

# ISO654x General Purpose Quad-Channel Functional Isolators

## 1 Features

- Up to 50Mbps data rate
- Robust SiO<sub>2</sub> isolation barrier
- Functional Isolation (DBQ-16):
  - 400V<sub>RMS</sub> , 566V<sub>DC</sub> working voltage
  - 707V<sub>RMS</sub> , 1000V<sub>DC</sub> transient voltage (60s)
- Wide temperature range: –40°C to 125°C
- ±150kV/μs typical CMTI
- Supply range: 1.71V to 5.5V
- Default output *high* ( ISO654x ) and *low* ( ISO654xF ) options
- 1.5mA per channel typical at 1Mbps and 3.3V (ISO6540)
- Low propagation delay: 11ns typical at 3.3V
- Robust electromagnetic compatibility (EMC)
  - System-level ESD, EFT, and surge immunity
  - Low emissions
- SSOP (DBQ-16) Package

## 2 Applications

- [Power supplies](#)
- [Grid, electricity meter](#)
- [Motor drives](#)
- [Factory automation](#)
- [Building automation](#)
- [Lighting](#)
- [Appliances](#)

## 3 Description

The ISO654x devices are general purpose functional isolators for cost sensitive, space constrained applications that require isolation for non-safety applications. The isolation barrier supports a working voltage of 400V<sub>RMS</sub> / 566V<sub>DC</sub> and transient over voltages of 707V<sub>RMS</sub> / 1000V<sub>DC</sub> .

The ISO654x devices provide high EMC performance while isolating CMOS or LVCMOS digital I/Os. ISO654x uses SiO<sub>2</sub> as the isolation barrier. Each isolation channel has a logic input and output buffer separated by the insulation barrier. These devices come with enable pins that can be used to put the respective outputs in high impedance.

The ISO6540 and ISO6540F devices have all channels in the forward direction. The ISO6541 and ISO6541F devices have one reverse-direction channel. The ISO6542 and ISO6542F devices have two reverse-direction channels.

In the event of input power or signal loss, the default output is *high* for devices without the suffix F and *low* for devices with the suffix F. See [Section 7.4](#) for further details.

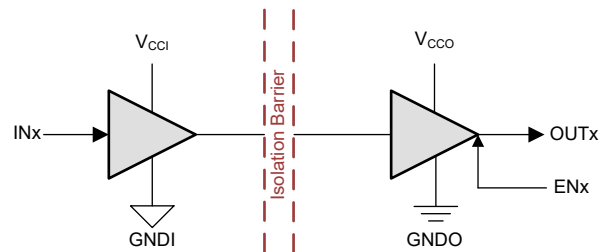
These devices help prevent noise currents on GPIOs or data buses such as SPI, UART RS-485, RS-232, and CAN from causing data corruption or damaging sensitive circuitry. Through chip design and layout techniques, the electromagnetic compatibility of the devices have been significantly enhanced to ease system-level design.

### Package Information

| PART NUMBER <sup>(1)</sup> | PACKAGE       | PACKAGE SIZE <sup>(2)</sup> |
|----------------------------|---------------|-----------------------------|
| ISO6540 , ISO6540F         | SSOP (DBQ-16) | 6mm × 4.9mm                 |
| ISO6541 , ISO6541F         |               |                             |
| ISO6542 , ISO6542F         |               |                             |

(1) For more information, see [Section 11](#).

(2) The package size (length × width) is a nominal value and includes pins, where applicable.



V<sub>CCI</sub>=Input supply, V<sub>CCO</sub>=Output supply  
 GNDI=Input ground, GNDO=Output ground

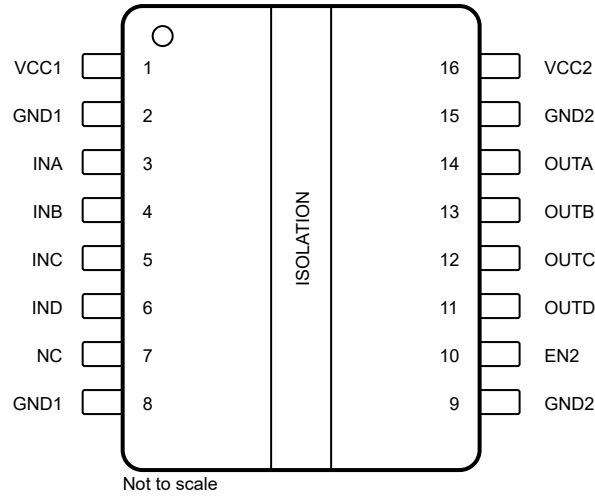
### Simplified Schematic



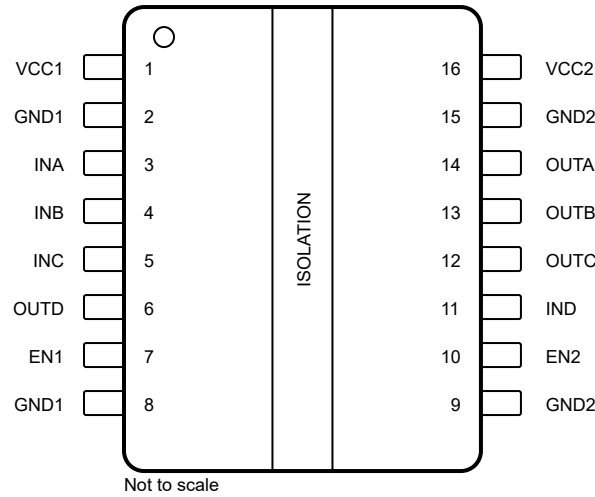
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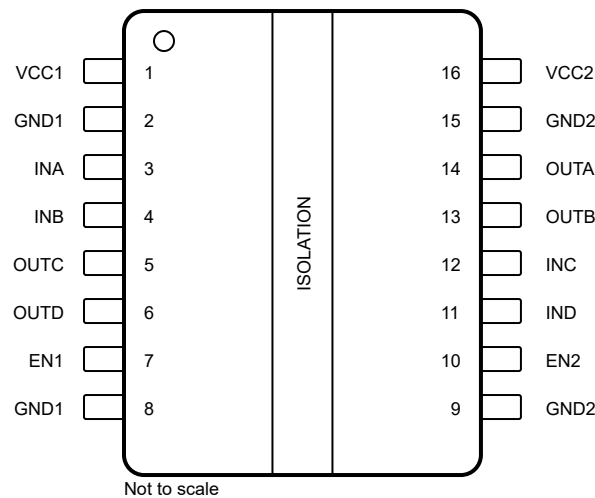
## 4 Pin Configuration and Functions



**Figure 4-1. ISO6540 and ISO6540F Top View**



**Figure 4-2. ISO6541 and ISO6541F Top View**



**Figure 4-3. ISO6542 and ISO6542F Top View**

**Table 4-1. Pin Functions**

| NAME             | PIN                   |                       |                       | Type <sup>(1)</sup> | DESCRIPTION  |
|------------------|-----------------------|-----------------------|-----------------------|---------------------|--|
|                  | ISO6540 ,<br>ISO6540F | ISO6541 ,<br>ISO6541F | ISO6542 ,<br>ISO6542F |                     |  |
| EN1              | -                     | 7                     | 7                     | I                   | Output enable 1. Output pins on side 1 are enabled when EN1 is high or open and in high-impedance state when EN1 is low. |
| EN2              | 10                    | 10                    | 10                    | I                   | Output enable 2. Output pins on side 2 are enabled when EN2 is high or open and in high-impedance state when EN2 is low. |
| GND1             | 2, 8                  | 2,8                   | 2,8                   | —                   | Ground connection for V <sub>CC1</sub>   |
| GND2             | 9, 15                 | 9,15                  | 9,15                  | —                   | Ground connection for V <sub>CC2</sub>   |
| INA              | 3                     | 3                     | 3                     | I                   | Input, channel A   |
| INB              | 4                     | 4                     | 4                     | I                   | Input, channel B   |
| INC              | 5                     | 5                     | 12                    | I                   | Input, channel C   |
| IND              | 6                     | 11                    | 11                    | I                   | Input, channel D   |
| NC               | 7                     | -                     | -                     |                     | Not connected  |
| OUTA             | 14                    | 14                    | 14                    | O                   | Output, channel A  |
| OUTB             | 13                    | 13                    | 13                    | O                   | Output, channel B  |
| OUTC             | 12                    | 12                    | 5                     | O                   | Output, channel C  |
| OUTD             | 11                    | 6                     | 6                     | O                   | Output, channel D  |
| V <sub>CC1</sub> | 1                     | 1                     | 1                     | —                   | Power supply, side 1   |
| V <sub>CC2</sub> | 16                    | 16                    | 16                    | —                   | Power supply, side 2   |

(1) I = Input, O = Output

## 5 Specifications

### 5.1 Absolute Maximum Ratings

See<sup>(1)</sup>

|                                       |  | MIN  | MAX                                   | UNIT             |
|---------------------------------------|--|------|---------------------------------------|------------------|
| Supply voltage <sup>(2)</sup>         | V <sub>CC1</sub> to GND1                       | -0.5 | 6                                     | V                |
|                                       | V <sub>CC2</sub> to GND2                       | -0.5 | 6                                     |                  |
| Input/Output Voltage                  | IN <sub>x</sub> to GND <sub>x</sub>            | -0.5 | V <sub>CCX</sub> + 0.5 <sup>(3)</sup> | V                |
|                                       | OUT <sub>x</sub> to GND <sub>x</sub>           | -0.5 | V <sub>CCX</sub> + 0.5 <sup>(3)</sup> |                  |
| Output current                        | I <sub>o</sub>                                 | -15  | 15                                    | mA               |
| Temperature                           | Operating junction temperature, T <sub>J</sub> |      | 150                                   | °C               |
|                                       | Storage temperature, T <sub>stg</sub>          | -65  | 150                                   | °C               |
| Transient Isolation Voltage (SSOP-16) | AC Voltage, t=60s                              |      | 707                                   | V <sub>RMS</sub> |
|                                       | DC Voltage, t=60s                              |      | 1000                                  | V <sub>DC</sub>  |

- (1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) All voltage values except differential I/O bus voltages are with respect to the local ground terminal (GND1 or GND2) and are peak voltage values
- (3) Maximum voltage must not exceed 6V.

### 5.2 ESD Ratings

|                    |                         |  | VALUE | UNIT |
|--------------------|-------------------------|--|-------|------|
| V <sub>(ESD)</sub> | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup>              | ±6000 | V    |
|                    |                         | Charged device model (CDM), per JEDEC specification JESD22-C101, all pins <sup>(2)</sup> | ±1500 |      |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 5.3 Recommended Operating Conditions

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

|                          |  |  | MIN                                 | NOM                  | MAX       | UNIT      |
|--------------------------|--|--|-------------------------------------|----------------------|-----------|-----------|
| $V_{CC1}$ <sup>(1)</sup> | Supply Voltage Side 1                          | $V_{CC} = 1.8V$ <sup>(3)</sup>         | 1.71                                |                      | 1.89      | V         |
| $V_{CC1}$ <sup>(1)</sup> | Supply Voltage Side 1                          | $V_{CC} = 2.5V$ to $5V$ <sup>(3)</sup> | 2.25                                |                      | 5.5       | V         |
| $V_{CC2}$ <sup>(1)</sup> | Supply Voltage Side 2                          | $V_{CC} = 1.8V$ <sup>(3)</sup>         | 1.71                                |                      | 1.89      | V         |
| $V_{CC2}$ <sup>(1)</sup> | Supply Voltage Side 2                          | $V_{CC} = 2.5V$ to $5V$ <sup>(3)</sup> | 2.25                                |                      | 5.5       | V         |
| $V_{CC}$ (UVLO+)         | UVLO threshold when supply voltage is rising   |  |                                     | 1.53                 | 1.71      | V         |
| $V_{CC}$ (UVLO-)         | UVLO threshold when supply voltage is falling  |  | 1.1                                 | 1.41                 |           | V         |
| $V_{hys}$ (UVLO)         | Supply voltage UVLO hysteresis                 |  | 0.08                                | 0.13                 |           | V         |
| $V_{IH}$                 | High level Input voltage                       |  | $0.7 \times V_{CCI}$ <sup>(2)</sup> |                      | $V_{CCI}$ | V         |
| $V_{IL}$                 | Low level Input voltage                        |  | 0                                   | $0.3 \times V_{CCI}$ |           | V         |
| $I_{OH}$                 | High level output current                      | $V_{CCO} = 5V$ <sup>(2)</sup>          | -4                                  |                      |           | mA        |
|                          |  | $V_{CCO} = 3.3V$                       | -2                                  |                      |           | mA        |
|                          |  | $V_{CCO} = 2.5V$                       | -1                                  |                      |           | mA        |
|                          |  | $V_{CCO} = 1.8V$                       | -1                                  |                      |           | mA        |
| $I_{OL}$                 | Low level output current                       | $V_{CCO} = 5V$                         |                                     |                      | 4         | mA        |
|                          |  | $V_{CCO} = 3.3V$                       |                                     |                      | 2         | mA        |
|                          |  | $V_{CCO} = 2.5V$                       |                                     |                      | 1         | mA        |
|                          |  | $V_{CCO} = 1.8V$                       |                                     |                      | 1         | mA        |
| DR                       | Data Rate                                      |  | 0                                   |                      | 50        | Mbps      |
| $T_A$                    | Ambient temperature                            |  | -40                                 | 25                   | 125       | °C        |
| $T_A$                    | Functional Isolation Working Voltage (SSOP-16) | AC Voltage (sine wave)                 |                                     |                      | 400       | $V_{RMS}$ |
|                          |  | DC Voltage                             |                                     |                      | 566       | $V_{DC}$  |

(1)  $V_{CC1}$  and  $V_{CC2}$  can be set independent of one another

(2)  $V_{CCI} =$  Input-side  $V_{CC}$ ;  $V_{CCO} =$  Output-side  $V_{CC}$

(3) The channel outputs are in undetermined state when  $1.89V < V_{CC1}$ ,  $V_{CC2} < 2.25V$  and  $1.05V < V_{CC1}$ ,  $V_{CC2} < 1.71V$

## 5.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |  | ISO654x    | UNIT |
|-------------------------------|--|------------|------|
|                               |  | DBQ (SSOP) |      |
|                               |  | 16 PINS    |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 73         | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 36.1       | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 40.4       | °C/W |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 17         | °C/W |
| $\Psi_{JB}$                   | Junction-to-board characterization parameter | 39.9       | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | —          | °C/W |

(1) For more information about traditional and new thermal metrics, see the [no.](#)

## 5.5 Package Characteristics

| PARAMETER       |   | TEST CONDITIONS                                  | VALUE             | UNIT |
|-----------------|---|--|-------------------|------|
|                 |   |  | DBQ-16            |      |
| CLR             | External clearance <sup>(1)</sup>                   | Side 1 to side 2 distance through air            | >3.7              | mm   |
| CPG             | External creepage <sup>(1)</sup>                    | Side 1 to side 2 distance across package surface | >3.7              | mm   |
| CTI             | Comparative tracking index                          | IEC 60112; UL 746A                               | >600              | V    |
|                 | Material group                                      | According to IEC 60664-1                         | I                 |      |
| C <sub>IO</sub> | Barrier capacitance, input to output <sup>(2)</sup> | V <sub>IO</sub> = 0.4 x sin(2πft), f = 1MHz      | ≅1                | pF   |
| R <sub>IO</sub> | Isolation resistance <sup>(2)</sup>                 | T <sub>A</sub> = 25°C                            | >10 <sup>12</sup> | Ω    |

- (1) Creepage and clearance requirements should be applied according to the specific equipment isolation standards of an application. Care should be taken to maintain the creepage and clearance distance of a board design to ensure that the mounting pads of the isolator on the printed-circuit board do not reduce this distance. Creepage and clearance on a printed-circuit board become equal in certain cases. Techniques such as inserting grooves and/or ribs on a printed-circuit board are used to help increase these specifications.
- (2) All pins on each side of the barrier tied together creating a two-terminal device.



## 5.6 Electrical Characteristics—5-V Supply

$V_{CC1} = V_{CC2} = 5\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER     |                                    | TEST CONDITIONS   | MIN                            | TYP                                 | MAX | UNIT                    |
|---------------|------------------------------------|---|--------------------------------|-------------------------------------|-----|-------------------------|
| $V_{OH}$      | High-level output voltage          | $I_{OH} = -4\text{mA}$ ; See <a href="#">Section 6</a>                                    | $V_{CCO} - 0.4$ <sup>(1)</sup> |                                     |     | V                       |
| $V_{OL}$      | Low-level output voltage           | $I_{OH} = 4\text{mA}$ ; See <a href="#">Section 6</a>                                     |                                |                                     | 0.4 | V                       |
| $V_{IT+(IN)}$ | Rising input switching threshold   |   |                                | $0.7 \times V_{CCI}$ <sup>(1)</sup> |     | V                       |
| $V_{IT-(IN)}$ | Falling input switching threshold  |   | $0.3 \times V_{CCI}$           |                                     |     | V                       |
| $V_{I(HYS)}$  | Input threshold voltage hysteresis |   | $0.1 \times V_{CCI}$           |                                     |     | V                       |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at INx  |                                |                                     | 10  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at INx  | -10                            |                                     |     | $\mu\text{A}$           |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at ENx  |                                |                                     | 28  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at ENx  | -28                            |                                     |     | $\mu\text{A}$           |
| CMTI          | Common mode transient immunity     | $V_I = V_{CC}$ or $0\text{ V}$ , $V_{CM} = 1200\text{ V}$ ; See <a href="#">Section 6</a> | 100                            | 150                                 |     | $\text{kV}/\mu\text{A}$ |
| $C_i$         | Input Capacitance <sup>(2)</sup>   | $V_I = V_{CC}/2 + 0.4 \times \sin(2\pi ft)$ , $f = 2\text{ MHz}$ , $V_{CC} = 5\text{ V}$  |                                | 2.8                                 |     | pF                      |

(1)  $V_{CCI}$  = Input-side  $V_{CC}$ ;  $V_{CCO}$  = Output-side  $V_{CC}$

(2) Measured from input pin to same side ground.

## 5.7 Supply Current Characteristics—5-V Supply

$V_{CC1} = V_{CC2} = 5\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER                         | TEST CONDITIONS   | SUPPLY CURRENT     | MIN                | TYP  | MAX  | UNIT |      |
|-----------------------------------|---|--------------------|--------------------|------|------|------|------|
| <b>ISO6540</b>                    |   |                    |                    |      |      |      |      |
| Supply current - DC signal<br>(2) | $V_I = V_{CC1}$ (1)(ISO6540); $V_I = 0\text{ V}$ (ISO6540 with F suffix)  | $I_{CC1}$          |                    | 1.6  | 2.4  | mA   |      |
|                                   |   | $I_{CC2}$          |                    | 2.1  | 3.7  |      |      |
|                                   | $V_I = 0\text{ V}$ (ISO6540); $V_I = V_{CC1}$ (ISO6540 with F suffix)     | $I_{CC1}$          |                    | 5.8  | 8    |      |      |
|                                   |   | $I_{CC2}$          |                    | 2.3  | 4.0  |      |      |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}$          |      | 3.7  |      | 5.1  |
|                                   |   |                    | $I_{CC2}$          |      | 2.4  |      | 4.1  |
|                                   |   | 10 Mbps            | $I_{CC1}$          |      | 3.8  |      | 5.3  |
|                                   |   |                    | $I_{CC2}$          |      | 4.8  |      | 6.6  |
|                                   |   | 50 Mbps            | $I_{CC1}$          |      | 4.4  | 6    |      |
|                                   |   |                    | $I_{CC2}$          |      | 15   | 18.1 |      |
| <b>ISO6541</b>                    |   |                    |                    |      |      |      |      |
| Supply current - DC signal<br>(2) | $V_I = V_{CCI}$ (1)(ISO6541); $V_I = 0\text{ V}$ (ISO6541 with F suffix)  | $I_{CC1}$          |                    | 1.9  | 2.9  | mA   |      |
|                                   |   | $I_{CC2}$          |                    | 2.2  | 3.8  |      |      |
|                                   | $V_I = 0\text{ V}$ (ISO6541); $V_I = V_{CCI}$ (ISO6541 with F suffix)     | $I_{CC1}$          |                    | 5.1  | 7.2  |      |      |
|                                   |   | $I_{CC2}$          |                    | 3.4  | 5.2  |      |      |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}$          |      | 3.6  |      | 5.1  |
|                                   |   |                    | $I_{CC2}$          |      | 3    |      | 4.7  |
|                                   |   | 10 Mbps            | $I_{CC1}$          |      | 4.2  |      | 5.8  |
|                                   |   |                    | $I_{CC2}$          |      | 4.8  |      | 6.5  |
|                                   |   | 50 Mbps            | $I_{CC1}$          |      | 7.3  | 9.3  |      |
|                                   |   |                    | $I_{CC2}$          |      | 12.6 | 15.3 |      |
| <b>ISO6542</b>                    |   |                    |                    |      |      |      |      |
| Supply current - DC signal<br>(2) | $V_I = V_{CCI}$ (1)(ISO6542); $V_I = 0\text{ V}$ (ISO6542 with F suffix)  | $I_{CC1}, I_{CC2}$ |                    | 2.2  | 3.5  | mA   |      |
|                                   | $V_I = 0\text{ V}$ (ISO6542); $V_I = V_{CCI}$ (ISO6542 with F suffix)     | $I_{CC1}, I_{CC2}$ |                    | 4.4  | 6.3  |      |      |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}, I_{CC2}$ |      | 3.4  |      | 5    |
|                                   |   |                    | $I_{CC1}, I_{CC2}$ |      | 4.7  |      | 6.4  |
|                                   |   | 10 Mbps            | $I_{CC1}, I_{CC2}$ |      | 4.7  |      | 6.4  |
|                                   |   |                    | $I_{CC1}, I_{CC2}$ |      | 10.2 |      | 12.5 |
| 50 Mbps                           | $I_{CC1}, I_{CC2}$  |                    | 10.2               | 12.5 |      |      |      |
|                                   | $I_{CC1}, I_{CC2}$  |                    | 10.2               | 12.5 |      |      |      |

- (1)  $V_{CCI} = \text{Input-side } V_{CC}$   
(2) Supply current valid for  $ENx = V_{CCx}$  and  $ENx = 0\text{ V}$   
(3) Supply current valid for  $ENx = V_{CCx}$

## 5.8 Electrical Characteristics—3.3-V Supply

$V_{CC1} = V_{CC2} = 3.3\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER     |                                    | TEST CONDITIONS   | MIN                            | TYP                                 | MAX | UNIT                    |
|---------------|------------------------------------|---|--------------------------------|-------------------------------------|-----|-------------------------|
| $V_{OH}$      | High-level output voltage          | $I_{OH} = -2\text{mA}$ ; See <a href="#">Section 6</a>                                      | $V_{CCO} - 0.2$ <sup>(1)</sup> |                                     |     | V                       |
| $V_{OL}$      | Low-level output voltage           | $I_{OH} = 2\text{mA}$ ; See <a href="#">Section 6</a>                                       |                                |                                     | 0.2 | V                       |
| $V_{IT+(IN)}$ | Rising input switching threshold   |   |                                | $0.7 \times V_{CCI}$ <sup>(1)</sup> |     | V                       |
| $V_{IT-(IN)}$ | Falling input switching threshold  |   | $0.3 \times V_{CCI}$           |                                     |     | V                       |
| $V_{I(HYS)}$  | Input threshold voltage hysteresis |   | $0.1 \times V_{CCI}$           |                                     |     | V                       |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at INx  |                                |                                     | 10  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at INx  | -10                            |                                     |     | $\mu\text{A}$           |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at ENx  |                                |                                     | 30  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at ENx  | -30                            |                                     |     | $\mu\text{A}$           |
| CMTI          | Common mode transient immunity     | $V_I = V_{CC}$ or $0\text{ V}$ , $V_{CM} = 1200\text{ V}$ ; See <a href="#">Section 6</a>   | 100                            | 150                                 |     | $\text{kV}/\mu\text{A}$ |
| $C_i$         | Input Capacitance <sup>(2)</sup>   | $V_I = V_{CC}/2 + 0.4 \times \sin(2\pi f t)$ , $f = 2\text{ MHz}$ , $V_{CC} = 3.3\text{ V}$ |                                | 2.8                                 |     | pF                      |

(1)  $V_{CCI} = \text{Input-side } V_{CC}$ ;  $V_{CCO} = \text{Output-side } V_{CC}$

(2) Measured from input pin to same side ground.

## 5.9 Supply Current Characteristics—3.3-V Supply

$V_{CC1} = V_{CC2} = 3.3\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER                                 | TEST CONDITIONS  | SUPPLY CURRENT     | MIN                | TYP                | MAX  | UNIT |     |
|---|--|--------------------|--------------------|--------------------|------|------|-----|
| <b>ISO6540</b>                            |  |                    |                    |                    |      |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CC1}$ <sup>(1)</sup> (ISO6540); $V_I = 0\text{ V}$ (ISO6540 with F suffix) | $I_{CC1}$          |                    | 1.6                | 2.3  | mA   |     |
|   |  | $I_{CC2}$          |                    | 2.1                | 3.7  |      |     |
|   | $V_I = 0\text{ V}$ (ISO6540); $V_I = V_{CC1}$ (ISO6540 with F suffix)                | $I_{CC1}$          |                    | 5.7                | 8    |      |     |
|   |  | $I_{CC2}$          |                    | 2.3                | 4.0  |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}$          |                    | 3.7  |      | 5.1 |
|   |  |                    | $I_{CC2}$          |                    | 2.4  |      | 4.0 |
|   |  | 10 Mbps            | $I_{CC1}$          |                    | 3.8  |      | 5.2 |
|   |  |                    | $I_{CC2}$          |                    | 4    |      | 5.8 |
|   |  | 50 Mbps            | $I_{CC1}$          |                    | 4.2  | 5.7  |     |
|   |  |                    | $I_{CC2}$          |                    | 11.2 | 13.8 |     |
| <b>ISO6541</b>                            |  |                    |                    |                    |      |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CCI}$ <sup>(1)</sup> (ISO6541); $V_I = 0\text{ V}$ (ISO6541 with F suffix) | $I_{CC1}$          |                    | 1.9                | 2.9  | mA   |     |
|   |  | $I_{CC2}$          |                    | 2.2                | 3.7  |      |     |
|   | $V_I = 0\text{ V}$ (ISO6541); $V_I = V_{CCI}$ (ISO6541 with F suffix)                | $I_{CC1}$          |                    | 5                  | 7.1  |      |     |
|   |  | $I_{CC2}$          |                    | 3.4                | 5.1  |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}$          |                    | 3.5  |      | 5   |
|   |  |                    | $I_{CC2}$          |                    | 2.9  |      | 4.6 |
|   |  | 10 Mbps            | $I_{CC1}$          |                    | 4    |      | 5.5 |
|   |  |                    | $I_{CC2}$          |                    | 4.2  |      | 5.9 |
|   |  | 50 Mbps            | $I_{CC1}$          |                    | 6.1  | 8    |     |
|   |  |                    | $I_{CC2}$          |                    | 9.7  | 12.1 |     |
| <b>ISO6542</b>                            |  |                    |                    |                    |      |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CCI}$ <sup>(1)</sup> (ISO6542); $V_I = 0\text{ V}$ (ISO6542 with F suffix) | $I_{CC1}, I_{CC2}$ |                    | 2.2                | 3.4  | mA   |     |
|   | $V_I = 0\text{ V}$ (ISO6542); $V_I = V_{CCI}$ (ISO6542 with F suffix)                | $I_{CC1}, I_{CC2}$ |                    | 4.4                | 6.3  |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}, I_{CC2}$ |                    | 3.4  |      | 4.9 |
|   |  |                    | 10 Mbps            | $I_{CC1}, I_{CC2}$ |      |      | 4.2 |
|   |  | 50 Mbps            |                    | $I_{CC1}, I_{CC2}$ |      |      | 8.2 |

- (1)  $V_{CCI} = \text{Input-side } V_{CC}$   
(2) Supply current valid for  $ENx = V_{CCx}$  and  $ENx = 0\text{V}$   
(3) Supply current valid for  $ENx = V_{CCx}$

## 5.10 Electrical Characteristics—2.5-V Supply

$V_{CC1} = V_{CC2} = 2.5 \text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER     |                                    | TEST CONDITIONS   | MIN                            | TYP                                 | MAX | UNIT                    |
|---------------|------------------------------------|---|--------------------------------|-------------------------------------|-----|-------------------------|
| $V_{OH}$      | High-level output voltage          | $I_{OH} = -1\text{mA}$ ; See <a href="#">Section 6</a>  | $V_{CCO} - 0.1$ <sup>(1)</sup> |                                     |     | V                       |
| $V_{OL}$      | Low-level output voltage           | $I_{OL} = 1\text{mA}$ ; See <a href="#">Section 6</a>   |                                |                                     | 0.1 | V                       |
| $V_{IT+(IN)}$ | Rising input switching threshold   |   |                                | $0.7 \times V_{CCI}$ <sup>(1)</sup> |     | V                       |
| $V_{IT-(IN)}$ | Falling input switching threshold  |   | $0.3 \times V_{CCI}$           |                                     |     | V                       |
| $V_{I(HYS)}$  | Input threshold voltage hysteresis |   | $0.1 \times V_{CCI}$           |                                     |     | V                       |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at INx  |                                |                                     | 10  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0 \text{ V}$ at INx   | -10                            |                                     |     | $\mu\text{A}$           |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at ENx  |                                |                                     | 30  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0 \text{ V}$ at ENx   | -30                            |                                     |     | $\mu\text{A}$           |
| CMTI          | Common mode transient immunity     | $V_I = V_{CC}$ or $0 \text{ V}$ , $V_{CM} = 1200 \text{ V}$ ; See <a href="#">Section 6</a>   | 100                            | 150                                 |     | $\text{kV}/\mu\text{A}$ |
| $C_i$         | Input Capacitance <sup>(2)</sup>   | $V_I = V_{CC}/2 + 0.4 \times \sin(2\pi f t)$ , $f = 2 \text{ MHz}$ , $V_{CC} = 2.5 \text{ V}$ |                                | 2.8                                 |     | pF                      |

(1)  $V_{CCI} = \text{Input-side } V_{CC}$ ;  $V_{CCO} = \text{Output-side } V_{CC}$

(2) Measured from input pin to same side ground.

## 5.11 Supply Current Characteristics—2.5-V Supply

$V_{CC1} = V_{CC2} = 2.5\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER                         | TEST CONDITIONS   | SUPPLY CURRENT     | MIN                | TYP | MAX | UNIT |     |
|-----------------------------------|---|--------------------|--------------------|-----|-----|------|-----|
| <b>ISO6540</b>                    |   |                    |                    |     |     |      |     |
| Supply current - DC signal<br>(2) | $V_I = V_{CC1}$ (1)(ISO6540); $V_I = 0\text{ V}$ (ISO6540 with F suffix)  | $I_{CC1}$          |                    | 1.6 | 2.3 | mA   |     |
|                                   |   | $I_{CC2}$          |                    | 2.1 | 3.7 |      |     |
|                                   | $V_I = 0\text{ V}$ (ISO6540); $V_I = V_{CC1}$ (ISO6540 with F suffix)     | $I_{CC1}$          |                    | 5.7 | 7.9 |      |     |
|                                   |   | $I_{CC2}$          |                    | 2.3 | 4.0 |      |     |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}$          |     | 3.7 |      | 5.1 |
|                                   |   |                    | $I_{CC2}$          |     | 2.3 |      | 4.0 |
|                                   |   | 10 Mbps            | $I_{CC1}$          |     | 3.7 |      | 5.1 |
|                                   |   |                    | $I_{CC2}$          |     | 3.5 |      | 5.3 |
|                                   |   | 50 Mbps            | $I_{CC1}$          |     | 4.1 | 5.6  |     |
|                                   |   |                    | $I_{CC2}$          |     | 9   | 11.5 |     |
| <b>ISO6541</b>                    |   |                    |                    |     |     |      |     |
| Supply current - DC signal<br>(2) | $V_I = V_{CCI}$ (1)(ISO6541); $V_I = 0\text{ V}$ (ISO6541 with F suffix)  | $I_{CC1}$          |                    | 1.9 | 2.9 | mA   |     |
|                                   |   | $I_{CC2}$          |                    | 2.2 | 3.7 |      |     |
|                                   | $V_I = 0\text{ V}$ (ISO6541); $V_I = V_{CCI}$ (ISO6541 with F suffix)     | $I_{CC1}$          |                    | 5   | 7.1 |      |     |
|                                   |   | $I_{CC2}$          |                    | 3.4 | 5.1 |      |     |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}$          |     | 3.5 |      | 5   |
|                                   |   |                    | $I_{CC2}$          |     | 2.9 |      | 4.5 |
|                                   |   | 10 Mbps            | $I_{CC1}$          |     | 3.9 |      | 5.4 |
|                                   |   |                    | $I_{CC2}$          |     | 3.8 |      | 5.5 |
|                                   |   | 50 Mbps            | $I_{CC1}$          |     | 5.5 | 7.2  |     |
|                                   |   |                    | $I_{CC2}$          |     | 8.1 | 10.2 |     |
| <b>ISO6542</b>                    |   |                    |                    |     |     |      |     |
| Supply current - DC signal<br>(2) | $V_I = V_{CCI}$ (1)(ISO6542); $V_I = 0\text{ V}$ (ISO6542 with F suffix)  | $I_{CC1}, I_{CC2}$ |                    | 2.2 | 3.4 | mA   |     |
|                                   | $V_I = 0\text{ V}$ (ISO6542); $V_I = V_{CCI}$ (ISO6542 with F suffix)     | $I_{CC1}, I_{CC2}$ |                    | 4.3 | 6.3 |      |     |
| Supply current - AC signal<br>(3) | All channels switching with square wave clock input; $C_L = 15\text{ pF}$ | 1 Mbps             | $I_{CC1}, I_{CC2}$ |     | 3.3 |      | 4.8 |
|                                   |   | 10 Mbps            | $I_{CC1}, I_{CC2}$ |     | 4   |      | 5.6 |
|                                   |   | 50 Mbps            | $I_{CC1}, I_{CC2}$ |     | 7   |      | 9   |

- (1)  $V_{CCI} = \text{Input-side } V_{CC}$   
(2) Supply current valid for  $ENx = V_{CCx}$  and  $ENx = 0\text{ V}$   
(3) Supply current valid for  $ENx = V_{CCx}$

## 5.12 Electrical Characteristics—1.8-V Supply

$V_{CC1} = V_{CC2} = 1.8\text{ V} \pm 5\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER     |                                    | TEST CONDITIONS  | MIN                            | TYP                                 | MAX | UNIT                    |
|---------------|------------------------------------|--|--------------------------------|-------------------------------------|-----|-------------------------|
| $V_{OH}$      | High-level output voltage          | $I_{OH} = -1\text{mA}$ ; See <a href="#">Section 6</a>                                     | $V_{CCO} - 0.1$ <sup>(1)</sup> |                                     |     | V                       |
| $V_{OL}$      | Low-level output voltage           | $I_{OL} = 1\text{mA}$ ; See <a href="#">Section 6</a>                                      |                                |                                     | 0.1 | V                       |
| $V_{IT+(IN)}$ | Rising input switching threshold   |  |                                | $0.7 \times V_{CCI}$ <sup>(1)</sup> |     | V                       |
| $V_{IT-(IN)}$ | Falling input switching threshold  |  | $0.3 \times V_{CCI}$           |                                     |     | V                       |
| $V_{I(HYS)}$  | Input threshold voltage hysteresis |  | $0.1 \times V_{CCI}$           |                                     |     | V                       |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at INx   |                                |                                     | 10  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at INx   | -10                            |                                     |     | $\mu\text{A}$           |
| $I_{IH}$      | High-level input current           | $V_{IH} = V_{CCI}$ <sup>(1)</sup> at ENx   |                                |                                     | 30  | $\mu\text{A}$           |
| $I_{IL}$      | Low-level input current            | $V_{IL} = 0\text{ V}$ at ENx   | -30                            |                                     |     | $\mu\text{A}$           |
| CMTI          | Common mode transient immunity     | $V_I = V_{CC}$ or $0\text{ V}$ , $V_{CM} = 1200\text{ V}$ ; See <a href="#">Section 6</a>  | 100                            | 150                                 |     | $\text{kV}/\mu\text{A}$ |
| $C_i$         | Input Capacitance <sup>(2)</sup>   | $V_I = V_{CC}/2 + 0.4 \times \sin(2\pi ft)$ , $f = 2\text{ MHz}$ , $V_{CC} = 1.8\text{ V}$ |                                | 2.8                                 |     | pF                      |

(1)  $V_{CCI}$  = Input-side  $V_{CC}$ ;  $V_{CCO}$  = Output-side  $V_{CC}$

(2) Measured from input pin to same side ground.

### 5.13 Supply Current Characteristics—1.8-V Supply

$V_{CC1} = V_{CC2} = 1.8\text{ V} \pm 5\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER                                 | TEST CONDITIONS  | SUPPLY CURRENT     | MIN                | TYP                | MAX | UNIT |     |
|---|--|--------------------|--------------------|--------------------|-----|------|-----|
| <b>ISO6540</b>                            |  |                    |                    |                    |     |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CC1}$ <sup>(1)</sup> (ISO6540); $V_I = 0\text{ V}$ (ISO6540 with F suffix) | $I_{CC1}$          |                    | 1.2                | 1.8 | mA   |     |
|   |  | $I_{CC2}$          |                    | 2                  | 3.7 |      |     |
|   | $V_I = 0\text{ V}$ (ISO6540); $V_I = V_{CC1}$ (ISO6540 with F suffix)                | $I_{CC1}$          |                    | 5.1                | 7.6 |      |     |
|   |  | $I_{CC2}$          |                    | 2.2                | 4.0 |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}$          |                    | 3.1 |      | 4.7 |
|   |  |                    | $I_{CC2}$          |                    | 2.2 |      | 4.0 |
|   |  | 10 Mbps            | $I_{CC1}$          |                    | 3.2 |      | 4.8 |
|   |  |                    | $I_{CC2}$          |                    | 3.1 |      | 4.9 |
|   |  | 50 Mbps            | $I_{CC1}$          |                    | 3.4 | 5.1  |     |
|   |  |                    | $I_{CC2}$          |                    | 7   | 9.7  |     |
| <b>ISO6541</b>                            |  |                    |                    |                    |     |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CCI}$ <sup>(1)</sup> (ISO6541); $V_I = 0\text{ V}$ (ISO6541 with F suffix) | $I_{CC1}$          |                    | 1.5                | 2.5 | mA   |     |
|   |  | $I_{CC2}$          |                    | 2                  | 3.6 |      |     |
|   | $V_I = 0\text{ V}$ (ISO6541); $V_I = V_{CCI}$ (ISO6541 with F suffix)                | $I_{CC1}$          |                    | 4.5                | 6.9 |      |     |
|   |  | $I_{CC2}$          |                    | 3.2                | 5   |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}$          |                    | 3.1 |      | 4.7 |
|   |  |                    | $I_{CC2}$          |                    | 2.7 |      | 4.4 |
|   |  | 10 Mbps            | $I_{CC1}$          |                    | 3.3 |      | 5   |
|   |  |                    | $I_{CC2}$          |                    | 3.4 |      | 5.1 |
|   |  | 50 Mbps            | $I_{CC1}$          |                    | 4.5 | 6.3  |     |
|   |  |                    | $I_{CC2}$          |                    | 6.4 | 8.7  |     |
| <b>ISO6542</b>                            |  |                    |                    |                    |     |      |     |
| Supply current - DC signal <sup>(2)</sup> | $V_I = V_{CCI}$ <sup>(1)</sup> (ISO6542); $V_I = 0\text{ V}$ (ISO6542 with F suffix) | $I_{CC1}, I_{CC2}$ |                    | 1.9                | 3.2 | mA   |     |
|   | $V_I = 0\text{ V}$ (ISO6542); $V_I = V_{CCI}$ (ISO6542 with F suffix)                | $I_{CC1}, I_{CC2}$ |                    | 4                  | 6.1 |      |     |
| Supply current - AC signal <sup>(3)</sup> | All channels switching with square wave clock input; $C_L = 15\text{ pF}$            | 1 Mbps             | $I_{CC1}, I_{CC2}$ |                    | 3   |      | 4.7 |
|   |  |                    | 10 Mbps            | $I_{CC1}, I_{CC2}$ |     |      | 3.5 |
|   |  | 50 Mbps            |                    | $I_{CC1}, I_{CC2}$ |     |      | 5.6 |

- (1)  $V_{CCI} = \text{Input-side } V_{CC}$
- (2) Supply current valid for  $ENx = V_{CCx}$  and  $ENx = 0\text{V}$
- (3) Supply current valid for  $ENx = V_{CCx}$



## 5.14 Switching Characteristics—5-V Supply

$V_{CC1} = V_{CC2} = 5\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER          |   | TEST CONDITIONS   | MIN | TYP  | MAX  | UNIT    |
|--------------------|---|---|-----|------|------|---------|
| $t_{PLH}, t_{PHL}$ | Propagation delay time  | at 100kbps<br>See <a href="#">Section 6</a>                               |     | 11   | 18   | ns      |
| PWD                | Pulse width distortion <sup>(1)</sup> $ t_{PHL} - t_{PLH} $         |   |     | 0.2  | 7    | ns      |
| $t_{sk(o)}$        | Channel-to-channel output skew time <sup>(2)</sup>                  | Same-direction channels   |     |      | 6    | ns      |
| $t_{sk(pp)}$       | Part-to-part skew time <sup>(3)</sup>                               |   |     |      | 6    | ns      |
| $t_r$              | Output signal rise time   | See <a href="#">Section 6</a>   |     | 2.6  | 4.5  | ns      |
| $t_f$              | Output signal fall time   |   |     | 2.6  | 4.5  | ns      |
| $t_{PHZ}$          | Disable propagation delay, high-to-high impedance output            | See <a href="#">Section 6</a>   |     | 18.6 | 25.8 | ns      |
| $t_{PLZ}$          | Disable propagation delay, low-to-high impedance output             |   |     | 18.6 | 25.8 | ns      |
| $t_{PZH}$          | Enable propagation delay, high impedance-to-high output for ISO654x |   |     | 14.2 | 21.1 | ns      |
| $t_{PZL}$          | Enable propagation delay, high impedance-to-low output for ISO654x  |   |     | 14.2 | 21.1 | ns      |
| $t_{PU}$           | Time from UVLO to valid output data                                 |   |     |      | 300  | $\mu$ s |
| $t_{DO}$           | Default output delay time from input power loss                     | Measured from the time VCC goes below 1.2V. See <a href="#">Section 6</a> |     | 0.1  | 0.3  | $\mu$ s |
| $t_{ie}$           | Time interval error   | $2^{16} - 1$ PRBS data at 50 Mbps   |     | 1    |      | ns      |

- (1) Also known as pulse skew.
- (2)  $t_{sk(o)}$  is the skew between outputs of a single device with all driving inputs connected together and the outputs switching in the same direction while driving identical loads.
- (3)  $t_{sk(pp)}$  is the magnitude of the difference in propagation delay times between any terminals of different devices switching in the same direction while operating at identical supply voltages, temperature, input signals and loads.

## 5.15 Switching Characteristics—3.3-V Supply

$V_{CC1} = V_{CC2} = 3.3\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER          |   | TEST CONDITIONS   | MIN | TYP  | MAX  | UNIT    |
|--------------------|---|---|-----|------|------|---------|
| $t_{PLH}, t_{PHL}$ | Propagation delay time  | at 100kbps<br>See <a href="#">Figure 1-1</a>                              |     | 11   | 18   | ns      |
| PWD                | Pulse width distortion <sup>(1)</sup> $ t_{PHL} - t_{PLH} $         |   |     | 0.5  | 7    | ns      |
| $t_{sk(o)}$        | Channel-to-channel output skew time <sup>(2)</sup>                  | Same-direction channels   |     |      | 6    | ns      |
| $t_{sk(pp)}$       | Part-to-part skew time <sup>(3)</sup>                               |   |     |      | 7    | ns      |
| $t_r$              | Output signal rise time   | See <a href="#">Section 6</a>   |     | 1.6  | 3.2  | ns      |
| $t_f$              | Output signal fall time   |   |     | 1.6  | 3.2  | ns      |
| $t_{PHZ}$          | Disable propagation delay, high-to-high impedance output            | See <a href="#">Section 6</a>   |     | 23.2 | 34.4 | ns      |
| $t_{PLZ}$          | Disable propagation delay, low-to-high impedance output             |   |     | 23.2 | 34.4 | ns      |
| $t_{PZH}$          | Enable propagation delay, high impedance-to-high output for ISO654x |   |     | 16.6 | 23   | ns      |
| $t_{PZL}$          | Enable propagation delay, high impedance-to-low output for ISO654x  |   |     | 16.6 | 23   | ns      |
| $t_{PU}$           | Time from UVLO to valid output data                                 |   |     |      | 300  | $\mu$ s |
| $t_{DO}$           | Default output delay time from input power loss                     | Measured from the time VCC goes below 1.2V. See <a href="#">Section 6</a> |     | 0.1  | 0.3  | $\mu$ s |
| $t_{ie}$           | Time interval error   | $2^{16} - 1$ PRBS data at 50 Mbps   |     | 1    |      | ns      |

- (1) Also known as pulse skew.
- (2)  $t_{sk(o)}$  is the skew between outputs of a single device with all driving inputs connected together and the outputs switching in the same direction while driving identical loads.
- (3)  $t_{sk(pp)}$  is the magnitude of the difference in propagation delay times between any terminals of different devices switching in the same direction while operating at identical supply voltages, temperature, input signals and loads.

## 5.16 Switching Characteristics—2.5-V Supply

$V_{CC1} = V_{CC2} = 2.5\text{ V} \pm 10\%$  (over recommended operating conditions unless otherwise noted)

| PARAMETER          |   | TEST CONDITIONS   | MIN | TYP  | MAX  | UNIT    |
|--------------------|---|---|-----|------|------|---------|
| $t_{PLH}, t_{PHL}$ | Propagation delay time  | at 100kbps<br>See <a href="#">Figure 1-1</a>                              |     | 12   | 20.5 | ns      |
| PWD                | Pulse width distortion <sup>(1)</sup> $ t_{PHL} - t_{PLH} $         |   |     | 0.6  | 7.1  | ns      |
| $t_{sk(o)}$        | Channel-to-channel output skew time <sup>(2)</sup>                  | Same-direction channels   |     |      | 6    | ns      |
| $t_{sk(pp)}$       | Part-to-part skew time <sup>(3)</sup>                               |   |     |      | 7    | ns      |
| $t_r$              | Output signal rise time   | See <a href="#">Section 6</a>   |     | 2    | 4    | ns      |
| $t_f$              | Output signal fall time   |   |     | 2    | 4    | ns      |
| $t_{PHZ}$          | Disable propagation delay, high-to-high impedance output            | See <a href="#">Section 6</a>   |     | 28.1 | 43   | ns      |
| $t_{PLZ}$          | Disable propagation delay, low-to-high impedance output             |   |     | 28.1 | 43   | ns      |
| $t_{PZH}$          | Enable propagation delay, high impedance-to-high output for ISO654x |   |     | 20.4 | 36.3 | ns      |
| $t_{PZL}$          | Enable propagation delay, high impedance-to-low output for ISO654x  |   |     | 20.4 | 36.3 | ns      |
| $t_{PU}$           | Time from UVLO to valid output data                                 |   |     |      | 300  | $\mu$ s |
| $t_{DO}$           | Default output delay time from input power loss                     | Measured from the time VCC goes below 1.2V. See <a href="#">Section 6</a> |     | 0.1  | 0.3  | $\mu$ s |
| $t_{ie}$           | Time interval error   | $2^{16} - 1$ PRBS data at 50 Mbps   |     | 1    |      | ns      |

- (1) Also known as pulse skew.
- (2)  $t_{sk(o)}$  is the skew between outputs of a single device with all driving inputs connected together and the outputs switching in the same direction while driving identical loads.
- (3)  $t_{sk(pp)}$  is the magnitude of the difference in propagation delay times between any terminals of different devices switching in the same direction while operating at identical supply voltages, temperature, input signals and loads.

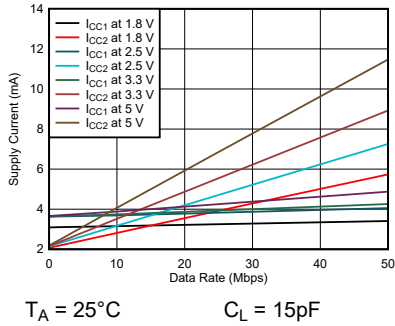
## 5.17 Switching Characteristics—1.8-V Supply

$V_{CC1} = V_{CC2} = 1.8\text{ V} \pm 5\%$  (over recommended operating conditions unless otherwise noted)

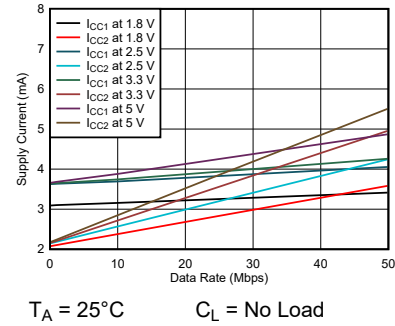
| PARAMETER             |   | TEST CONDITIONS   | MIN | TYP  | MAX  | UNIT    |
|-----------------------|---|---|-----|------|------|---------|
| $t_{PLH}$ , $t_{PHL}$ | Propagation delay time  | at 100kbps<br>See <a href="#">Figure 1-1</a>                              |     | 15   | 24   | ns      |
| PWD                   | Pulse width distortion <sup>(1)</sup> $ t_{PHL} - t_{PLH} $         |   |     | 0.7  | 8.2  | ns      |
| $t_{sk(o)}$           | Channel-to-channel output skew time <sup>(2)</sup>                  | Same-direction channels   |     |      | 6    | ns      |
| $t_{sk(pp)}$          | Part-to-part skew time <sup>(3)</sup>                               |   |     |      | 8.8  | ns      |
| $t_r$                 | Output signal rise time   | See <a href="#">Section 6</a>   |     | 2.7  | 5.3  | ns      |
| $t_f$                 | Output signal fall time   |   |     | 2.7  | 5.3  | ns      |
| $t_{PHZ}$             | Disable propagation delay, high-to-high impedance output            | See <a href="#">Section 6</a>   |     | 40.3 | 63   | ns      |
| $t_{PLZ}$             | Disable propagation delay, low-to-high impedance output             |   |     | 40.3 | 63   | ns      |
| $t_{PZH}$             | Enable propagation delay, high impedance-to-high output for ISO654x |   |     | 30   | 51.4 | ns      |
| $t_{PZL}$             | Enable propagation delay, high impedance-to-low output for ISO654x  |   |     | 30   | 51.4 | ns      |
| $t_{PU}$              | Time from UVLO to valid output data                                 |   |     |      | 300  | $\mu$ s |
| $t_{DO}$              | Default output delay time from input power loss                     | Measured from the time VCC goes below 1.2V. See <a href="#">Section 6</a> |     | 0.1  | 0.3  | $\mu$ s |
| $t_{ie}$              | Time interval error   | $2^{16} - 1$ PRBS data at 50 Mbps   |     | 1    |      | ns      |

- (1) Also known as pulse skew.
- (2)  $t_{sk(o)}$  is the skew between outputs of a single device with all driving inputs connected together and the outputs switching in the same direction while driving identical loads.
- (3)  $t_{sk(pp)}$  is the magnitude of the difference in propagation delay times between any terminals of different devices switching in the same direction while operating at identical supply voltages, temperature, input signals and loads.

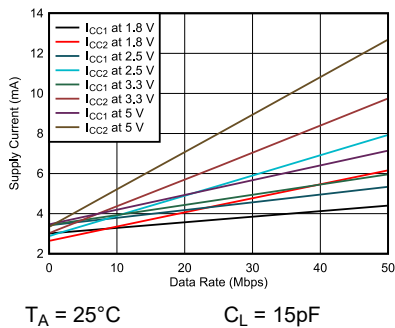
## 5.18 Typical Characteristics



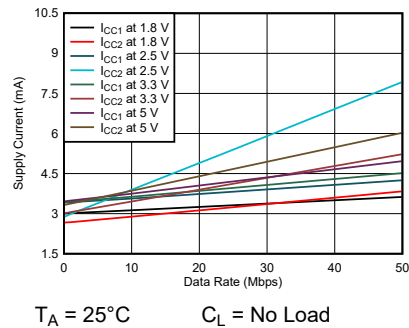
**Figure 5-1. ISO6540 or ISO6540F Supply Current vs Data Rate (With 15pF Load)**



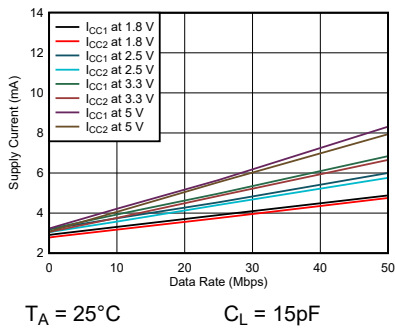
**Figure 5-2. ISO6540 or ISO6540F Supply Current vs Data Rate (With No Load)**



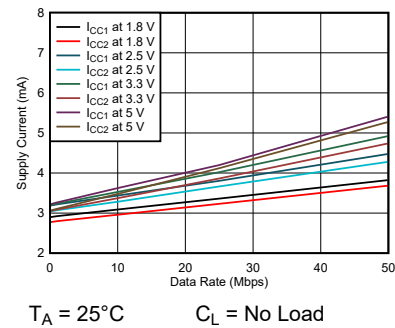
**Figure 5-3. ISO6541 or ISO6541F Supply Current vs Data Rate (With 15pF Load)**



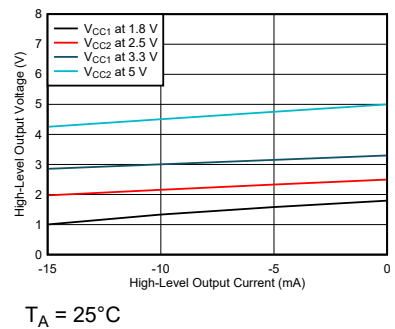
**Figure 5-4. ISO6541 or ISO6541F Supply Current vs Data Rate (With No Load)**



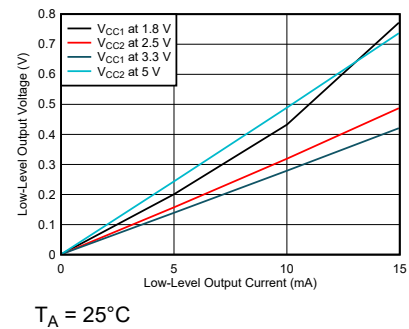
**Figure 5-5. ISO6542 or ISO6542F Supply Current vs Data Rate (With 15pF Load)**



**Figure 5-6. ISO6542 or ISO6542F Supply Current vs Data Rate (With No Load)**

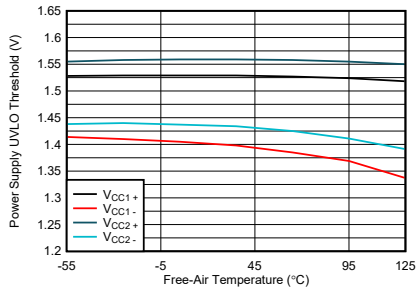


**Figure 5-7. High-Level Output Voltage vs High-level Output Current**

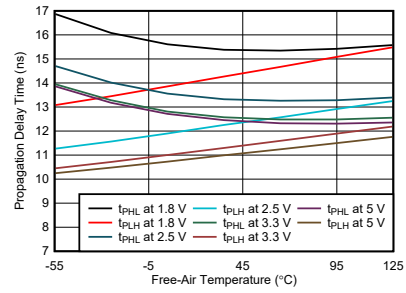


**Figure 5-8. Low-Level Output Voltage vs Low-Level Output Current**

### 5.18 Typical Characteristics (continued)

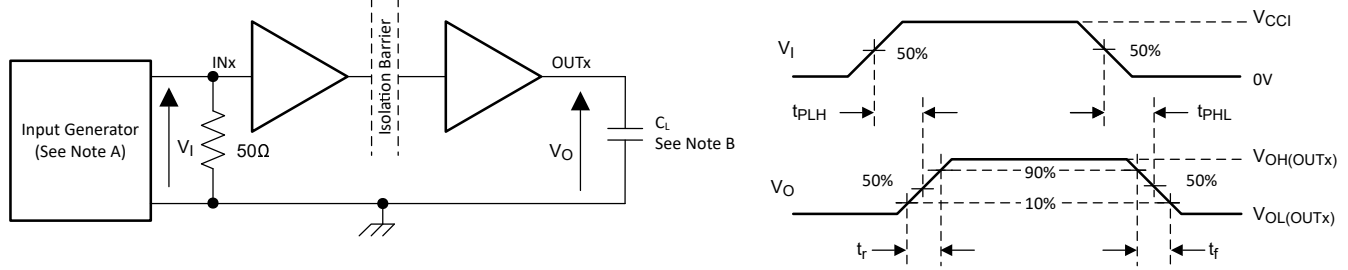


**Figure 5-9. Power Supply Undervoltage Threshold vs Free-Air Temperature**



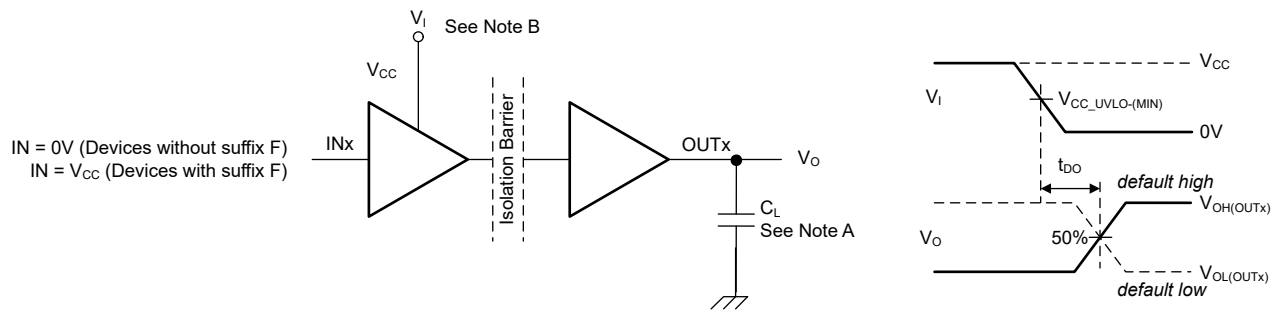
**Figure 5-10. Propagation Delay Time vs Free-Air Temperature**

## 6 Parameter Measurement Information



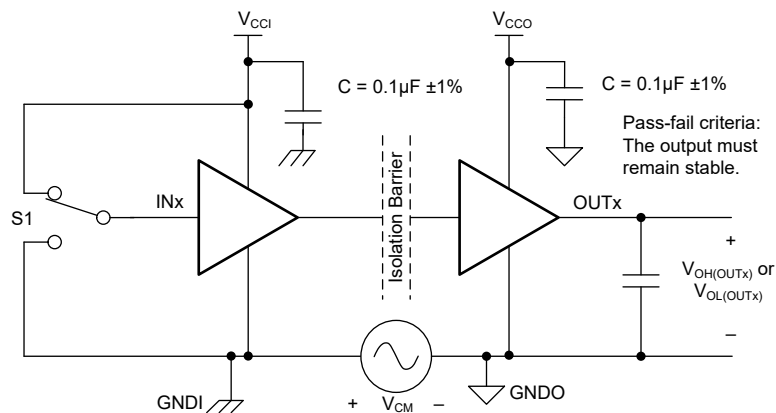
- A. The input pulse is supplied by a generator having the following characteristics: PRR  $\leq$  50kHz, 50% duty cycle,  $t_r \leq$  3ns,  $t_f \leq$  3ns,  $Z_0 = 50\Omega$ . At the input,  $50\Omega$  resistor is required to terminate INx (input) generator signal. The  $50\Omega$  resistor is not needed in the actual application.
- B.  $C_L = 15\text{pF}$  and includes instrumentation and fixture capacitance within  $\pm 20\%$ .

Figure 6-1. Switching Characteristics Test Circuit and Voltage Waveforms



- A.  $C_L = 15\text{pF}$  and includes instrumentation and fixture capacitance within  $\pm 20\%$ .
- B. Power Supply Ramp Rate = 10mV/ns

Figure 6-2. Default Output Delay Time Test Circuit and Voltage Waveforms



- A.  $C_L = 15\text{pF}$  and includes instrumentation and fixture capacitance within  $\pm 20\%$ .
- B.  $ENx = V_{CC}$ , channels are enabled during CMTI test.

Figure 6-3. Common-Mode Transient Immunity Test Circuit

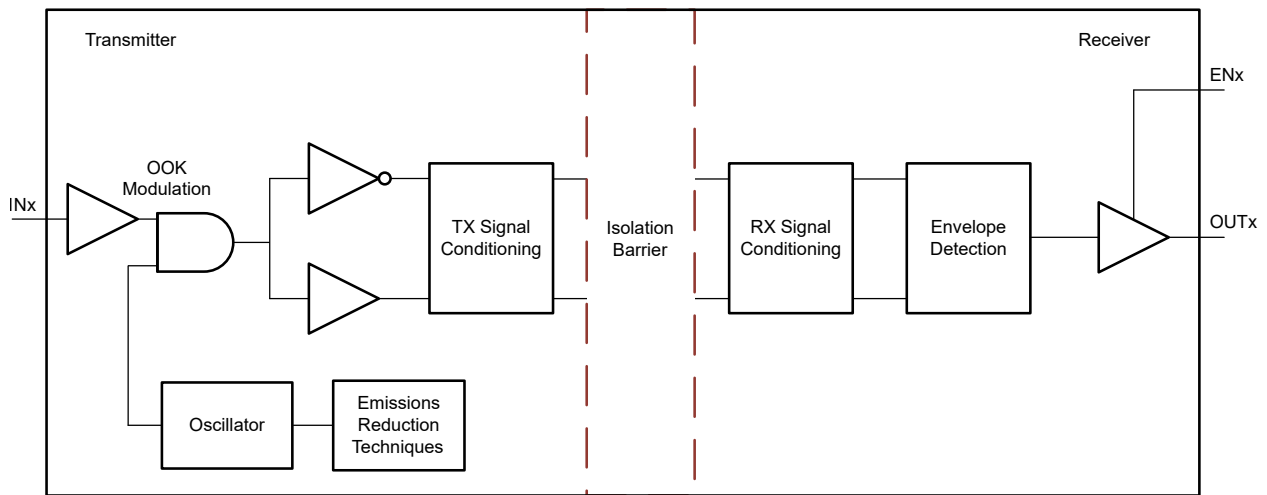
## 7 Detailed Description

### 7.1 Overview

The ISO654x family of devices have an ON-OFF keying (OOK) modulation scheme to transmit the digital data across a silicon dioxide based isolation barrier.

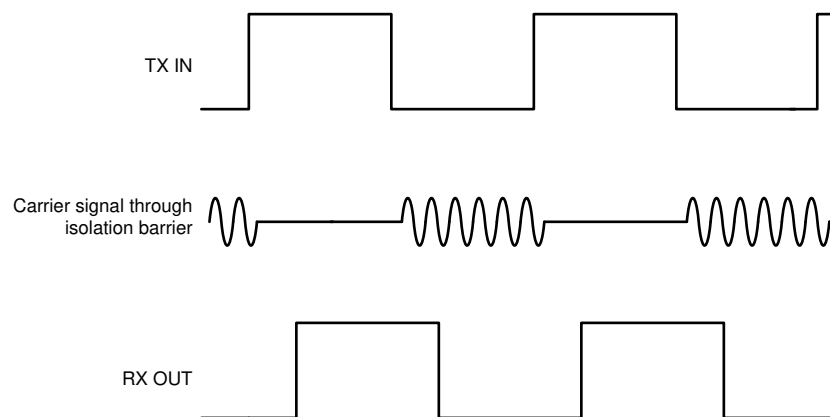
The transmitter sends a high frequency carrier across the barrier to represent one digital state and sends no signal to represent the other digital state. The receiver demodulates the signal after advanced signal conditioning and produces the output through a buffer stage. The ISO654x devices also incorporate advanced circuit techniques to maximize the CMTI performance and minimize the radiated emissions due to the high frequency carrier and IO buffer switching.

### 7.2 Functional Block Diagram



**Figure 7-1. Conceptual Block Diagram of an OOK Based Digital Isolator**

Figure 7-2 shows a conceptual detail of how the ON-OFF keying scheme works.



**Figure 7-2. On-Off Keying (OOK) Based Modulation Scheme**



## 7.3 Feature Description

Table 7-1 provides an overview of the device features.

**Table 7-1. Device Features**

| PART NUMBER | CHANNEL DIRECTION      | MAXIMUM DATA RATE | DEFAULT OUTPUT | PACKAGE |
|-------------|------------------------|-------------------|----------------|---------|
| ISO6540     | 4 Forward<br>0 Reverse | 50Mbps            | High           | DBQ-16  |
| ISO6540F    | 4 Forward<br>0 Reverse | 50Mbps            | Low            | DBQ-16  |
| ISO6541     | 3 Forward<br>1 Reverse | 50Mbps            | High           | DBQ-16  |
| ISO6541F    | 3 Forward<br>1 Reverse | 50Mbps            | Low            | DBQ-16  |
| ISO6542     | 2 Forward<br>2 Reverse | 50Mbps            | High           | DBQ-16  |
| ISO6542F    | 2 Forward<br>2 Reverse | 50Mbps            | Low            | DBQ-16  |

### 7.3.1 Electromagnetic Compatibility (EMC) Considerations

Many applications in harsh industrial environment are sensitive to disturbances such as electrostatic discharge (ESD), electrical fast transient (EFT), surge and electromagnetic emissions. These electromagnetic disturbances are defined and tested by international standards such as IEC 61000-4-x and CISPR 32. Although system-level performance and reliability depends, to a large extent, on the application board design and layout, the ISO654x family of devices incorporates many chip-level design techniques to help overall system robustness.

## 7.4 Device Functional Modes

Table 7-2 lists the functional modes for the ISO654x devices.

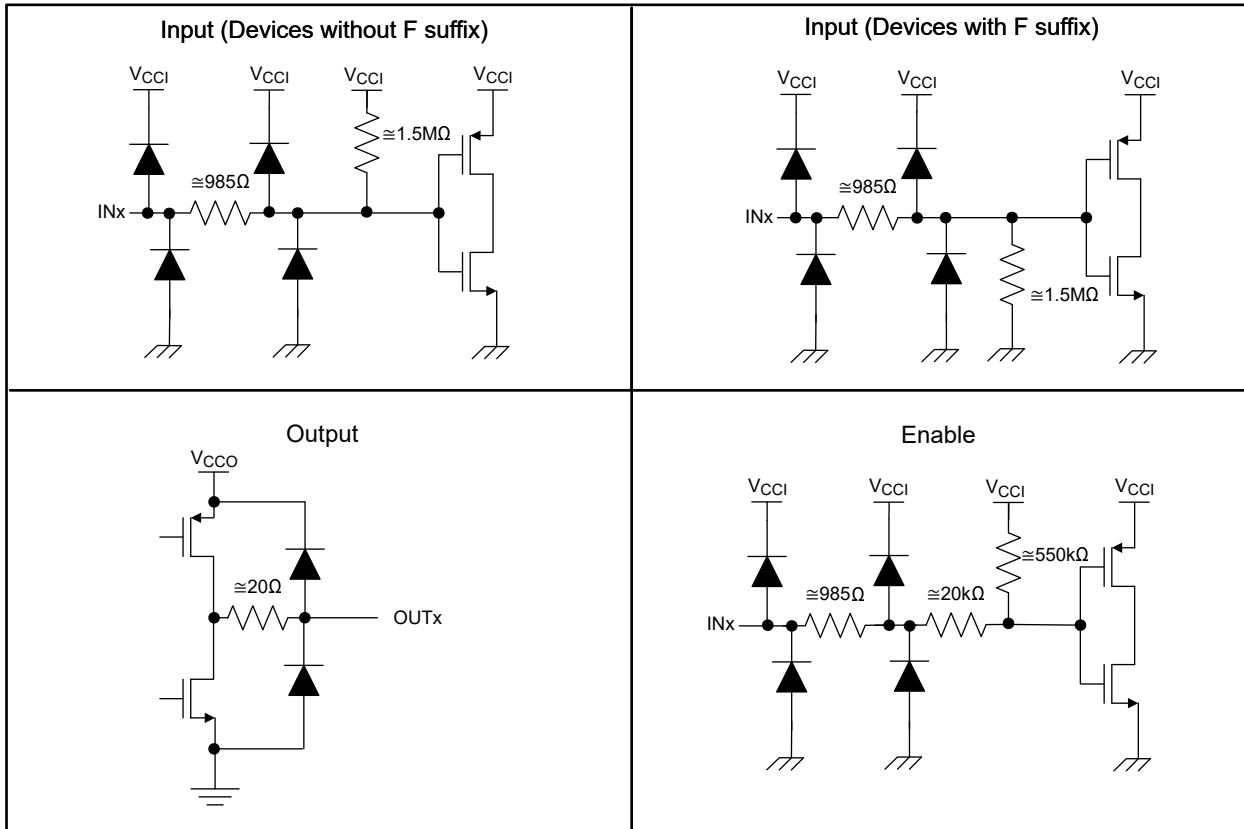
**Table 7-2. Function Table**

| V <sub>CCI</sub> (1) | V <sub>CCO</sub> | INPUT (IN <sub>x</sub> ) | OUTPUT ENABLE (EN <sub>x</sub> ) | OUTPUT (OUT <sub>x</sub> ) | COMMENTS   |
|----------------------|------------------|--------------------------|----------------------------------|----------------------------|--|
| PU                   | PU               | H                        | H or open                        | H                          | Normal Operation: A channel output assumes the logic state of the input.   |
|                      |                  | L                        | H or open                        | L                          |  |
|                      |                  | Open                     | H or open                        | Default                    | Default mode: When IN <sub>x</sub> is open, the corresponding channel output goes to the default logic state. Default is <i>High</i> for ISO654x and <i>Low</i> for ISO654xF (with F suffix).  |
| X                    | PU               | X                        | L                                | Z                          | A low value of output enable causes the outputs to be high-impedance.  |
| PD                   | PU               | X                        | H or open                        | Default                    | Default mode: When V <sub>CCI</sub> is unpowered, a channel output assumes the logic state based on the selected default option. Default is <i>High</i> for ISO654x and <i>Low</i> for ISO654xF (with F suffix).<br>When V <sub>CCI</sub> transitions from unpowered to powered-up, a channel output assumes the logic state of the input.<br>When V <sub>CCI</sub> transitions from powered-up to unpowered, channel output assumes the selected default state. |
| X                    | PD               | X                        | X                                | Undetermined               | When V <sub>CCO</sub> is unpowered, a channel output is undetermined <sup>(2)</sup> . When V <sub>CCO</sub> transitions from unpowered to powered-up, a channel output assumes the logic state of the input.   |

(1) V<sub>CCI</sub> = Input-side V<sub>CC</sub>; V<sub>CCO</sub> = Output-side V<sub>CC</sub>; PU = Powered up (V<sub>CC</sub> ≥ V<sub>CC\_RO(MIN)</sub>); PD = Powered down (V<sub>CC</sub> ≤ V<sub>CC\_UVLO-</sub>); X = Irrelevant; H = High level; L = Low level; Z = High Impedance

(2) The outputs are in undetermined state when V<sub>CC\_UVLO-</sub> ≤ V<sub>CCI</sub> or V<sub>CCO</sub> < V<sub>CC</sub> ≥ V<sub>CC\_RO(MIN)</sub>.

## 7.5 Device I/O Schematics



## 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

The ISO654x devices are high-performance, low power, quad-channel digital isolators. These devices come with enable pins on each side which can be used to put the respective outputs in high impedance for parallel (multiple) driver applications. The ISO654x devices use single-ended CMOS-logic switching technology.

The supply voltage range is from 1.71V to 5.5V for both supplies,  $V_{CC1}$  and  $V_{CC2}$ . Since an isolation barrier separates the two sides, each side can be sourced independently with any voltage within recommended operating conditions. As an example, supplying ISO654x  $V_{CC1}$  with 3.3V (which is within 1.71V to 5.5V) and  $V_{CC2}$  with 5V (which is also within 1.71V to 5.5V) is possible. You can use the digital isolator as a logic-level translator in addition to providing isolation. When designing with digital isolators, keep in mind that because of the single-ended design structure, digital isolators do not conform to any specific interface standard and are only intended for isolating single-ended CMOS or TTL digital signal lines. The isolator is typically placed between the data controller (that is, MCU or FPGA), and a data converter or a line transceiver, regardless of the interface type or standard.

### Note

ISO654x is a functional isolator, and is not certified for isolation by standard bodies. For applications that require certified isolation by standard bodies, customers must choose [ISO644x](#), [ISO674x](#), [ISO774x](#) or [ISO784x](#) families of digital isolators.

### 8.2 Typical Application

Figure 8-1 shows the isolated serial peripheral interface (SPI).

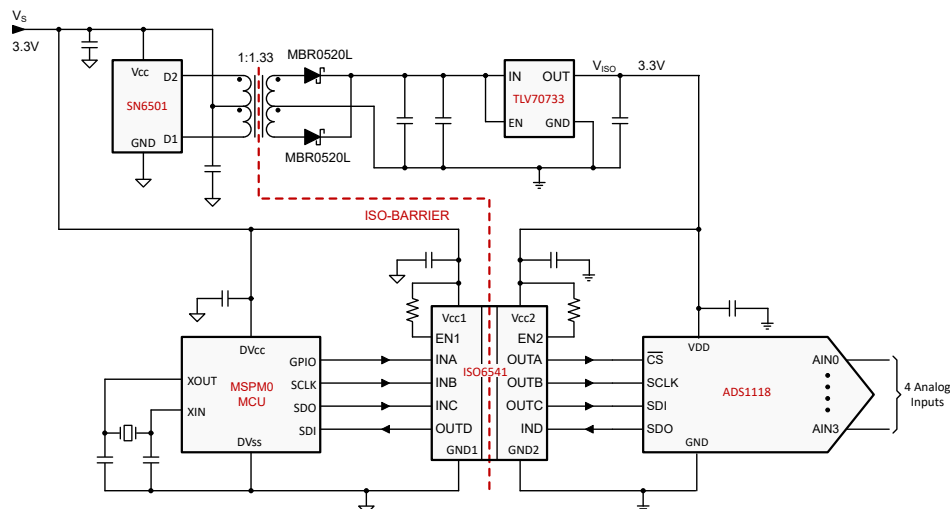


Figure 8-1. Isolated SPI for an Analog Input Module With 4 Inputs

### 8.2.1 Design Requirements

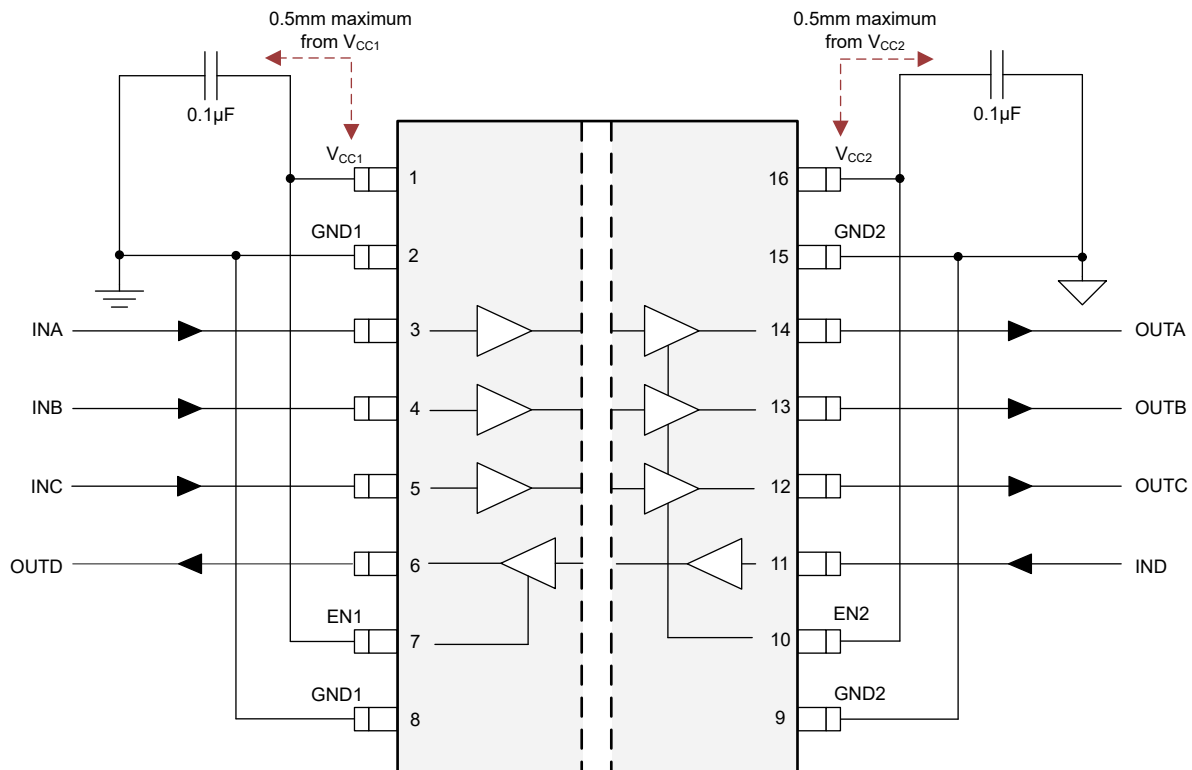
To design with these devices, use the parameters listed in [Table 8-1](#).

**Table 8-1. Design Parameters**

| PARAMETER                                       | VALUE         |
|---|---------------|
| Supply voltage, $V_{CC1}$ and $V_{CC2}$         | 1.71V to 5.5V |
| Decoupling capacitor between $V_{CC1}$ and GND1 | 0.1 $\mu$ F   |
| Decoupling capacitor from $V_{CC2}$ and GND2    | 0.1 $\mu$ F   |

### 8.2.2 Detailed Design Procedure

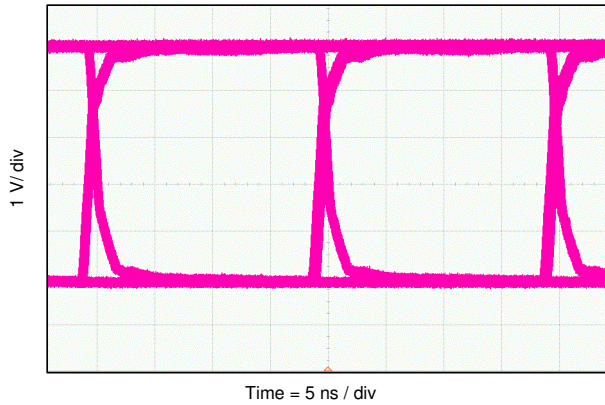
Unlike optocouplers, which require external components to improve performance, provide bias, or limit current, the ISO654x family of devices only require two external bypass capacitors to operate.



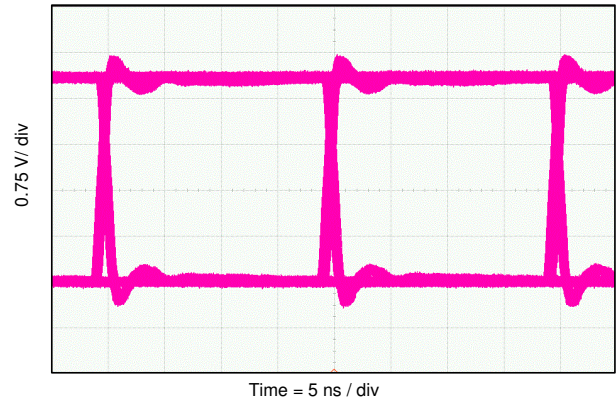
**Figure 8-2. Typical ISO654x Circuit**

### 8.2.3 Application Curve

The following typical eye diagrams of the ISO654x family of devices indicates low jitter and wide open eye at the maximum data rate of 50Mbps.



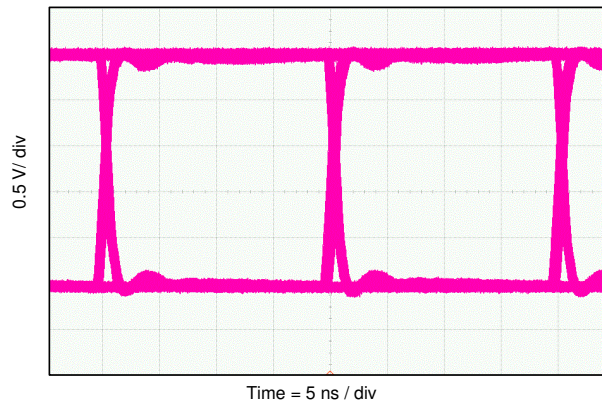
Horizontal 5ns / division, Vertical 1V / division.



Horizontal 5ns / division, Vertical 750mV / division.

**Figure 8-3. ISO654x Eye Diagram at 50Mbps PRBS  $2^{16} - 1$ , 5V and 25°C**

**Figure 8-4. ISO654x Eye Diagram at 50Mbps PRBS  $2^{16} - 1$ , 3.3V and 25°C**



Horizontal 5ns / division, Vertical 500mV / division.

**Figure 8-5. ISO654x Eye Diagram at 50Mbps PRBS  $2^{16} - 1$ , 2.5V and 25°C**

## 8.3 Power Supply Recommendations

To provide reliable operation at data rates and supply voltages, a 0.1 $\mu$ F bypass capacitor is recommended at the input and output supply pins ( $V_{CC1}$  and  $V_{CC2}$ ). The capacitors must be placed as close to the supply pins as possible. If only a single primary-side power supply is available in an application, isolated power can be generated for the secondary-side with the help of a transformer driver. For industrial applications, please use Texas Instruments' [SN6501](#) or [SN6505B](#). For such applications, detailed power supply design and transformer selection recommendations are available in [SN6501 Transformer Driver for Isolated Power Supplies](#) or [SN6505B Low-noise, 1-A Transformer Drivers for Isolated Power Supplies](#).

## 8.4 Layout

### 8.4.1 Layout Guidelines

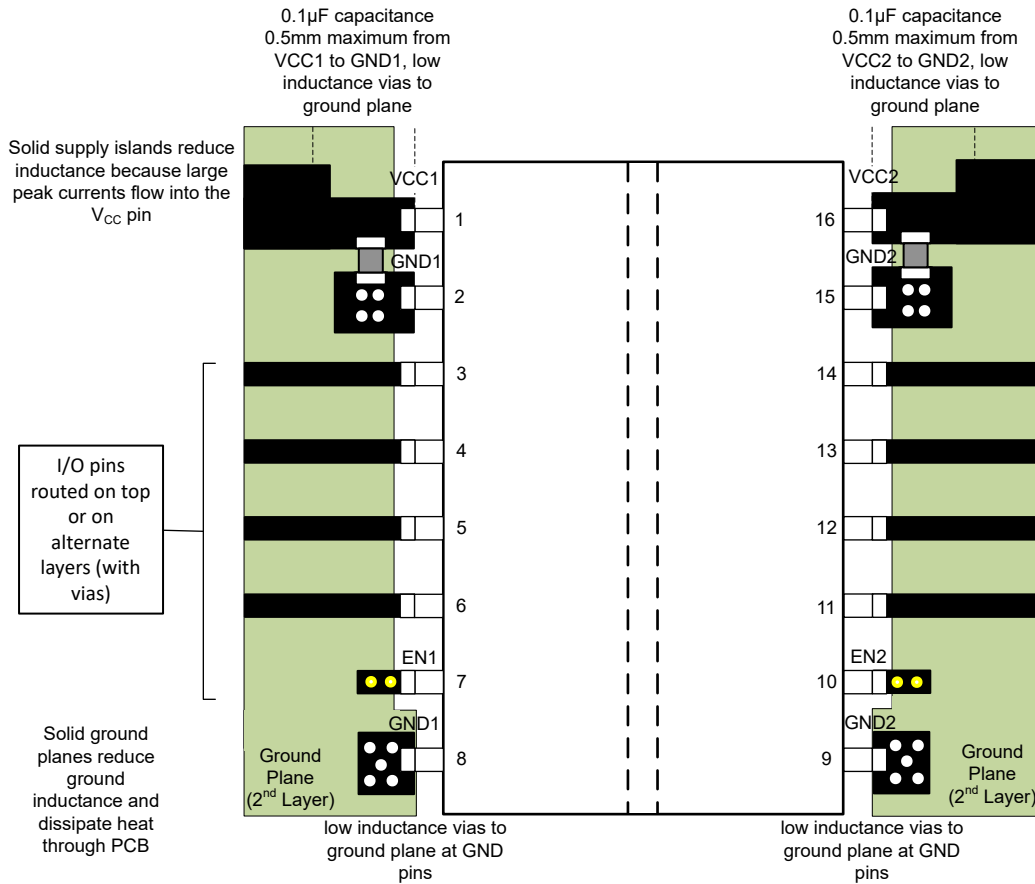
A minimum of two layers is required to accomplish a cost optimized and low EMI PCB design. To further improve EMI, a four layer board can be used (see [Layout Example Schematic](#)). Layer stacking for a four layer board must be in the following order (top-to-bottom): high-speed signal layer, ground plane, power plane and low-frequency signal layer.

- Routing the high-speed traces on the top layer avoids the use of vias (and the introduction of the inductances) and allows for clean interconnects between the isolator and the transmitter and receiver circuits of the data link.
- Placing a solid ground plane next to the high-speed signal layer establishes controlled impedance for transmission line interconnects and provides an excellent low-inductance path for the return current flow.
- Placing the power plane next to the ground plane creates additional high-frequency bypass capacitance of approximately 100pF/inch<sup>2</sup>.
- Routing the slower speed control signals on the bottom layer allows for greater flexibility as these signal links typically have margin to tolerate discontinuities such as vias.

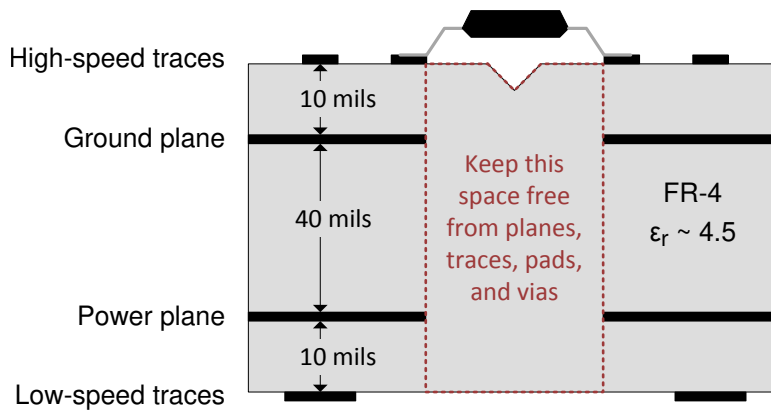
If an additional supply voltage plane or signal layer is needed, add a second power or ground plane system to the stack to keep the planes symmetrical. This design makes the stack mechanically stable and prevents warping. Also the power and ground plane of each power system can be placed closer together, thus increasing the high-frequency bypass capacitance significantly.

For detailed layout recommendations, refer to the [Digital Isolator Design Guide](#) application note.

### 8.4.2 Layout Example



**Figure 8-6. Layout Example**



**Figure 8-7. Layout Example PCB cross section**

## 9 Device and Documentation Support

### 9.1 Documentation Support

#### 9.1.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, [ISO6540 Technical Documents](#)
- Texas Instruments, [ISO6541 Technical Documents](#)
- Texas Instruments, [ISO6542 Technical Documents](#)
- Texas Instruments, [Digital Isolator Design Guide](#), application note
- Texas Instruments, [Digital Isolator Design Guide](#), application note
- Texas Instruments, [Isolation Glossary](#), application note
- Texas Instruments, [How to use isolation to improve ESD, EFT, and Surge immunity in industrial systems](#), application note
- Texas Instruments, [SN6501 Transformer Driver for Isolated Power Supplies](#), data sheet

### 9.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 9.3 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is 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](#).

### 9.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.  
All trademarks are the property of their respective owners.

### 9.5 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 9.6 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

## 10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| DATE       | REVISION | NOTES           |
|------------|----------|-----------------|
| April 2025 | *        | Initial release |

## 11 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.



**PACKAGING INFORMATION**

| Orderable part number        | Status<br>(1) | Material type<br>(2) | Package   Pins  | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------|---------------|----------------------|-----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">ISO6540FDBQR</a> | Active        | Production           | SSOP (DBQ)   16 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 6540F               |
| <a href="#">ISO6541DBQR</a>  | Active        | Production           | SSOP (DBQ)   16 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 6541                |
| <a href="#">ISO6541FDBQR</a> | Active        | Production           | SSOP (DBQ)   16 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 6541F               |
| <a href="#">ISO6542DBQR</a>  | Active        | Production           | SSOP (DBQ)   16 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 6542                |
| <a href="#">ISO6542FDBQR</a> | Active        | Production           | SSOP (DBQ)   16 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 6542F               |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts 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.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**OTHER QUALIFIED VERSIONS OF ISO6540, ISO6541, ISO6542 :**

- Automotive : [ISO6540-Q1](#), [ISO6541-Q1](#), [ISO6542-Q1](#)

## NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects



# DBQ0016A

# PACKAGE OUTLINE

## SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



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### NOTES:

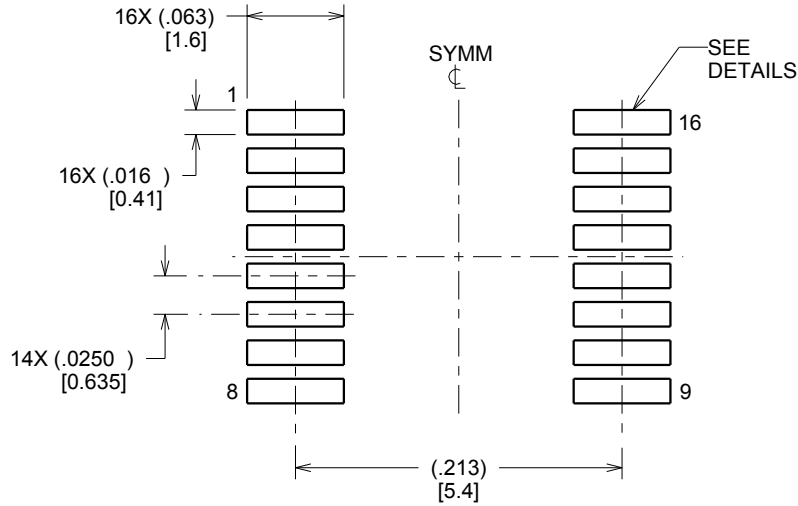
1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 inch, per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MO-137, variation AB.

# EXAMPLE BOARD LAYOUT

DBQ0016A

SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
SCALE:8X



SOLDER MASK DETAILS

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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

DBQ0016A

SSOP - 1.75 mm max height

SHRINK SMALL-OUTLINE PACKAGE



SOLDER PASTE EXAMPLE  
BASED ON .005 INCH [0.127 MM] THICK STENCIL  
SCALE:8X

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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.

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