACK**

When the SDA line remains high during the ACK/NACK-related clock period, this is a NACK signal. There are several conditions that lead to the generation of a NACK:

- The receiver is unable to receive or transmit because it is performing some real-time function and is not ready to start communication with the master.
- During the transfer, the receiver gets data or commands that it does not understand.
- During the transfer, the receiver cannot receive any more data bytes.
- A master-receiver is done reading data and indicates this to the slave through a NACK.


**Figure 25. Example use of NACK**
**7.5.2 I<sup>2</sup>C Write and Read Operation**
**7.5.2.1 Auto Increment Function**

Auto increment allows multiple bytes to be written to or read from consecutive registers without requiring the master to repeatedly send the device address and register address for each data byte. This is beneficial because auto increment substantially reduces the number of bytes transferred between the master and slave.

For the TPL0102, the registers will auto increment as long as the user continues to enter data. Auto increment will stop once the user is finished entering data bytes.

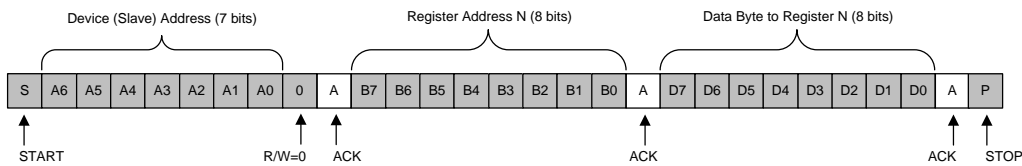
## Programming with I<sup>2</sup>C (continued)

If there are more bytes to write or read after the last register address is written to or read from in the register map, auto increment will loop around to the register address at the beginning of the register map. For example, after the ACR (register address 0x10h) has been written to, if there are more bytes to be written, the register address will loop to the IVRA (register address 0x00h) at the beginning of the register map.

### 7.5.2.2 Write Operation

- Master controls SDA line
- Slave controls SDA line

#### Write to one register in a device



#### Write to multiple registers in a device

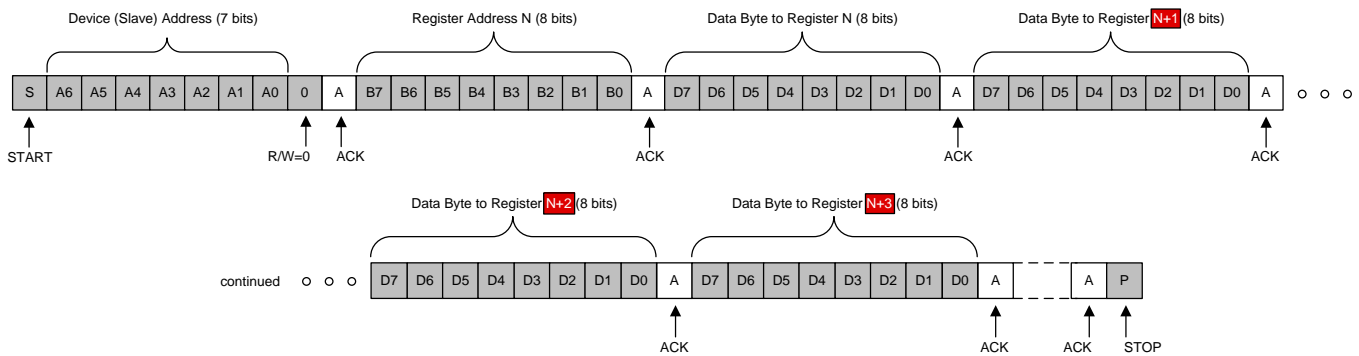


Figure 26. Write Operation to One or Multiple Registers

### 7.5.2.3 Repeated Start

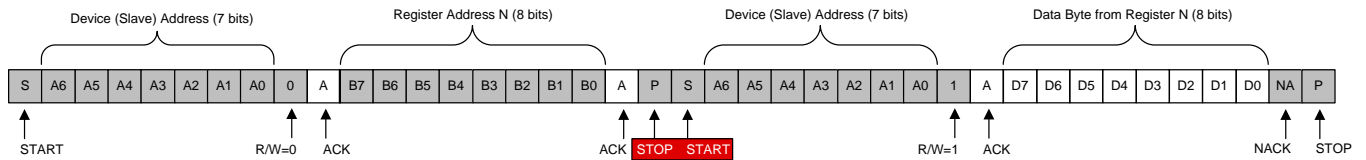
A repeated START condition may be used in place of a complete STOP condition followed by another START condition when performing a read function. The advantage of this is that the I<sup>2</sup>C bus does not become available after the stop and therefore prevents other devices from grabbing the bus between transfers.

## Programming with I<sup>2</sup>C (continued)

### 7.5.2.4 Read Operation

- Master controls SDA line
- Slave controls SDA line

Read from one register in a device



Read from one register in a device (Repeated Start)

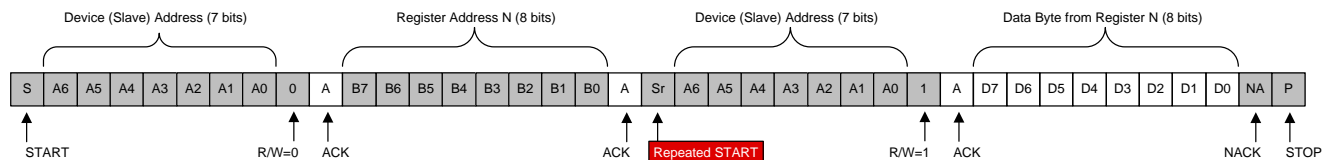
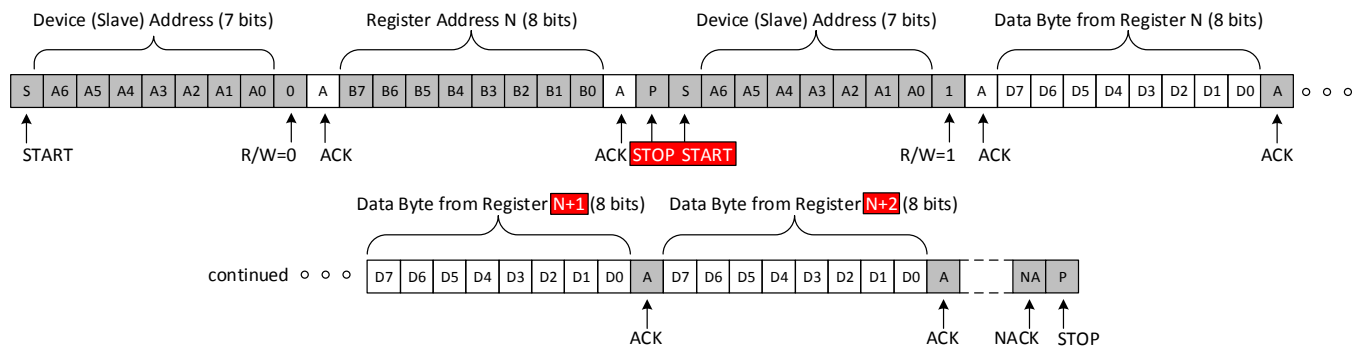


Figure 27. Read Operation from One Register

Read from multiple registers in a device



Read from multiple registers in a device (Repeated Start)

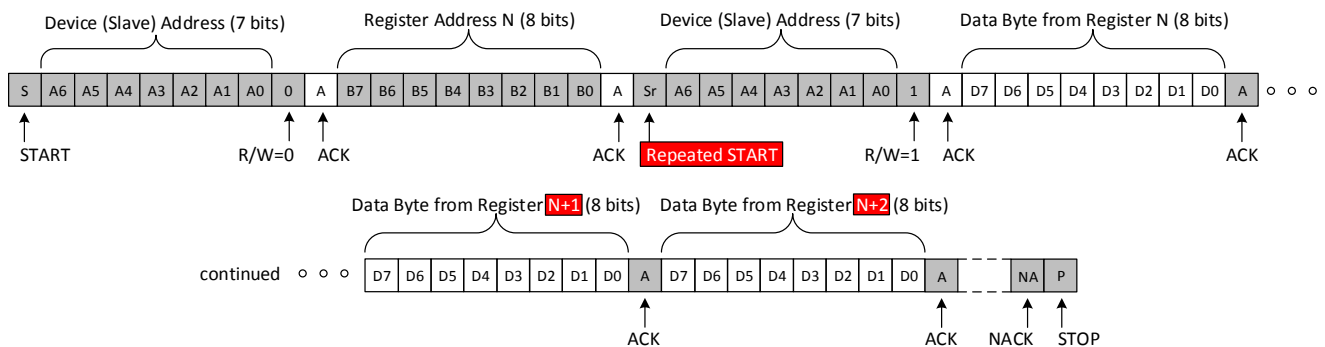


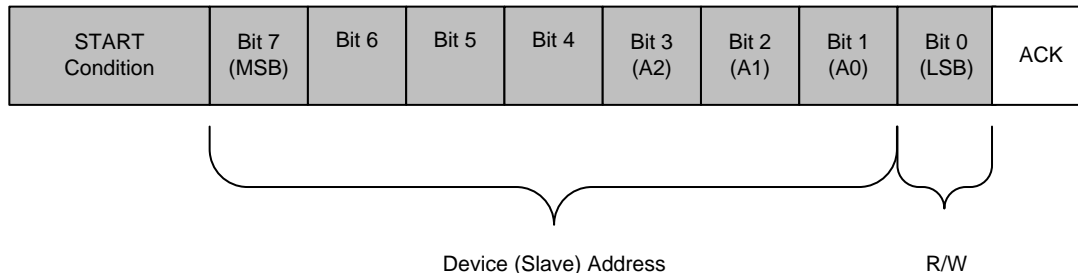
Figure 28. Read Operation from Multiple Registers



## 7.6 Register Maps

### 7.6.1 Slave Address

The device (slave) address can be configured by the user with 3 bits (A2, A1, and A0), allowing for 8 different possibilities for the device address. Please see the [Figure 30](#) for an example.

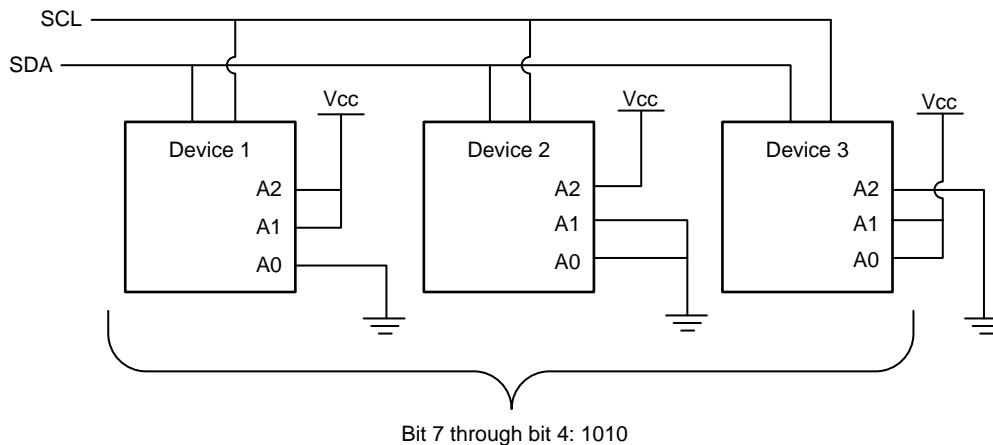


**Figure 29. Device Address in Context with START and ACK**

| Bit 7 (MSB) | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 (LSB) |
|-------------|-------|-------|-------|-------|-------|-------|-------------|
| 1           | 0     | 1     | 0     | A2    | A1    | A0    | R/W         |

[Figure 30](#) shows an example of how to configure A2, A1 and A0 to give unique device addresses on the same I<sup>2</sup>C bus. When a bit is wired to Vcc, this gives that bit a value of 1. When a bit is wired to GND, this gives that bit a value of 0.

For example, Device 1 could be the TPL0102 on the I<sup>2</sup>C bus, which would have a 7 bit device address of 1010 110. There are some interfaces that will require the device address to be inputted in hex. In order to make the device address 8 bits for hex notation, a leading 0 is added to the left of the 7 bit device address. For Device 1, the 8 bit device address is 0101 0110 (0x56h). Device 2 would have a 7 bit device address of 1010 100, which with a leading 0 results in an 8 bit device address of 0101 0100 (0x54h). Device 3 would have a 7 bit device address of 1010 011, and with a leading 0 results in an 8 bit device address of 0101 0011 (0x53h).



**Figure 30. Examples of Device Address Configuration on I<sup>2</sup>C Bus**

### 7.6.2 TPL0102 Register Map

- When writing the entire register map using auto increment, general purpose registers in the register address map need to be written with dummy bytes. The general purpose registers do not effect the outputs of the potentiometers.
- As stated in the [Overview](#), the VOL bit from the [ACR \(Access Control Register\)](#) provides two options for register accessibility. Either only volatile registers (WR) are accessible to change the wiper setting without storing the value in non-volatile memory or volatile registers (WR) and non-volatile registers (IVR) are accessible to change the wiper setting, which allows the value to be stored in non-volatile memory.
- The respective non-volatile and volatile registers have the same register address, thus to write to both the volatile and non-volatile locations, only one register address needs to be entered and the VOL bit needs to be configured properly.

| REGISTER ADDRESS (HEX) | REGISTER ADDRESS (BINARY) | NON-VOLATILE    | VOLATILE |
|------------------------|---------------------------|-----------------|----------|
| 0x00h                  | 0000 0000                 | IVRA            | WRA      |
| 0x01h                  | 0000 0001                 | IVRB            | WRB      |
| 0x02h                  | 0000 0010                 | General purpose | N/A      |
| 0x03h                  | 0000 0011                 | General purpose | N/A      |
| 0x04h                  | 0000 0100                 | General purpose | N/A      |
| 0x05h                  | 0000 0101                 | General purpose | N/A      |
| 0x06h                  | 0000 0110                 | General purpose | N/A      |
| 0x07h                  | 0000 0111                 | General purpose | N/A      |
| 0x08h                  | 0000 1000                 | General purpose | N/A      |
| 0x09h                  | 0000 1001                 | General purpose | N/A      |
| 0x0Ah                  | 0000 1010                 | General purpose | N/A      |
| 0x0Bh                  | 0000 1011                 | General purpose | N/A      |
| 0x0Ch                  | 0000 1100                 | General purpose | N/A      |
| 0x0Dh                  | 0000 1101                 | General purpose | N/A      |
| 0x0Eh                  | 0000 1110                 | General purpose | N/A      |
| 0x0Fh                  | 0000 1111                 |                 | Reserved |
| 0x10h                  | 0001 0000                 | N/A             | ACR      |

### 7.6.3 IVRA (Initial Value Register for Potentiometer A)

- Non-volatile register to store wiper position for potentiometer A
- Register will hold value even when device is powered down

| NAME | TYPE                    | SIZE (BITS) | REGISTER ADDRESS | FACTORY PROGRAMMED VALUE |
|------|-------------------------|-------------|------------------|--------------------------|
| IVRA | Non-volatile Write/Read | 8           | 0x00h            | 0x80h                    |

### 7.6.4 WRA (Wiper Resistance Register for Potentiometer A)

- Volatile register to change wiper position for potentiometer A
- IVRA loads value to WRA to determine wiper position

| NAME | TYPE                | SIZE (BITS) | REGISTER ADDRESS | VALUE UPON RESET |
|------|---------------------|-------------|------------------|------------------|
| WRA  | Volatile Write/Read | 8           | 0x00h            | IVRA value       |

### 7.6.5 IVRB (Initial Value Register for Potentiometer B)

- Non-volatile register to store wiper position for potentiometer B
- Register will hold value even when device is powered down

| NAME | TYPE                    | SIZE (BITS) | REGISTER ADDRESS | FACTORY PROGRAMMED VALUE |
|------|-------------------------|-------------|------------------|--------------------------|
| IVRB | Non-volatile Write/Read | 8           | 0x01h            | 0x80h                    |

### 7.6.6 WRB (Wiper Resistance Register for Potentiometer B)

- Volatile register to change wiper position for potentiometer B
- IVRB loads value to WRB to determine wiper position

| NAME | TYPE                | SIZE (BITS) | REGISTER ADDRESS | VALUE UPON RESET |
|------|---------------------|-------------|------------------|------------------|
| WRB  | Volatile Write/Read | 8           | 0x01h            | IVRB value       |

### 7.6.7 ACR (Access Control Register)

- Volatile register to control register access, determine shut-down mode, and read non-volatile write operations

| NAME | TYPE                | SIZE (BITS) | REGISTER ADDRESS | VALUE UPON RESET |
|------|---------------------|-------------|------------------|------------------|
| ACR  | Volatile Write/Read | 8           | 0x10h            | 0x40h            |

| NAME                  | BIT ASSIGNMENT |                          |       |       |       |       |       |       |
|-----------------------|----------------|--------------------------|-------|-------|-------|-------|-------|-------|
|                       | Bit 7          | Bit 6                    | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
| ACR                   | VOL            | $\overline{\text{SHDN}}$ | WIP   | 0     | 0     | 0     | 0     | 0     |
| Reset (Default) Value | 0              | 1                        | 0     | 0     | 0     | 0     | 0     | 0     |

| NAME                     | TYPE                | SIZE (BITS) | BIT VALUE | DESCRIPTION   |
|--------------------------|---------------------|-------------|-----------|---|
| VOL                      | Volatile Write/Read | 1           | 0         | Non-volatile registers (IVRA, IVRB) are accessible. Value written to IVR register is also written to the corresponding WR. If read operation is performed, only non-volatile register (IVRA, IVRB) values will be reported. |
|                          |                     |             | 1         | Only Volatile Registers (WR) are accessible. If read operation is performed, only volatile (WRA, WRB) values will be reported.  |
| $\overline{\text{SHDN}}$ | Volatile Write/Read | 1           | 0         | Shutdown mode is enabled. Both potentiometers are in shutdown mode. (see <a href="#">Shutdown Mode</a> )  |
|                          |                     |             | 1         | Shutdown mode is disabled   |
| WIP                      | Volatile Read       | 1           | 0         | Non-volatile write operation is not in progress   |
|                          |                     |             | 1         | Non-volatile write operation is in progress (it is not possible to write to the WR or ACR while WIP = 1)  |

## 8 Application and Implementation

### NOTE

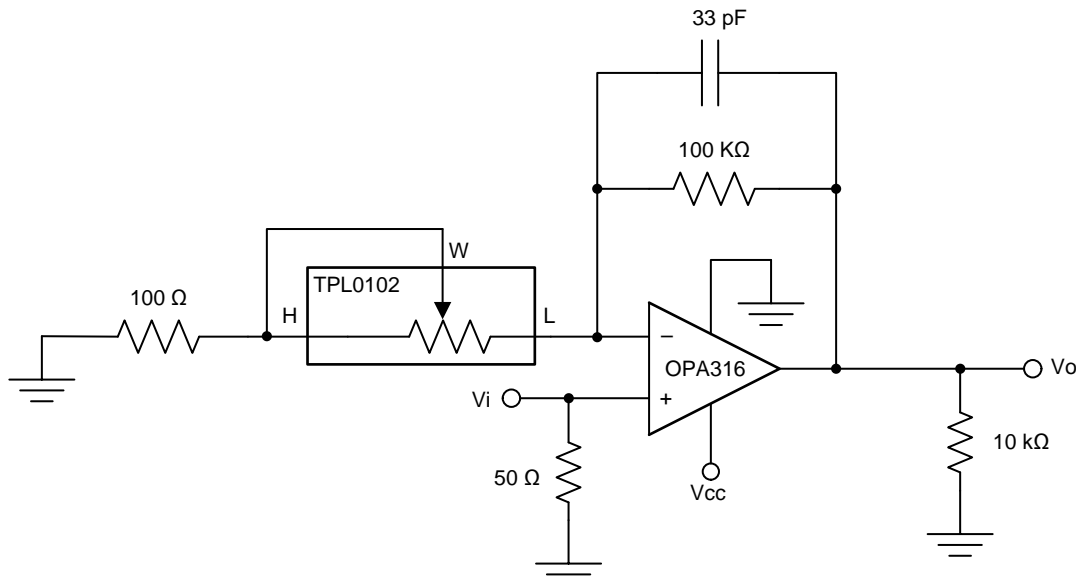
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 8.1 Application Information

There are many applications in which variable resistance or voltage division is needed through the use of a digital potentiometer such as the TPL0102; these are just a few examples. In conjunction with various amplifiers, the TPL0102 can effectively be used in rheostat mode to modify the gain of an amplifier, in voltage divider mode to create a Digital to Analog Converter, or one of the potentiometers can be used in voltage divider mode while the other is in rheostat mode to create a variable current sink.

### 8.2 Typical Applications

#### 8.2.1 Adjustable Gain Non-Inverting Amplifier



**Figure 31. Gain Control Compensation Schematic**

##### 8.2.1.1 Design Requirements

| DESIGN PARAMETER | EXAMPLE VALUE |
|------------------|---------------|
| Gain range       | 6 to 60 dB    |

##### 8.2.1.2 Detailed Design Procedure

The TPL0102 can be used in rheostat mode with an OPA316 to create an adjustable gain non-inverting amplifier. The capacitor and resistor values were chosen based upon the Non-Inverting Amplifier Gain equation:

$$\text{Gain} = 1 + \frac{Z_f}{Z_{in}} \quad (5)$$

Where  $Z_{in}$  is the impedance between the inverting input and GND and  $Z_f$  is the impedance of the feedback network.

In this application, the following equations are used:

$$Z_{in} = \text{TPL0102 resistance} + 100 \, \Omega \quad (6)$$

and

$$Z_f = R_f \parallel C_f \quad (7)$$

Where  $R_f$  and  $C_f$  are the feedback resistor and capacitor, respectively.

A 100  $\Omega$  resistor is added in series with the TPL0102 resistance in order to stop the op amp from producing infinite gain. When the TPL0102 is at zero-scale, the resistance between terminal L and terminal W is  $\sim 0 \, \Omega$ . This would normally cause infinite gain, but with the 100  $\Omega$  resistor in series, the lowest  $Z_{in}$  can be is 100  $\Omega$ , which at DC will create a gain of roughly 60 dB.

$$\text{Gain} = 1 + \frac{100 \, \text{k}\Omega}{\sim 0 \, \Omega + 100 \, \Omega} = 1 + \frac{100 \, \text{k}\Omega}{100 \, \Omega} = 1 + 1000 = 1001 \frac{\text{V}}{\text{V}} \cong 60 \, \text{dB} \quad (8)$$

$R_f$  and  $C_f$  were chosen based upon characteristics of the potentiometer and op amp, respectively. The value of  $R_f$  affects the level of gain, primarily at low frequencies. Since the TPL0102 has a full-scale resistance of 100 k $\Omega$  between terminal W and terminal L, the  $R_f$  was chosen to match this full-scale resistance, which produces the minimum gain of 6 dB:

$$\text{Gain} = 1 + \frac{100 \, \text{k}\Omega}{100 \, \text{k}\Omega + 100 \, \Omega} \cong 1 + \frac{100 \, \text{k}\Omega}{100 \, \text{k}\Omega} = 1 + 1 = 2 \frac{\text{V}}{\text{V}} \cong 6 \, \text{dB} \quad (9)$$

As frequency increases,  $C_f$  begins to have an impact on gain. A frequency roll-off will occur due to the open-loop gain of the op amp, but in this application, the desired effect is to have  $C_f$  impact the roll off before the open loop gain of the op amp. At a gain of 40 dB, the op amp open loop gain will force the roll off to occur at 100 kHz. Therefore, in order for  $C_f$  to impact the roll off before the open loop gain, roll off due to the capacitor must occur at less than 100 kHz. In this application, 50 kHz is the desired roll off frequency, resulting in a  $C_f$  value of 33 pF.

$$C_f = \frac{1}{2 \times \pi \times R_f \times f(-3 \, \text{dB})} = \frac{1}{2 \times \pi \times 100 \, \text{k}\Omega \times 50 \, \text{kHz}} = 33 \, \text{pF} \quad (10)$$

Measurements were taken with a 10 k $\Omega$  load. A 50  $\Omega$  resistor is included at the input for termination of measurement equipment.

### 8.2.1.3 Application Curves

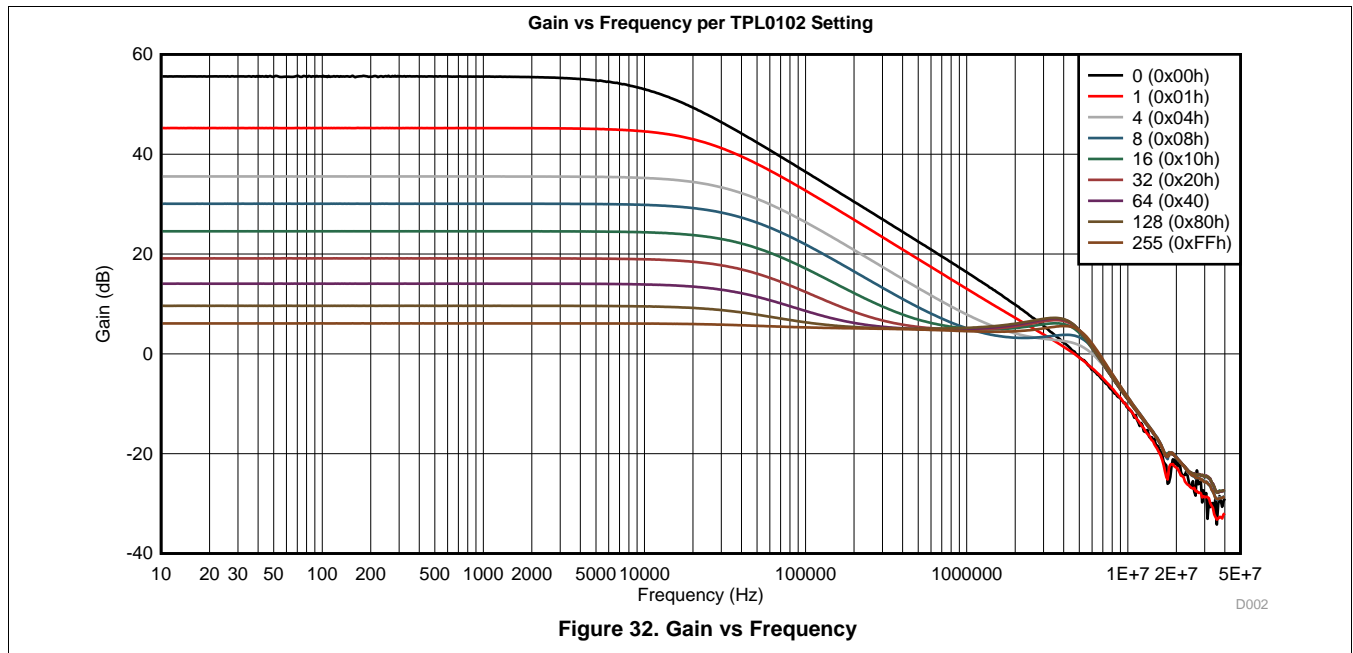
As the TPL0102 moves from full-scale to zero-scale,  $Z_{in}$  decreases, which causes the gain of the op amp to increase from 6 dB to 56 dB. The amplifier does not reach the full 60 dB of calculated gain because the resistance in the TPL0102 did not reach 0  $\Omega$ . At zero-scale, the TPL0102 had a remaining resistance of approximately 58  $\Omega$ .

$$\text{Gain} = 1 + \frac{100 \, \text{k}\Omega}{58 \, \Omega + 100 \, \Omega} = 1 + \frac{100 \, \text{k}\Omega}{158 \, \Omega} = 1 + 633 = 634 \frac{\text{V}}{\text{V}} \cong 56 \, \text{dB} \quad (11)$$

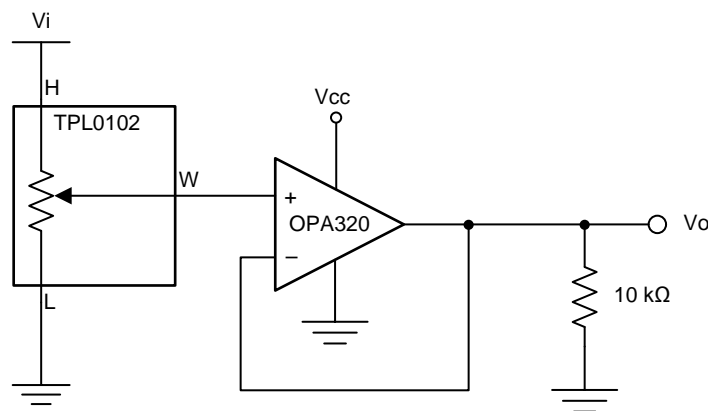
The application curve clearly shows the effect of the low pass filter created by the  $R_f$  and  $C_f$  combination. Roll off begins as frequencies approach 50 kHz because of the pole created by the 33 pF capacitor. As the frequency increases beyond 50 kHz, the gain decreases by -20 dB/dec until the gain levels off at 1V/V or 0dB. The gain levels off due to the nature of non-inverting op amp transfer functions. The feedback impedance,  $Z_f$ , is approximately zero at high frequency because  $C_f$  acts as a short. As shown below, this results in a gain of 0 dB:

$$\text{Gain} = 1 + \frac{Z_f}{Z_{in}} = 1 + \frac{\sim 0}{Z_{in}} = 1 \frac{\text{V}}{\text{V}} = 0 \, \text{dB} \quad (12)$$

At approximately 3 MHz, the gain is again reduced by -20 dB/dec due to the pole created by open-loop gain of the OPA316.



### 8.2.2 Digital to Analog Converter (DAC)



**Figure 33. Digital to Analog Converter Schematic**

#### 8.2.2.1 Design Requirements

| DESIGN PARAMETER     | EXAMPLE VALUE |
|----------------------|---------------|
| Input Voltage Range  | 0 to 5 V      |
| Output Voltage Range | 0 to 5 V      |

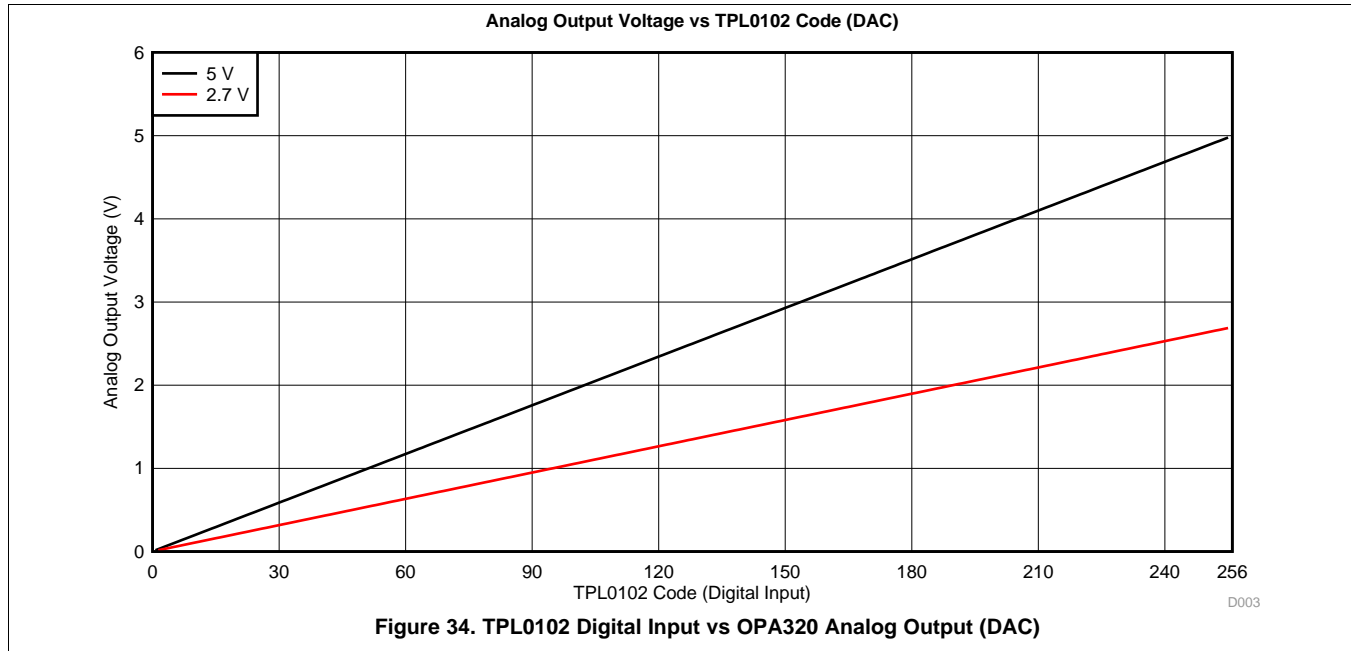
#### 8.2.2.2 Detailed Design Procedure

The TPL0102 can be used in voltage divider mode with a unity-gain op amp buffer to create an 8-bit Digital to Analog Converter (DAC). The analog output voltage of the circuit is determined by the wiper setting programmed through the I<sup>2</sup>C bus.

The op amp is required to buffer the high-impedance output of the TPL0102 or else loading placed on the output of the voltage divider will affect the output voltage.

### 8.2.2.3 Application Curves

The voltage at terminal H determines the maximum analog voltage at the output. As the TPL0102 moves from zero-scale to full-scale, the voltage divider adjusts with relation to the voltage divider formula (Equation 1), resulting in the desired voltage at terminal W. The voltage at terminal W will range linearly from 0 V to the terminal H voltage. In this example,  $V_{in}$  at terminal H is 5 V and 2.7 V.



### 8.2.3 Variable Current Sink

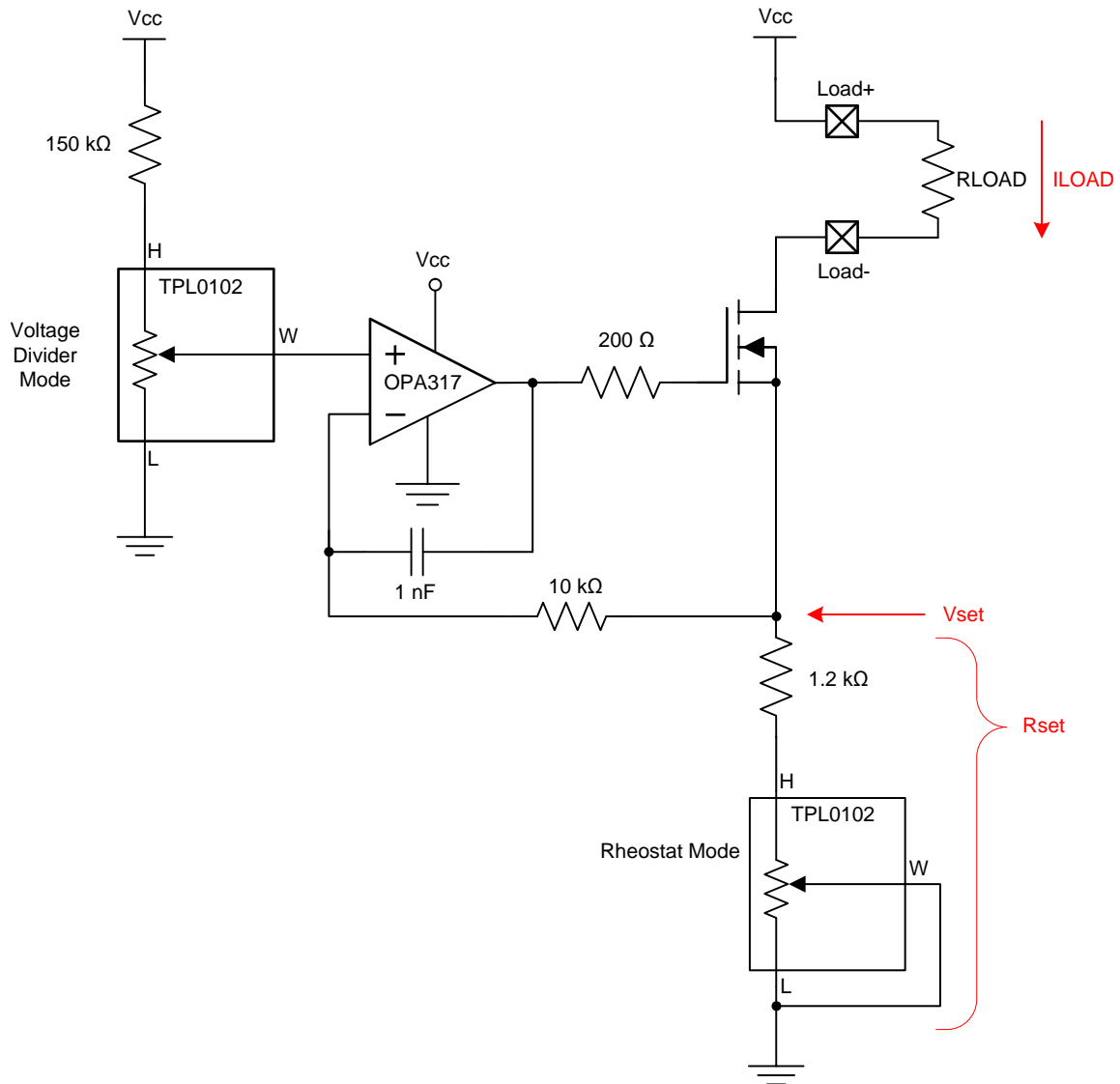


Figure 35. Variable Current Sink Schematic

#### 8.2.3.1 Design Requirements

| DESIGN PARAMETER   | EXAMPLE VALUE   |
|--------------------|-----------------|
| Load Current Range | 0 μA to 1.33 mA |

#### 8.2.3.2 Detailed Design Procedure

Both potentiometers within the TPL0102 can be used with an OPA317 op amp and N-Channel MOSFET to produce a variable current sink. The first potentiometer, configured in voltage divider mode, is used to set the input voltage to the OPA317. The second potentiometer, configured in rheostat mode, is used to set the span of the current ( $I_{LOAD}$ ) running through  $R_{LOAD}$ . The load current for the circuit is shown below:

$$I_{LOAD} = \frac{V_{set}}{R_{set}} \tag{13}$$



Based upon the voltage divider formula between the setting of the TPL0102 and the 150 kΩ resistor, the voltage at the positive input of the OPA317,  $V_{set}$ , can range from 0 to 2 V. This leaves a maximum of 3 V of voltage drop from the positive side to the negative side of the external load with a 5 V supply. A 1.2 kΩ resistor is placed in series with the TPL0102 span setting potentiometer ( $R_{set}$ ). At full scale of the span setting potentiometer and the maximum voltage at  $V_{set}$  (2 V), the maximum value for  $I_{LOAD}$  is:

$$I_{LOAD\_MAX} = \frac{V_{set}}{R_{set}} = \frac{V_{set}}{TPL0102_{HW(Resistance)} + 1.2\text{ k}\Omega} = \frac{2\text{ V}}{300\ \Omega + 1.2\text{ k}\Omega} = 1.33\text{ mA} \quad (14)$$

When the span setting potentiometer is at zero scale with the maximum voltage at  $V_{set}$ , the maximum value for  $I_{LOAD}$  is:

$$I_{LOAD} = \frac{V_{set}}{R_{set}} = \frac{V_{set}}{TPL0102_{HW(Resistance)} + 1.2\text{ k}\Omega} = \frac{2\text{ V}}{100\text{ k}\Omega + 1.2\text{ k}\Omega} = 19.76\ \mu\text{A} \quad (15)$$

The same calculations can be made when the potentiometer in voltage divider mode is a zero scale. At zero scale,  $V_{set}$  will be almost negligible, resulting in 0 A of current no matter the value of the span setting potentiometer.

### 8.2.3.2.1 Compensation Components

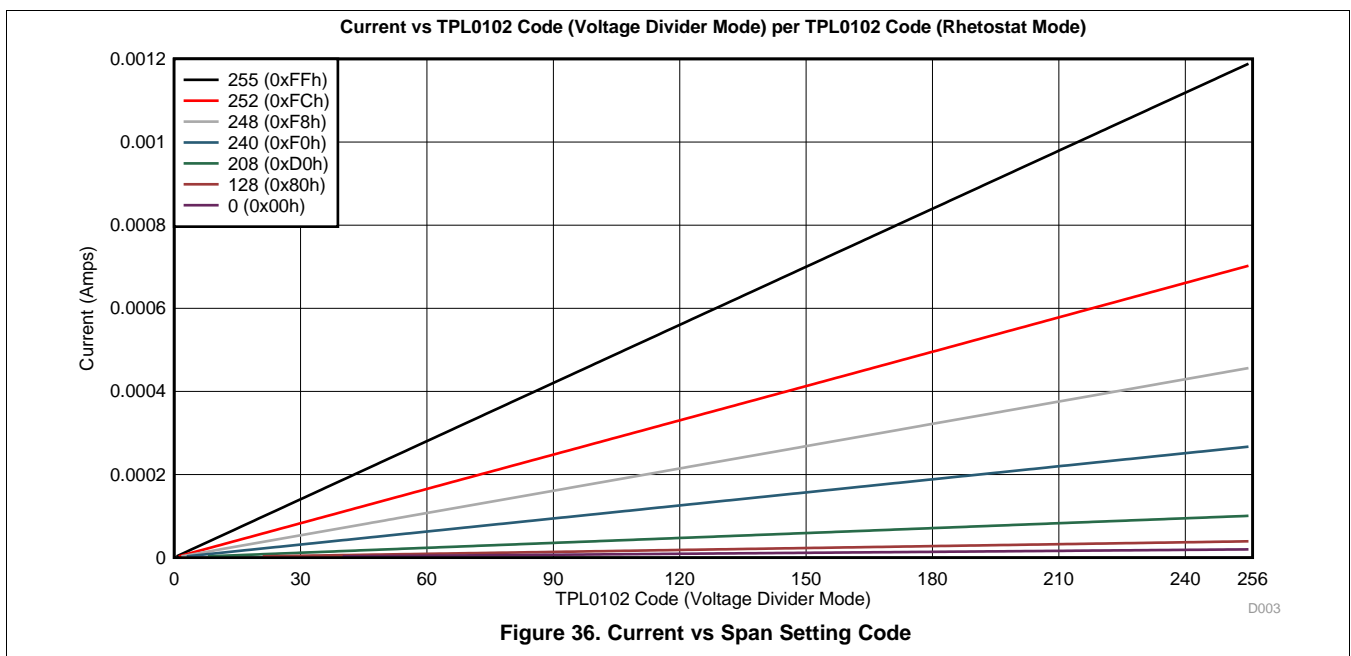
This design requires a few compensation components to stabilize the feedback network. These include the 1 nF capacitor and the 200 Ω and 10 kΩ resistors, which were selected based upon the [TIPD102 reference design](#).

### 8.2.3.3 Application Curves

As the TPL0102 in rheostat mode (span setting potentiometer) moves from zero-scale to full-scale, a new step (line) is created with a larger achievable maximum current. The rheostat mode potentiometer directly corresponds to  $R_{set}$  in Equation 13. The TPL0102 in voltage divider mode produces the granular current values between the minimum and maximum range. The voltage divider potentiometer directly corresponds to  $V_{set}$  in Equation 13. For example, when the potentiometer in rheostat mode is at code 256, the potentiometer in voltage divider mode produces a theoretical maximum current of 1.33 mA at code 256 and a minimum current of 0 μA at code 0.

The current sink does not reach the full 1.33 mA because of the error in resistance of the span setting potentiometer. At full-scale, the resistor had an actual resistance of 480 Ω.

$$I_{LOAD\_MAX} = \frac{V_{set}}{R_{set}} = \frac{V_{set}}{TPL0102_{HW(Resistance)} + 1.2\text{ k}\Omega} = \frac{2\text{ V}}{480\ \Omega + 1.2\text{ k}\Omega} = 1.19\text{ mA} \quad (16)$$



## 9 Power Supply Recommendations

### 9.1 Power Sequence

Protection diodes limit the voltage compliance at terminal H, terminal L, and terminal W, making it important to power up  $V_{DD}$  first before applying any voltage to terminal H, terminal L, and terminal W. The diodes are forward-biasing, meaning  $V_{DD}$  can be powered unintentionally if  $V_{DD}$  is not powered first. The ideal power-up sequence is  $V_{SS}$ ,  $V_{DD}$ ,  $V_{LOGIC}$ , digital inputs, and  $V_H$ ,  $V_L$ , and  $V_W$ . The order of powering digital inputs,  $V_H$ ,  $V_L$ , and  $V_W$  does not matter as long as they are powered after  $V_{SS}$ ,  $V_{DD}$ , and  $V_{LOGIC}$ .

### 9.2 Wiper Position Upon Power Up

It is prudent to know that when the DPOT is powered off, the impedance of the device is not known. Upon power up, the device will go to 0x80h code for a very short period of time while it loads the stored wiper position in the EEPROM and then will go to the stored position. This happens in less than 100  $\mu$ S.

### 9.3 Dual-Supply vs Single-Supply

Dual-supply operation allows the TPL0102 to handle voltage that may swing negative. This is especially useful for any application that involves negative voltages, such as the input to an Op Amp or audio signals. It is recommended that  $V_{SS}$  (negative supply) is mirrored with  $V_{DD}$  (positive supply) and both are centered around GND. For example, if dual-supply is desired and  $V_{DD} = 2.50$  V, then  $V_{SS}$  should be equal to  $-2.50$  V, which will result in GND centered between  $V_{DD}$  and  $V_{SS}$ .

Single-supply operation allows the TPL0102 to handle positive voltages only. In single-supply, it is recommended that  $V_{SS}$  is tied to GND.

## 10 Layout

### 10.1 Layout Guidelines

To ensure reliability of the device, please follow common printed-circuit board layout guidelines.

- Leads to the input should be as direct as possible with a minimum conductor length.
- The ground path should have low resistance and low inductance.
- Short trace-lengths should be used to avoid excessive loading.
- It is common to have a dedicated ground plane on an inner layer of the board.
- Terminals that are connected to ground should have a low-impedance path to the ground plane in the form of wide polygon pours and multiple vias.
- Bypass capacitors should be used on power supplies and should be placed as close as possible to the VDD and VSS pins.
- Apply low equivalent series resistance 0.1  $\mu\text{F}$  to 10  $\mu\text{F}$  tantalum or electrolytic capacitors at the supplies to minimize transient disturbances and to filter low frequency ripple.
- To reduce the total I<sup>2</sup>C bus capacitance added by PCB parasitics, data lines (SCL and SDA) should be as short as possible and the widths of the traces should also be minimized (e.g. 5-10 mils depending on copper weight).

### 10.2 Layout Example

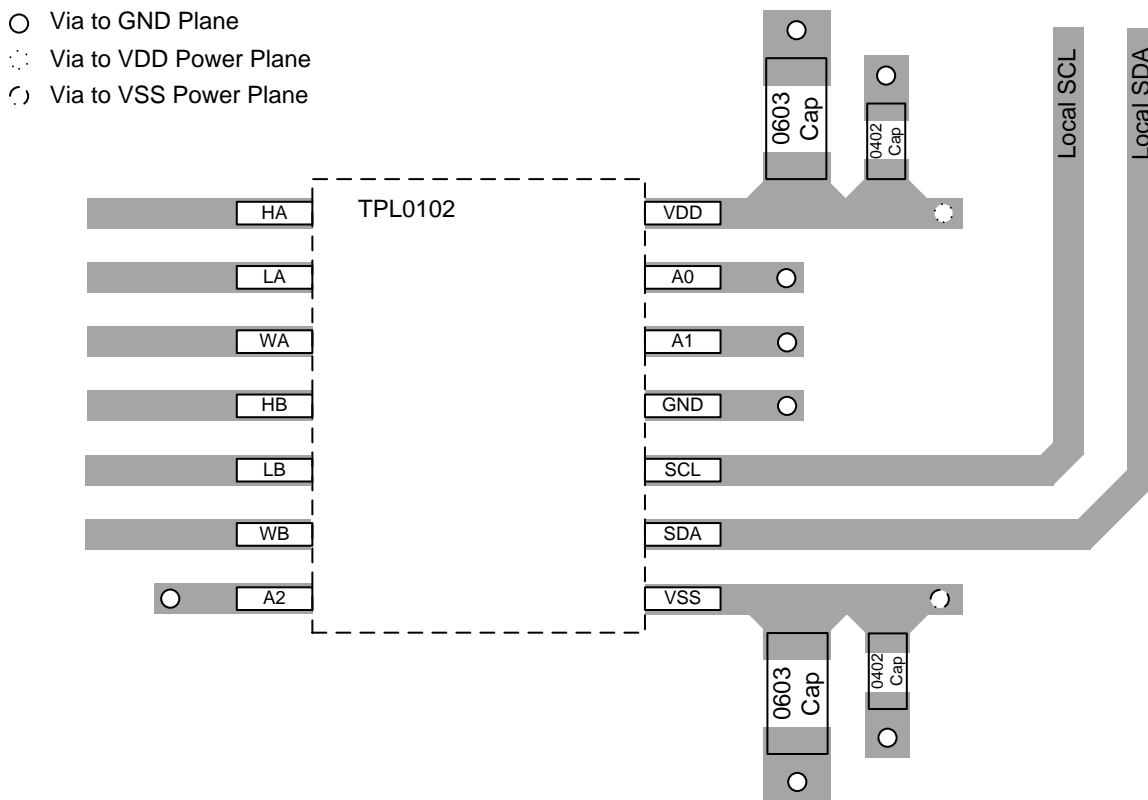


Figure 37. TPL0102 Layout Example

## 11 器件和文档支持

### 11.1 社区资源

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At [e2e.ti.com](http://e2e.ti.com), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 11.2 商标

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### 11.3 静电放电警告



这些装置包含有限的内置 ESD 保护。存储或装卸时，应将导线一起截短或将装置放置于导电泡棉中，以防止 MOS 门极遭受静电损伤。

### 11.4 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 12 机械、封装和可订购信息

以下页中包括机械、封装和可订购信息。这些信息是针对指定器件可提供的最新数据。这些数据会在无通知且不对本文档进行修订的情况下发生改变。欲获得该数据表的浏览器版本，请查阅左侧的导航栏。

**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan<br>(2) | Lead finish/<br>Ball material<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|-----------------|------|-------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| TPL0102-100PWR   | ACTIVE        | TSSOP        | PW              | 14   | 2000        | RoHS & Green    | NIPDAU                               | Level-1-260C-UNLIM   | -40 to 85    | EL-100                  | <a href="#">Samples</a> |
| TPL0102-100RUCR  | ACTIVE        | QFN          | RUC             | 14   | 3000        | RoHS & Green    | NIPDAUAG                             | Level-1-260C-UNLIM   | -40 to 85    | 6NH                     | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

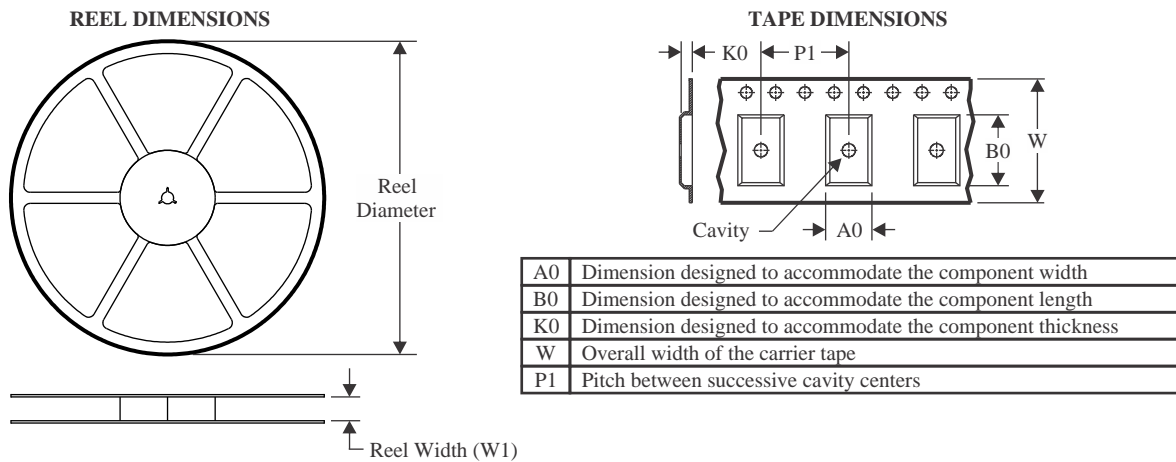
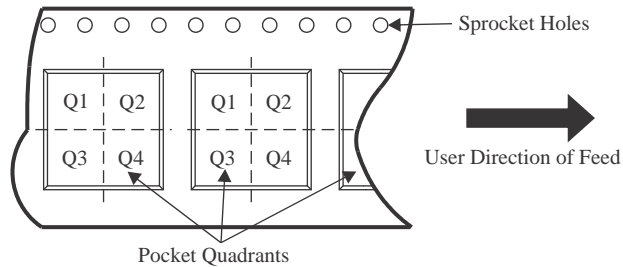
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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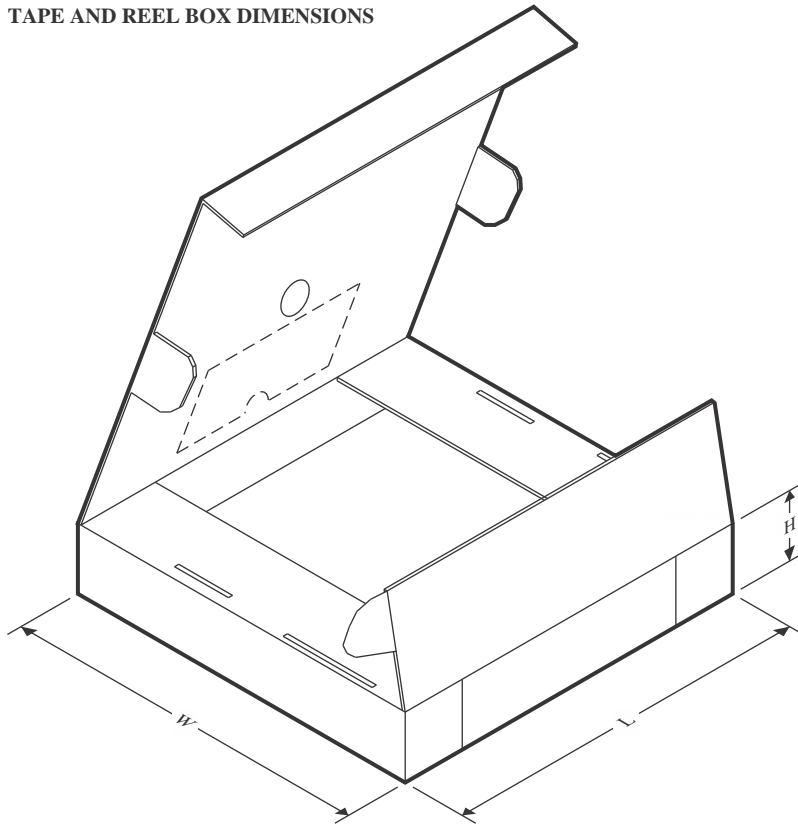


**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

| Device          | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPL0102-100PWR  | TSSOP        | PW              | 14   | 2000 | 330.0              | 12.4               | 6.9     | 5.6     | 1.6     | 8.0     | 12.0   | Q1            |
| TPL0102-100RUCR | QFN          | RUC             | 14   | 3000 | 180.0              | 8.4                | 2.3     | 2.3     | 0.55    | 4.0     | 8.0    | Q2            |

## TAPE AND REEL BOX DIMENSIONS

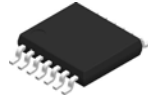


\*All dimensions are nominal

| Device          | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|-----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPL0102-100PWR  | TSSOP        | PW              | 14   | 2000 | 356.0       | 356.0      | 35.0        |
| TPL0102-100RUCR | QFN          | RUC             | 14   | 3000 | 202.0       | 201.0      | 28.0        |



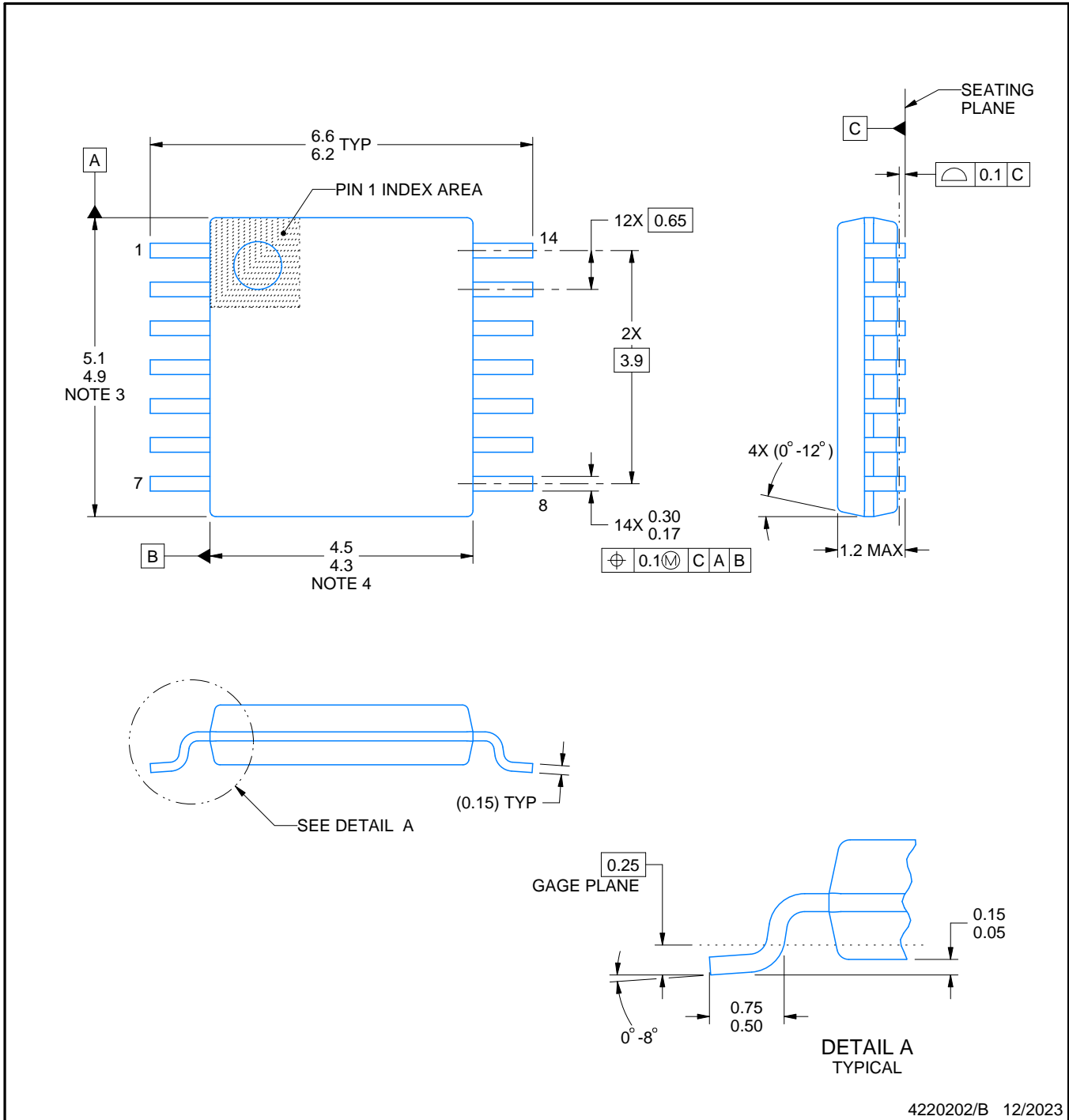
PW0014A



PACKAGE OUTLINE

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



4220202/B 12/2023

NOTES:

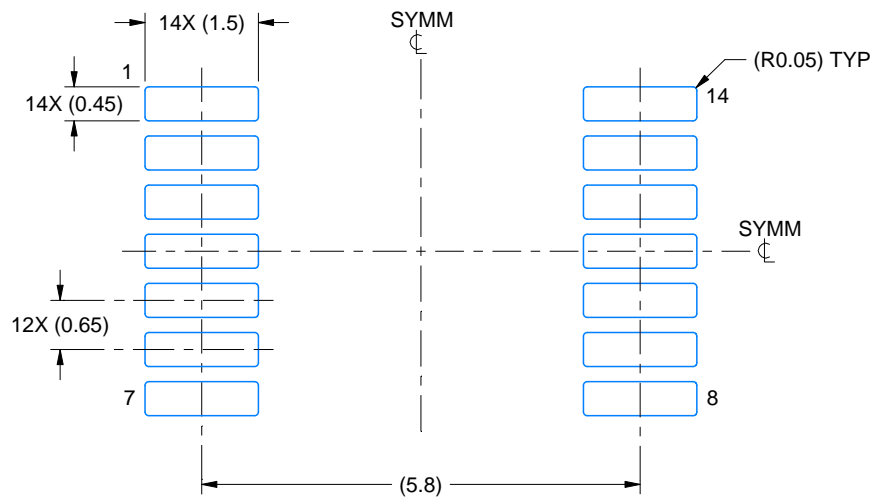
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153.

# EXAMPLE BOARD LAYOUT

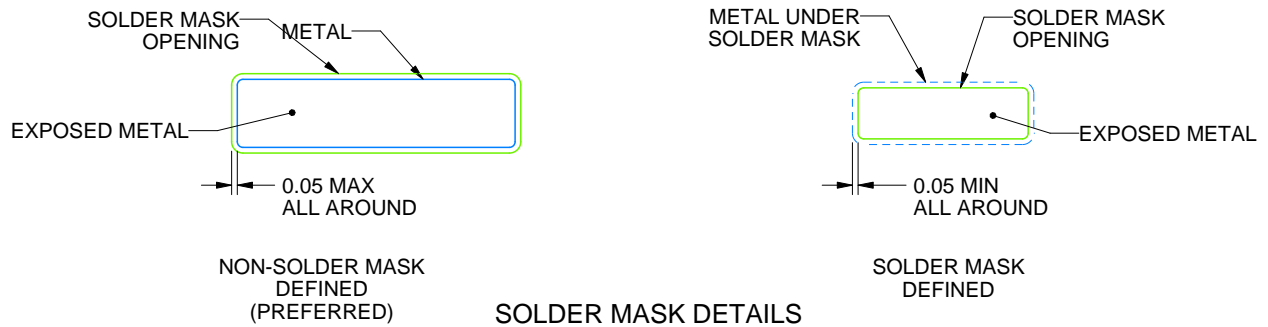
PW0014A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 10X



4220202/B 12/2023

NOTES: (continued)

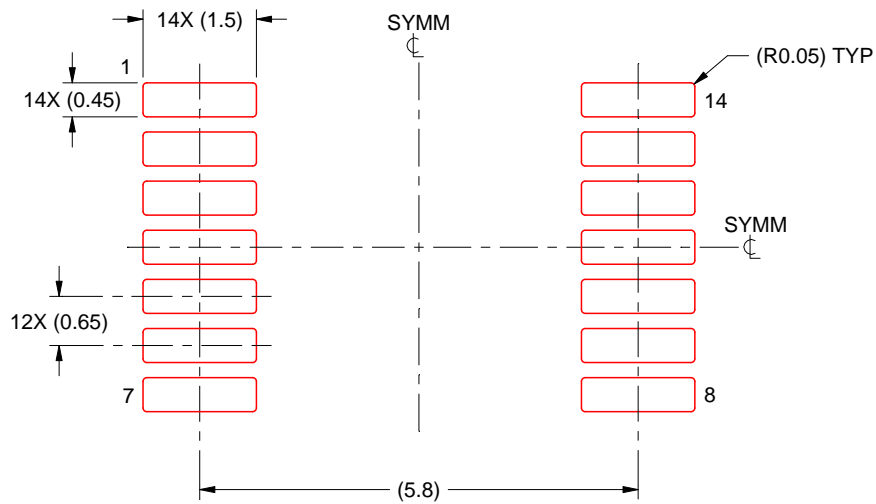
- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

PW0014A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE: 10X

4220202/B 12/2023

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

## GENERIC PACKAGE VIEW

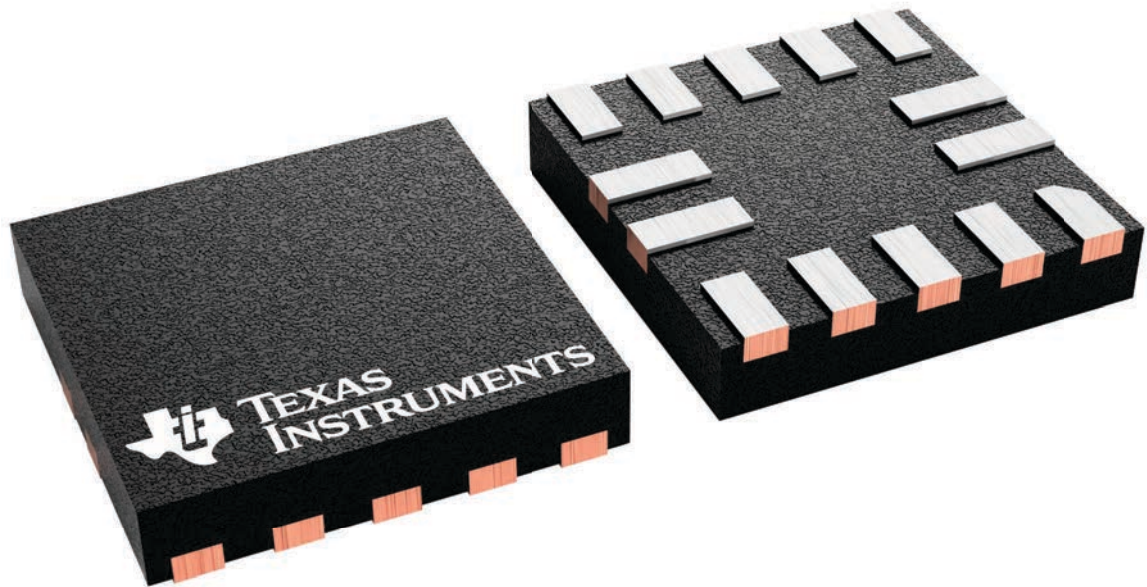
**RUC 14**

**X2QFN - 0.4 mm max height**

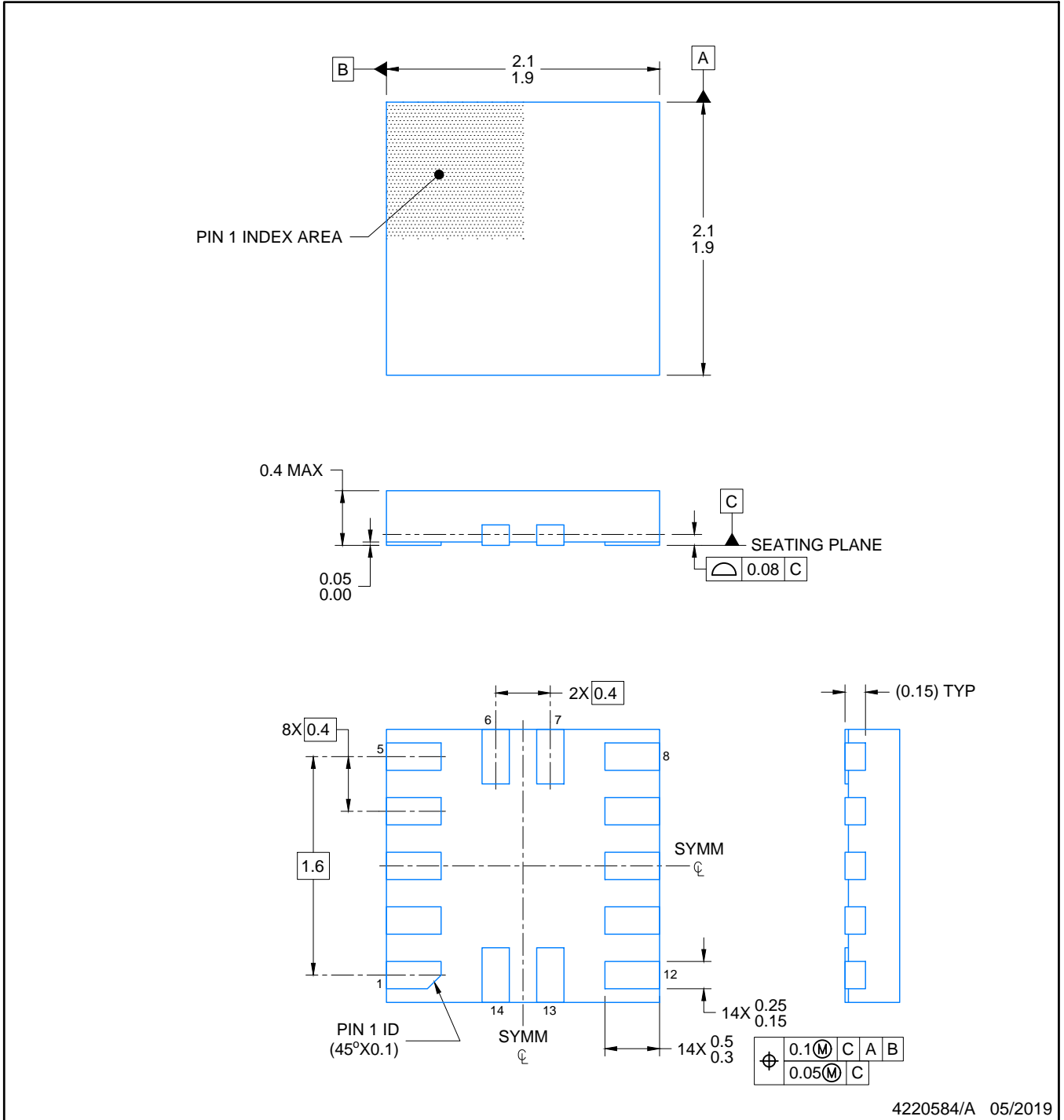
2 x 2, 0.4 mm pitch

PLASTIC QUAD FLATPACK - NO LEAD

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



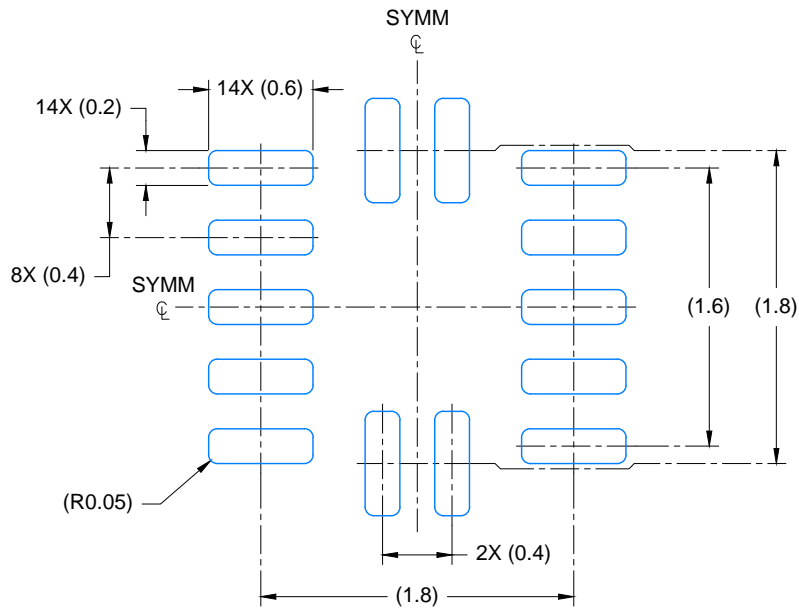
4229871/A



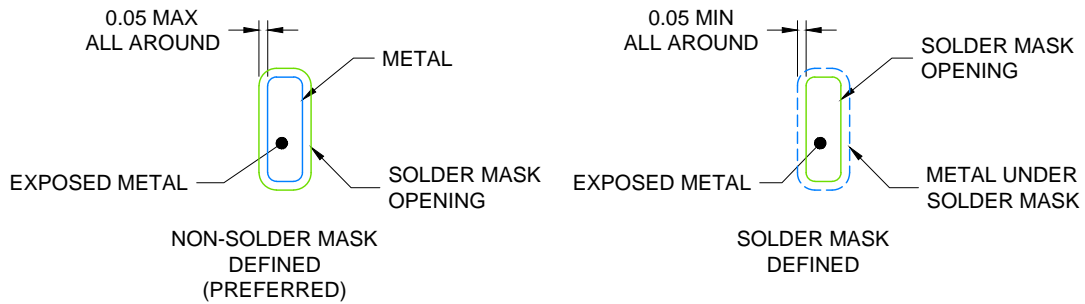
4220584/A 05/2019

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 23X



SOLDER MASK DETAILS

4220584/A 05/2019

NOTES: (continued)

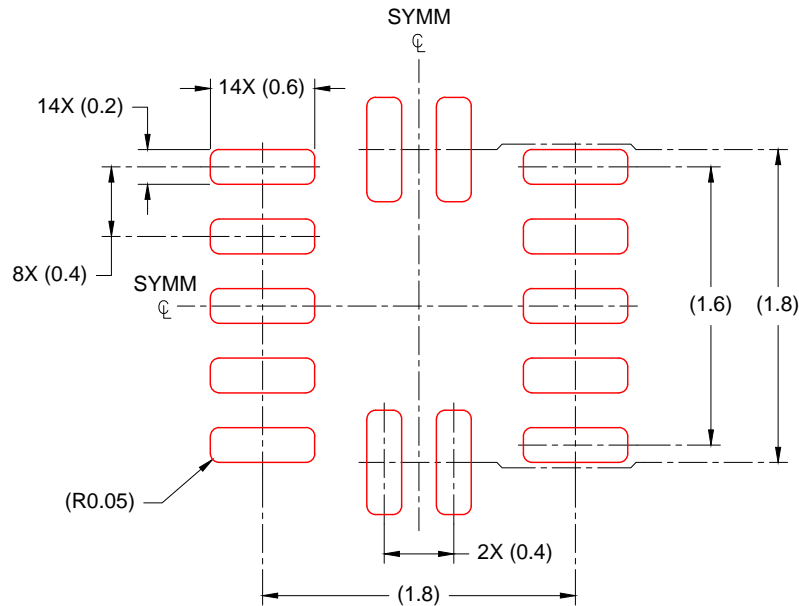
- For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).

# EXAMPLE STENCIL DESIGN

RUC0014A

X2QFN - 0.4 mm max height

PLASTIC QUAD FLAT PACK- NO LEAD



SOLDER PASTE EXAMPLE  
BASED ON 0.100mm THICK STENCIL  
SCALE: 23X

4220584/A 05/2019

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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