

# MAX14591

## High-Speed, Open-Drain Capable Logic-Level Translator

### General Description

The MAX14591 is a dual-channel, bidirectional logic-level translator with the level shifting necessary to allow data transfer in a multivoltage system. Externally applied voltages,  $V_{CC}$  and  $V_L$ , set the logic levels on either side of the device. A logic signal present on the  $V_L$  side of the device appears as the same logic signal on the  $V_{CC}$  side of the device, and vice-versa.

The device is optimized for the I<sup>2</sup>C bus as well as the management data input/output (MDIO) bus where often high-speed, open-drain operation is required. When  $\overline{TS}$  is high, the device allows the pullup to be connected to the I/O port that has the power. This allows continuous I<sup>2</sup>C operation on the powered side without any disruption while the level translation function is off.

The part is specified over the extended -40°C to +85°C temperature range, and is available in 8-bump WLP and 8-pin TDFN packages.

### Applications

Devices with I<sup>2</sup>C Communication  
 Devices with MDIO Communication  
 General Logic-Level Translation

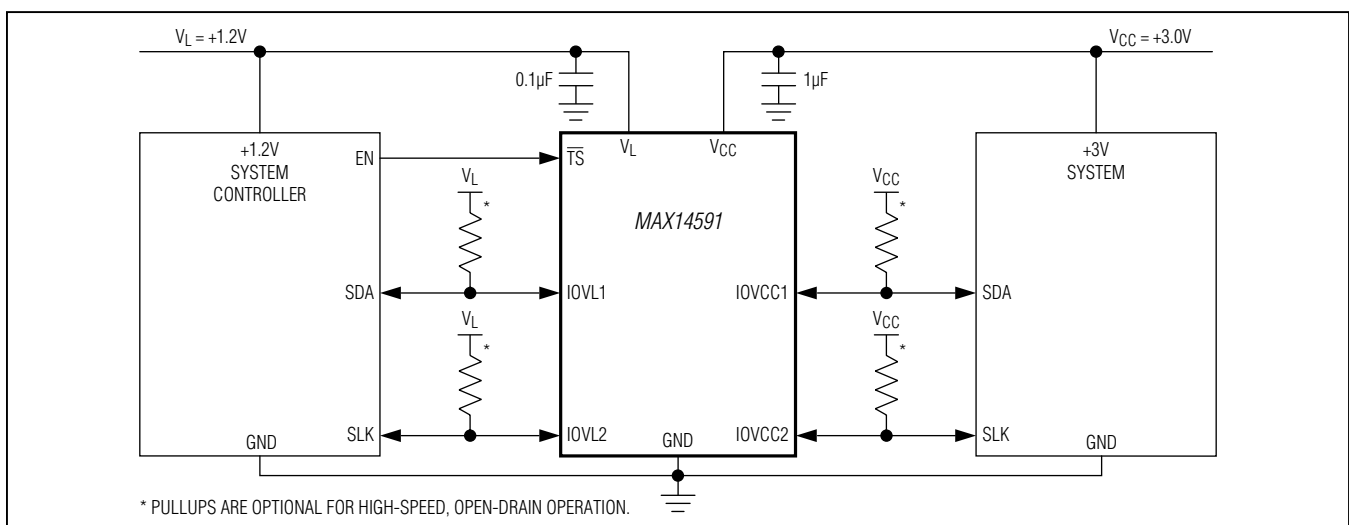
### Benefits and Features

- ◆ **Meets Industry Standards**
  - ◇ I<sup>2</sup>C Requirements for Standard, Fast, and High\* Speeds
  - ◇ MDIO Open Drain Above 4MHz\*
- ◆ **Allows Greater Design Flexibility**
  - ◇ Down to 0.9V Operation on  $V_L$  Side
  - ◇ Supports Above 8MHz Push-Pull Operation
- ◆ **Offers Low Power Consumption**
  - ◇ 23 $\mu$ A (typ)  $V_{CC}$  Supply Current
  - ◇ 0.5 $\mu$ A (typ)  $V_L$  Supply Current
- ◆ **Provides High Level of Integration**
  - ◇ Pullup Resistor Enabled with One Side Power Supply when  $\overline{TS}$  Is High
  - ◇ 12k $\Omega$  (max) Internal Pullup
  - ◇ Low Transmission Gate  $R_{ON}$ : 17 $\Omega$  (max)
- ◆ **Saves Space**
  - ◇ 8-Bump, 0.4mm pitch, 0.8mm x 1.6mm WLP Package
  - ◇ 8-Pin, 2mm x 2mm TDFN Package

\*Requires external pullups.

[Ordering Information](#) appears at end of data sheet.

### Typical Operating Circuit



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### ABSOLUTE MAXIMUM RATINGS

Voltages referenced to GND.

$V_{CC}$ , $V_L$ , $\overline{TS}$	-0.5V to +6V
IOVCC1, IOVCC2	-0.5V to $+(V_{CC} + 0.5V)$
IOVL1, IOVL2	-0.5V to $+(V_L + 0.5V)$
Short-Circuit Duration IOVCC1, IOVCC2, IOVL1, IOVL2 to GND	Continuous
$V_{CC}$ , IOVCC_ Maximum Continuous Current at +110°C	100mA
$V_L$ , IOVL_ Maximum Continuous Current at +110°C	40mA

$\overline{TS}$ Maximum Continuous Current at +110°C	70mA
Continuous Power Dissipation ( $T_A = +70^\circ\text{C}$ )	
TDFN (derate 6.2mW/°C above +70°C)	496mW
WLP (derate 11.8mW/°C above +70°C)	944mW
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (TDFN only, soldering, 10s)	+300°C
Soldering Temperature (reflow)	+260°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### PACKAGE THERMAL CHARACTERISTICS (Note 1)

TDFN	162°C/W	WLP	85°C/W
Junction-to-Ambient Thermal Resistance ( $\theta_{JA}$ )		Junction-to-Ambient Thermal Resistance ( $\theta_{JA}$ )	
Junction-to-Case Thermal Resistance ( $\theta_{JC}$ )	20°C/W		

**Note 1:** Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to [www.maximintegrated.com/thermal-tutorial](http://www.maximintegrated.com/thermal-tutorial).

### ELECTRICAL CHARACTERISTICS

( $V_{CC} = +1.65V$  to  $+5.5V$ ,  $V_L = +0.9V$  to  $\min(V_{CC} + 0.3V, +3.6V)$ ,  $T_A = -40^\circ\text{C}$  to  $+85^\circ\text{C}$ , unless otherwise noted. Typical values are at  $V_{CC} = +3V$ ,  $V_L = +1.2V$ , and  $T_A = +25^\circ\text{C}$ .) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>POWER SUPPLY</b>						
Power Supply Range	$V_L$		0.9		5.5	V
	$V_{CC}$		1.65		5.5	
$V_{CC}$ Supply Current	$I_{CC}$	IOVCC_ = $V_{CC}$ , IOVL_ = $V_L$ , $\overline{TS} = V_{CC}$		23	47	$\mu\text{A}$
$V_L$ Supply Current	$I_L$	IOVCC_ = $V_{CC}$ , IOVL_ = $V_L$ , $\overline{TS} = V_{CC}$		0.5	6	$\mu\text{A}$
$V_{CC}$ Shutdown Supply Current	$I_{CC-SHDN}$	$\overline{TS} = \text{GND}$		1	2.2	$\mu\text{A}$
		$\overline{TS} = V_{CC}$ , $V_L = \text{GND}$ , IOVCC_ = unconnected		1	2.2	
$V_L$ Shutdown Supply Current	$I_{L-SHDN}$	$\overline{TS} = \text{GND}$		0.1	1	$\mu\text{A}$
		$\overline{TS} = V_L$ , $V_{CC} = \text{GND}$ , IOVL_ = unconnected		0.1	1	
IOVCC_, IOVL_ Three-State Leakage Current	$I_{LEAK}$	$T_A = +25^\circ\text{C}$ , $\overline{TS} = \text{GND}$		0.1	1	$\mu\text{A}$
$\overline{TS}$ Input Leakage Current	$I_{LEAK\_TS}$	$T_A = +25^\circ\text{C}$			1	$\mu\text{A}$
$V_{CC}$ Shutdown Threshold	$V_{TH\_VCC}$	$\overline{TS} = V_L$ , $V_{CC}$ falling, $V_L = 0.9V$		0.8	1.35	V
$V_L$ Shutdown Threshold	$V_{TH\_VL}$	$\overline{TS} = V_{CC}$ , $V_L$ falling	0.15	0.3	0.8	V
$V_L$ Above $V_{CC}$ Shutdown Threshold	$V_{TH\_VL-VCC}$	$V_L$ rising above $V_{CC}$ , $V_{CC} = +1.65V$	0.4	0.73	1.1	V
IOVL_ Pullup Resistor	$R_{VL\_PU}$	Inferred from $V_{OHL}$ Measurements	3	7.6	12	k $\Omega$
IOVCC_ Pullup Resistor	$R_{VCC\_PU}$	Inferred from $V_{OHC}$ Measurements	3	7.6	12	k $\Omega$
IOVL_ to IOVCC_ DC Resistance	$R_{IOVL-IOVCC}$	Inferred from $V_{OHx}$ Measurements		6	17	$\Omega$

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### ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = +1.65V$  to  $+5.5V$ ,  $V_L = +0.9V$  to  $\min(V_{CC} + 0.3V, +3.6V)$ ,  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted. Typical values are at  $V_{CC} = +3V$ ,  $V_L = +1.2V$ , and  $T_A = +25^\circ C$ .) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>LOGIC LEVELS</b>						
IOVL_ Input-Voltage High	$V_{IHL}$	IOVL_ rising, $V_L = +0.9V$ , $V_{CC} = +1.65V$ (Note 4)	$V_L - 0.2$			V
IOVL_ Input-Voltage Low	$V_{ILL}$	IOVL_ falling, $V_L = +0.9V$ , $V_{CC} = +1.65V$ (Note 4)			0.15	V
IOVCC_ Input-Voltage High	$V_{IHC}$	IOVCC_ rising, $V_L = +0.9V$ , $V_{CC} = +1.65V$ (Note 4)	$V_{CC} - 0.4$			V
IOVCC_ Input-Voltage Low	$V_{ILC}$	IOVCC_ falling, $V_L = +0.9V$ , $V_{CC} = +1.65V$ (Note 4)			0.2	V
$\overline{TS}$ Input-Voltage High	$V_{IH}$	$\overline{TS}$ rising, $V_L = +0.9V$ or $+3.6V$ , $V_{CC} > V_L$	$V_L - 0.15$			V
$\overline{TS}$ Input-Voltage Low	$V_{IL}$	$\overline{TS}$ falling, $V_L = +0.9V$ or $+3.6V$ , $V_{CC} > V_L$			0.2	V
IOVL_ Output-Voltage High	$V_{OHL}$	IOVL_ source current $20\mu A$ , $V_{IOVCC_} = V_L$ to $V_{CC}$ ( $V_{CC} \geq V_L$ )	$0.7 \times V_L$			V
IOVL_ Output-Voltage Low	$V_{OLL}$	IOVL_ sink current $5mA$ , $V_{IOVCC_} \leq 0.05V$			0.2	V
IOVCC_ Output-Voltage High	$V_{OHC}$	IOVCC_ source current $20\mu A$ , $V_{IOVL_} = V_L$	$0.7 \times V_{CC}$			V
IOVCC_ Output-Voltage Low	$V_{OLC}$	IOVCC_ sink current $5mA$ , $V_{IOVL_} \leq 0.05V$			0.25	V
<b>RISE/FALL TIME ACCELERATOR STAGE</b>						
Accelerator Pulse Duration		$V_L = +0.9V$ , $V_{CC} = +1.65V$	9	22	48	ns
IOVL_ Output Accelerator Source Impedance		$V_L = +0.9V$ , $IOVL_ = GND$ , $V_{CC} = +1.65V$		26		$\Omega$
		$V_L = +3.3V$ , $IOVL_ = GND$ , $V_{CC} = +5V$		6.8		
IOVCC_ Output Accelerator Source Impedance		$V_{CC} = +1.65V$ , $IOVCC_ = GND$		26		$\Omega$
		$V_{CC} = +5V$ , $IOVCC_ = GND$		6.5		
<b>THERMAL PROTECTION</b>						
Thermal Shutdown	$T_{SHDN}$			+150		$^\circ C$
Thermal Hysteresis	$T_{HYST}$			10		$^\circ C$
<b>ESD PROTECTION</b>						
All Pins		HBM		$\pm 2$		kV

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### TIMING CHARACTERISTICS

( $V_{CC} = +1.65V$  to  $+5.5V$ ,  $V_L = +0.9V$  to  $+3.6V$ ,  $V_{CC} \geq V_L$ ,  $\overline{TS} = V_L$ ,  $C_{VCC} = 1\mu F$ ,  $C_{VL} = 0.1\mu F$ ,  $C_{IOVL\_} \leq 100pF$ ,  $C_{IOVCC\_} \leq 100pF$ ,  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted. Typical values are at  $V_{CC} = +3V$ ,  $V_L = +1.2V$  and  $T_A = +25^\circ C$ . All timing is 10% to 90% for rise time and 90% to 10% for fall time.) (Note 5)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Turn-On Time for Q1	$t_{ON}$	$V_{\overline{TS}} = 0V$ to $V_L$ (see the <i>Block Diagram</i> )			80	200	$\mu s$
IOVCC_ Rise Time	$t_{RCC}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 1)			3.7	10	ns
		Open-drain driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 2)			7.9		
IOVCC_ Fall Time	$t_{FCC}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 1)			5.1	15	ns
		Open-drain driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 2)			6.1		
IOVL_ Rise Time	$t_{RL}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 3)			2.7	8	ns
		Open-drain driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 4)			13		
IOVL_ Fall Time	$t_{FL}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 3)			2.8	12	ns
		Open-drain driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 4)			3.3		
Propagation Delay (Driving IOVL_)	$t_{PD\_LCC}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 1)	Rising		3.4	7	ns
			Falling		3	8	
Propagation Delay (Driving IOVCC_)	$t_{PD\_CCL}$	Push-pull driving, $V_L = +1.2V$ , $V_{CC} = +3V$ (Figure 3)	Rising		1.9	3	ns
			Falling		1.5	7	
Channel-to-Channel Skew	$t_{SKEW}$	Input rise time/fall time $< 6ns$				1.3	ns
Maximum Data Rate		Push-pull operation			8		MHz
		Open-drain operation (Note 6)			4		

**Note 2:** All devices are 100% production tested at  $T_A = +25^\circ C$ . Limits over the operating temperature range are guaranteed by design and not production tested.

**Note 3:**  $V_L$  must be less than or equal to  $V_{CC}$  during normal operation. However,  $V_L$  can be greater than  $V_{CC}$  during startup and shutdown conditions.

**Note 4:**  $V_{IHL}$ ,  $V_{ILL}$ ,  $V_{IHC}$ , and  $V_{ILC}$  are intended to define the range where the accelerator triggers.

**Note 5:** Guaranteed by design.

**Note 6:** External pullup resistors are required.

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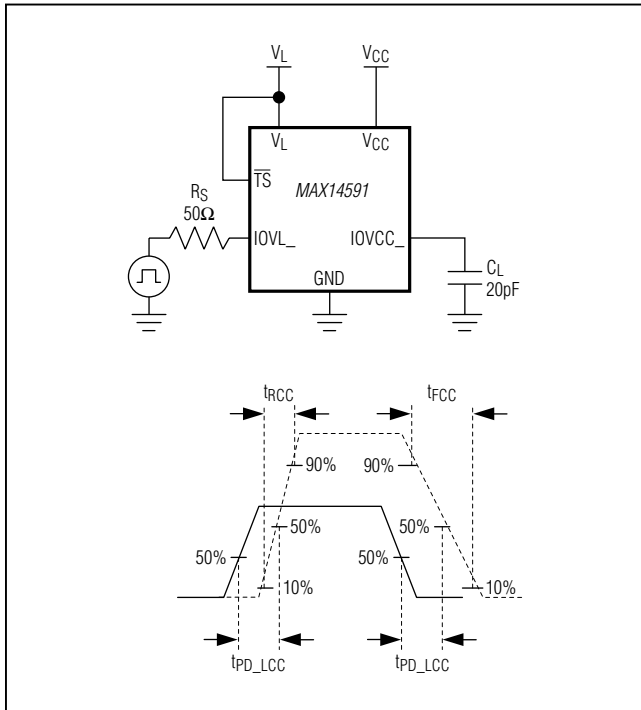


Figure 1. Push-Pull Driving  $IOVL_$

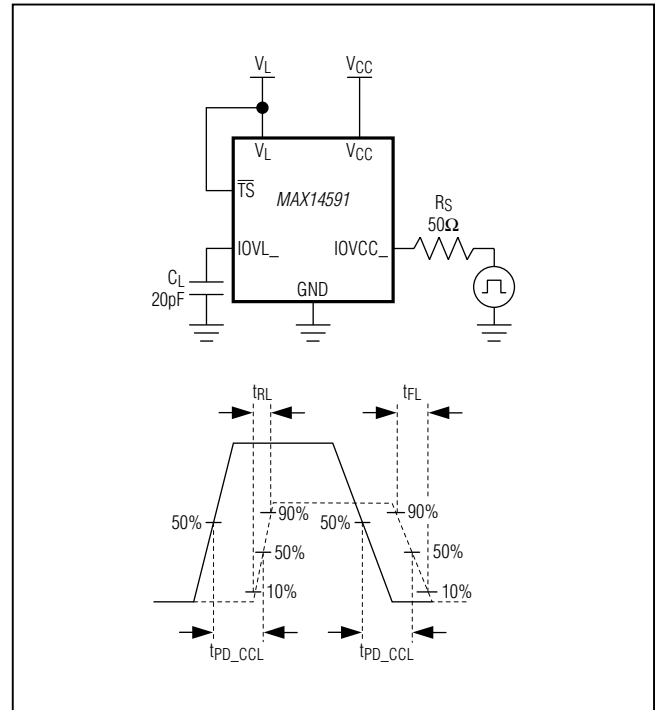


Figure 3. Push-Pull Driving  $IOVCC_$

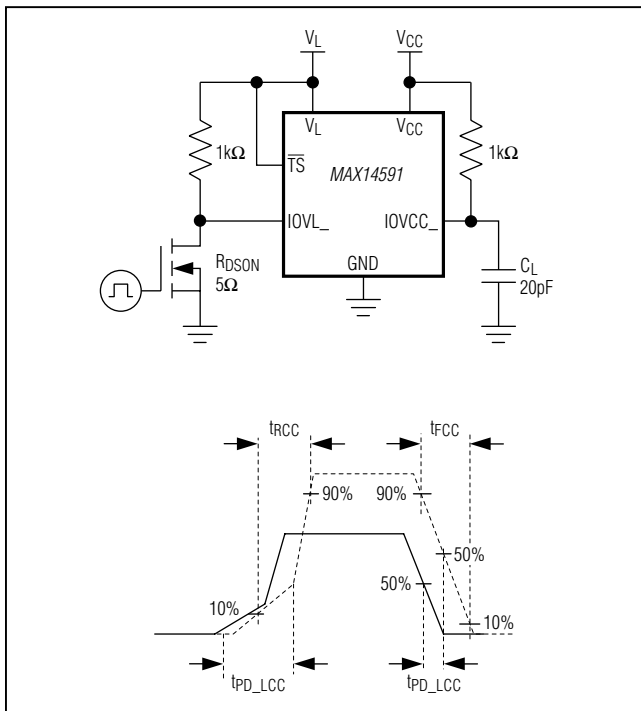


Figure 2. Open-Drain Driving  $IOVL_$

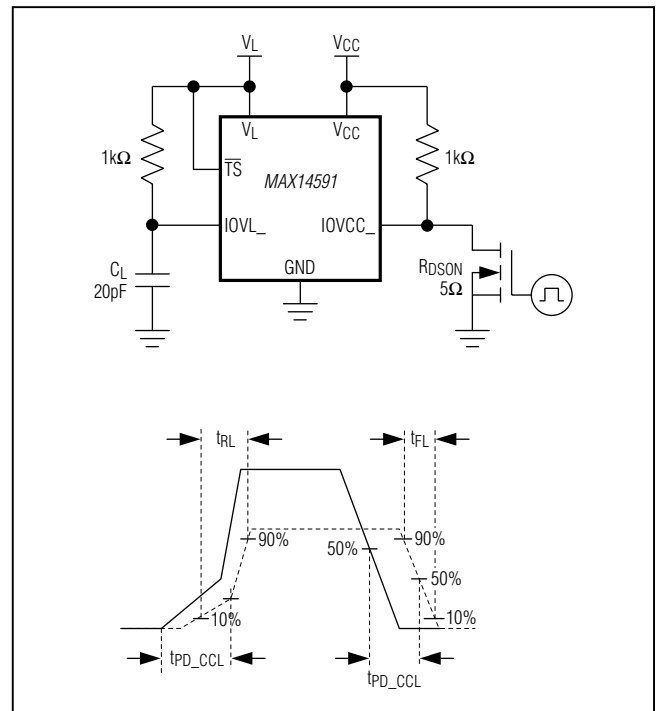


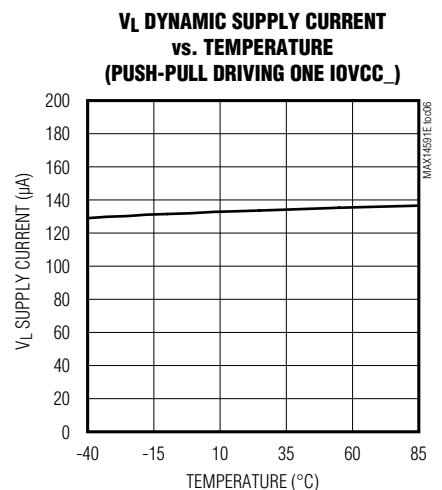
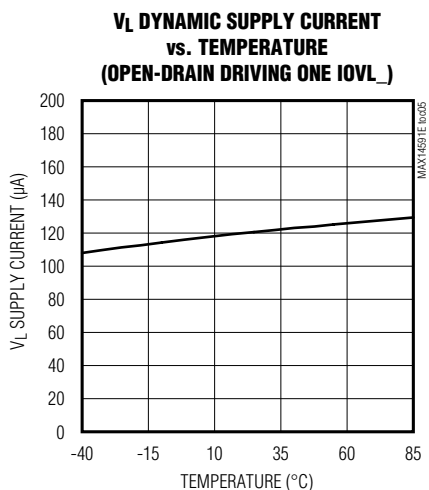
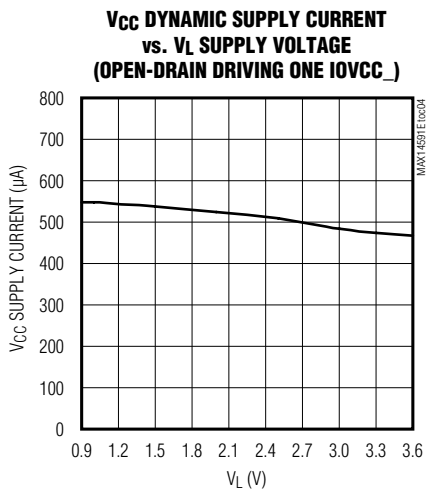
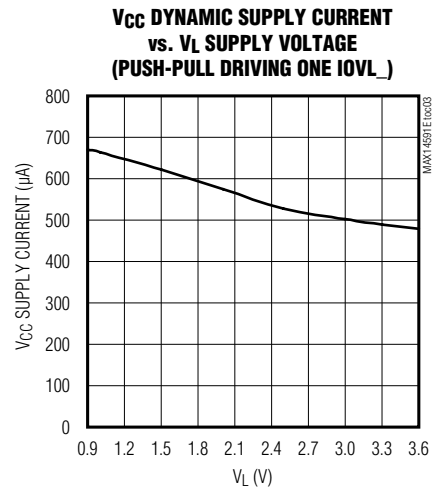
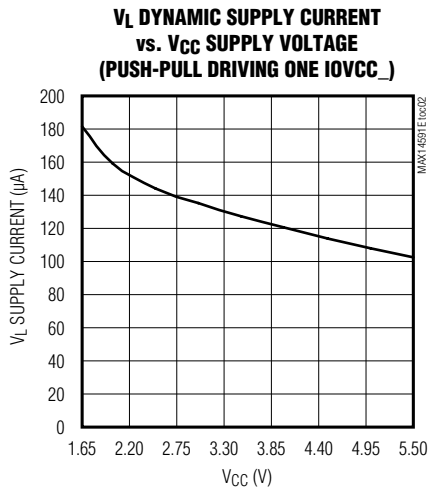
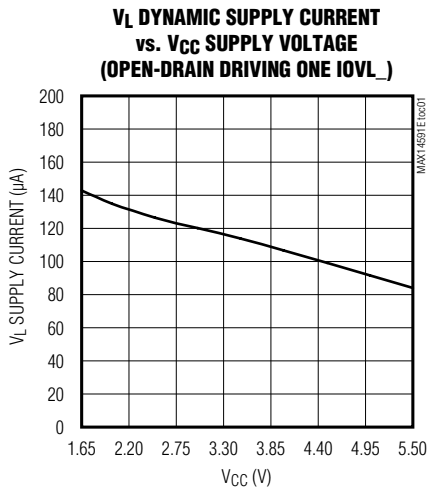
Figure 4. Open-Drain Driving  $IOVCC_$

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## High-Speed, Open-Drain Capable Logic-Level Translator

### Typical Operating Characteristics

( $V_{CC} = +3V$ ,  $V_L = +1.5V$ ,  $R_L = 1M\Omega$ ,  $C_L = 15pF$ , push-pull driving data rate = 8Mbps,  $T_A = +25^\circ C$ , unless otherwise noted.)

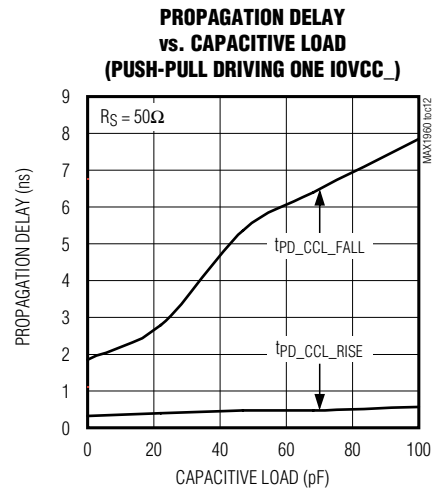
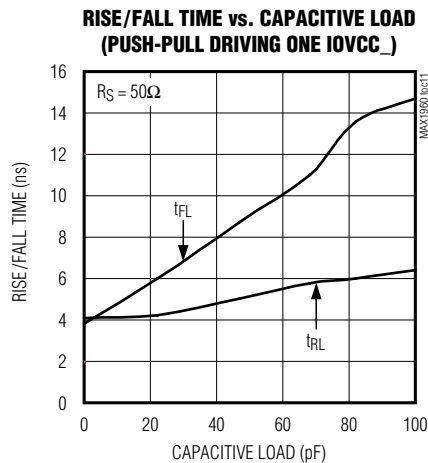
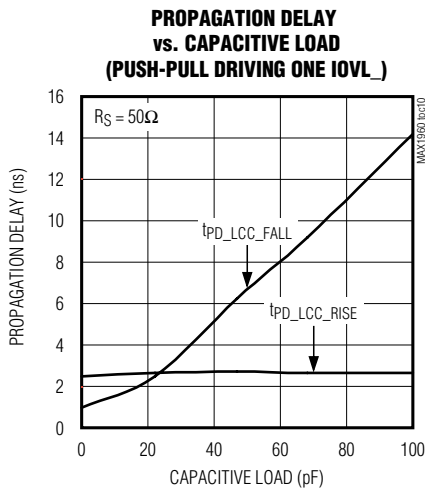
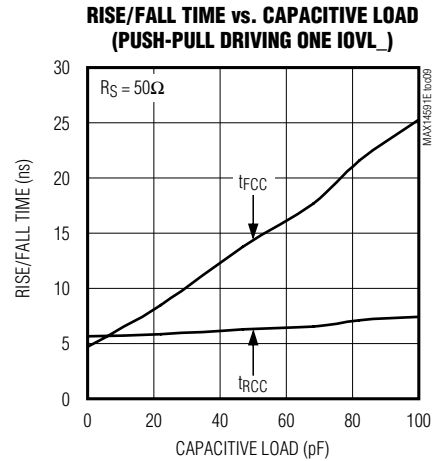
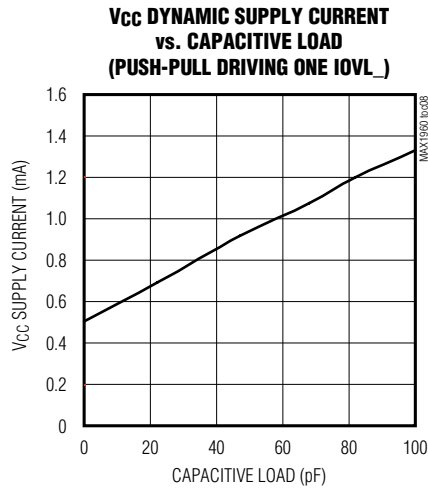
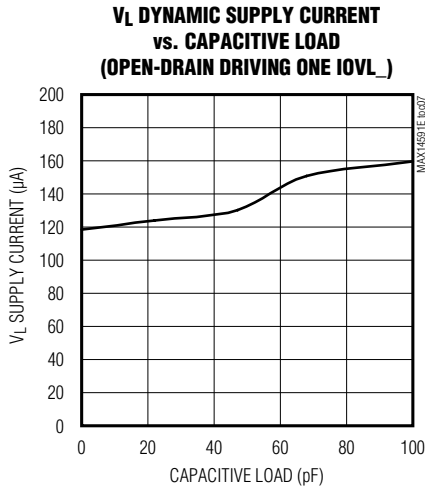


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## High-Speed, Open-Drain Capable Logic-Level Translator

### Typical Operating Characteristics (continued)

( $V_{CC} = +3V$ ,  $V_L = +1.5V$ ,  $R_L = 1M\Omega$ ,  $C_L = 15pF$ , push-pull driving data rate = 8Mbps,  $T_A = +25^\circ C$ , unless otherwise noted.)

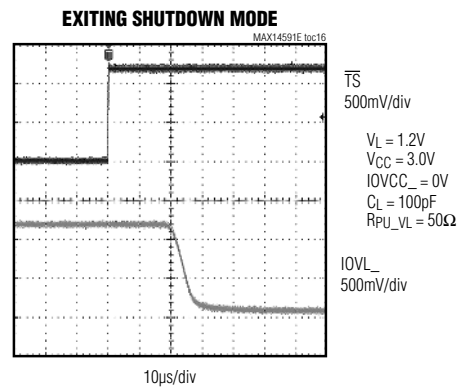
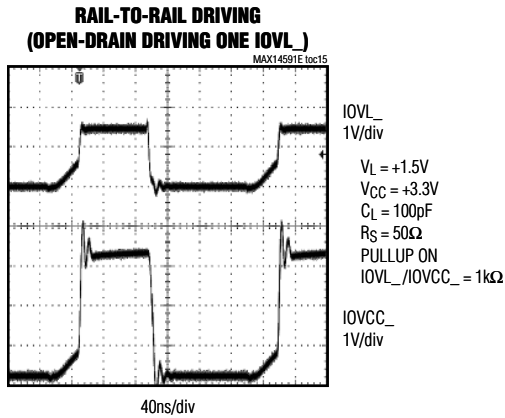
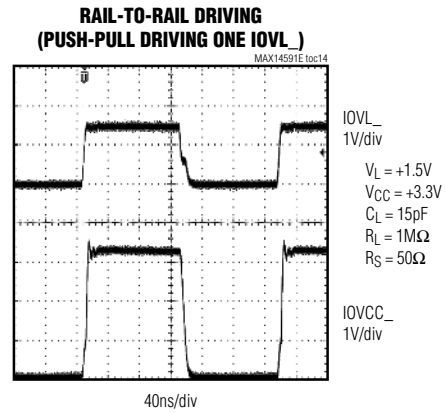
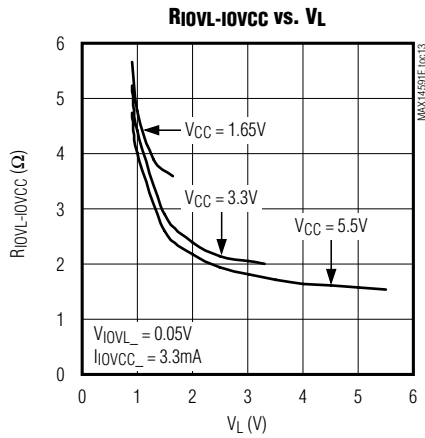


# MAX14591

## High-Speed, Open-Drain Capable Logic-Level Translator

### Typical Operating Characteristics (continued)

( $V_{CC} = +3V$ ,  $V_L = +1.5V$ ,  $R_L = 1M\Omega$ ,  $C_L = 15pF$ , push-pull driving data rate = 8Mbps,  $T_A = +25^\circ C$ , unless otherwise noted.)

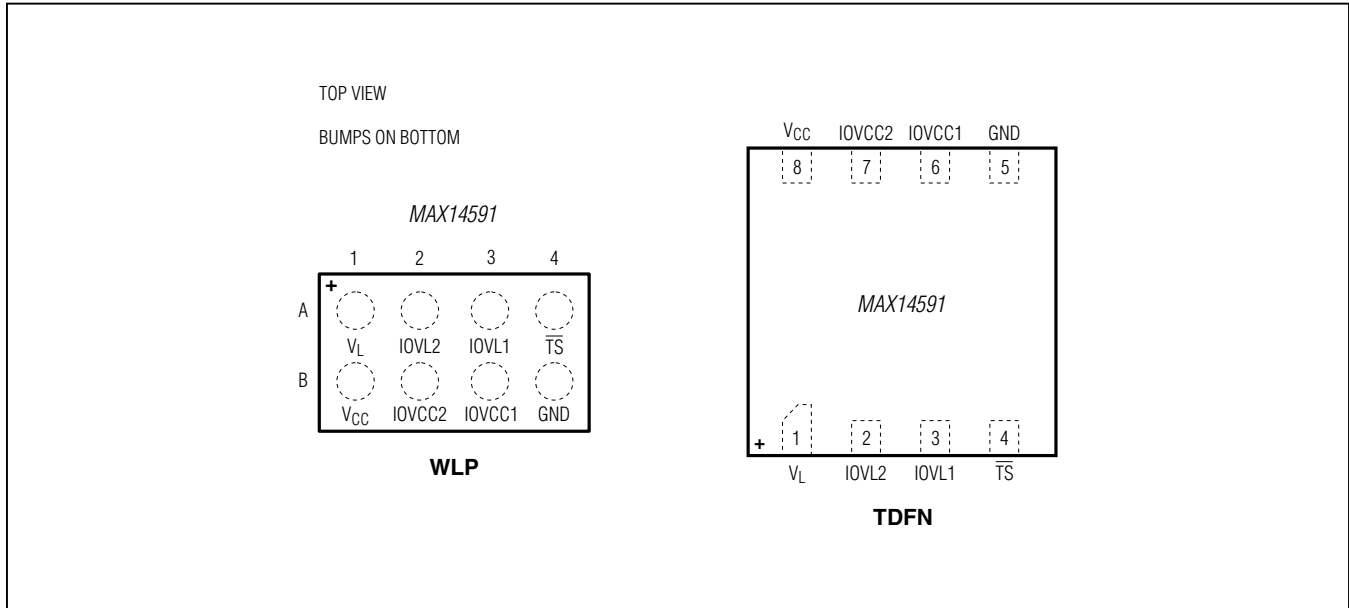




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## High-Speed, Open-Drain Capable Logic-Level Translator

### Pin Configurations



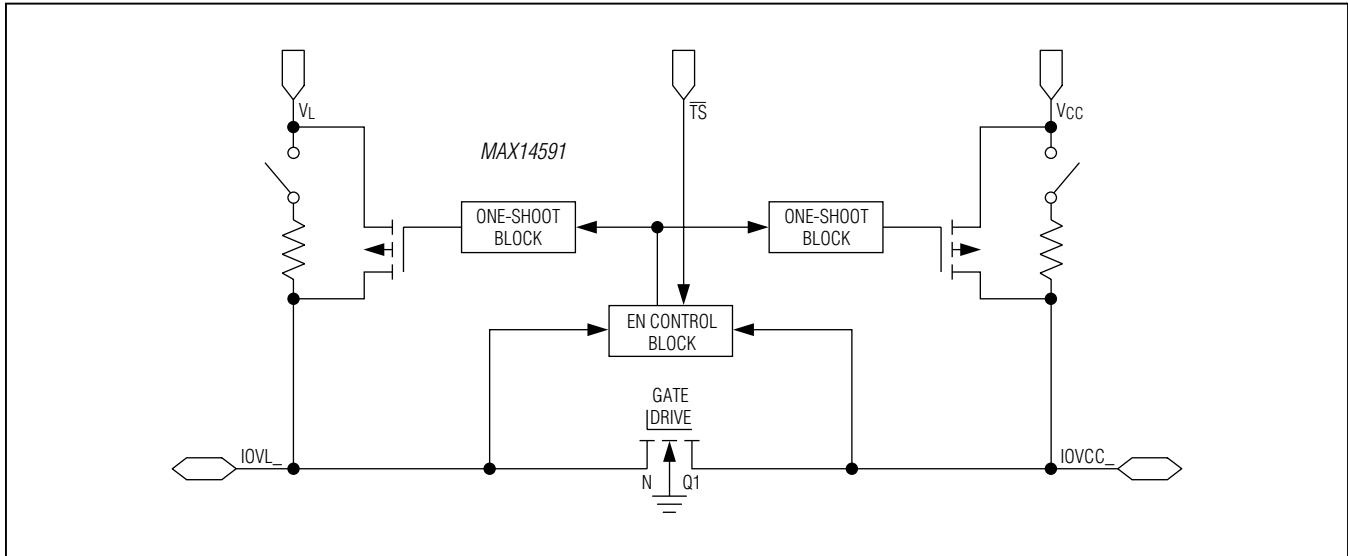
### Pin Description

BUMP/PIN		NAME	FUNCTION
WLP	TDFN		
A1	1	$V_L$	Logic Supply Voltage, +0.9V to min( $V_{CC} + 0.3V$ , +3.6V). Bypass $V_L$ to GND with a 0.1 $\mu$ F ceramic capacitor as close as possible to the device.
A2	2	IOVL2	Input/Output 2. Reference to $V_L$ .
A3	3	IOVL1	Input/Output 1. Reference to $V_L$ .
A4	4	$\overline{TS}$	Active-Low Three-State Input. Drive $\overline{TS}$ low to place the device in shutdown mode with high-impedance output and internal pullup resistors disconnected. Drive $\overline{TS}$ high for normal operation.
B1	8	$V_{CC}$	Power Supply Voltage, +1.65V to +5.5V. Bypass $V_{CC}$ to GND with a 1 $\mu$ F ceramic capacitor as close to the device as possible.
B2	7	IOVCC2	Input/Output 2. Reference to $V_{CC}$ .
B3	6	IOVCC1	Input/Output 1. Reference to $V_{CC}$ .
B4	5	GND	Ground

# MAX14591

## High-Speed, Open-Drain Capable Logic-Level Translator

### Block Diagram



### Detailed Description

The MAX14591 is a dual-channel, bidirectional level translator. The device translates low voltage down to +0.9V on the  $V_L$  side to high voltage on the  $V_{CC}$  side and vice-versa. The device is optimized for open-drain and high-speed operation, such as I<sup>2</sup>C bus and MDIO bus.

The device has low on-resistance (17 $\Omega$  max), which is important for high-speed, open-drain operation. The device also features internal pullup resistors that are active when the corresponding power is on and  $\overline{TS}$  is high.

#### Level Translation

For proper operation, ensure that  $+1.65V \leq V_{CC} \leq +5.5V$ , and  $+0.9V \leq V_L \leq V_{CC}$ . When power is supplied to  $V_L$  while  $V_{CC}$  is less than  $V_L$ , the device automatically disables logic-level translation function. Also, the device enters shutdown mode when  $\overline{TS} = GND$ .

#### High-Speed Operation

The device meets the requirements of high-speed I<sup>2</sup>C and MDIO open-drain operation. The maximum data rate is at least 4MHz for open-drain operation with the total bus capacitance equal to or less than 100pF.

### Three-State Input $\overline{TS}$

The device features a three-state input that can put the device into high-impedance mode. When  $\overline{TS}$  is low, IOVCC\_ and IOVL\_ are all high impedance and the internal pullup resistors are disconnected. When  $\overline{TS}$  is high, the internal pullup resistors are connected when the corresponding power is in regulation, and the resistors are disconnected at the side that has no power on. In many portable applications, one supply is turned off but the other side is still operating and requires the pullup resistors to be present. This feature eliminates the need for external pullup resistors. The level translation function is off until both power supplies are in range.

### Thermal-Shutdown Protection

The device features thermal-shutdown protection to protect the part from overheating. The device enters thermal shutdown when the junction temperature exceeds +150°C (typ), and the device is back to normal operation again after the temperature drops by approximately 10°C (typ). When the device is in thermal shutdown, the level translator is disabled.

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## High-Speed, Open-Drain Capable Logic-Level Translator

### Applications Information

#### Layout Recommendations

Use standard high-speed layout practices when laying out a board with the MAX14591. For example, to minimize line coupling, place all other signal lines not connected to the device at least 1x the substrate height of the PCB away from the input and output lines of the device.

#### Extended ESD

ESD protection structures are incorporated on all pins to protect against electrostatic discharges up to  $\pm 2\text{kV}$  (HBM) encountered during handling and assembly. After an ESD event, the device continues to function without latchup.

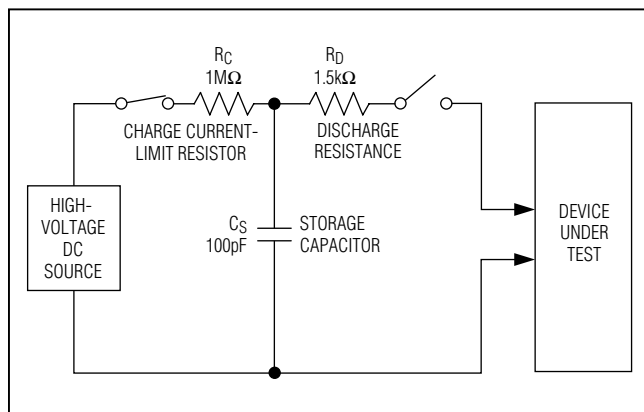


Figure 5. Human Body ESD Test Model

#### ESD Test Conditions

ESD performance depends on a variety of conditions. Contact Maxim for a reliability report that documents test setup, test methodology, and test results.

#### Human Body Model

Figure 5 shows the Human Body Model. Figure 6 shows the current waveform it generates when discharged into a low impedance. This model consists of a 100pF capacitor charged to the ESD voltage of interest that is then discharged into the device through a 1.5kΩ resistor.

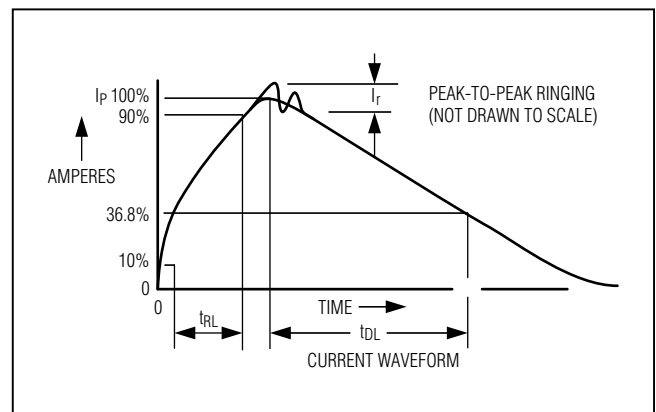


Figure 6. Human Body Current Waveform

# MAX14591

## High-Speed, Open-Drain Capable Logic-Level Translator

### Ordering Information

PART	TOP MARK	PIN-PACKAGE
MAX14591ETA+T	BNS	8 TDFN
MAX14591EWA+T	AAD	8 WLP

**Note:** All devices are specified over  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  operating temperature range.

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

T = Tape and reel.

### Chip Information

PROCESS: BiCMOS

### Package Information

For the latest package outline information and land patterns (footprints), go to [www.maximintegrated.com/packages](http://www.maximintegrated.com/packages). Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 TDFN	T822CN+1	<a href="#">21-0487</a>	<a href="#">90-0349</a>
8 WLP	W80A1+1	<a href="#">21-0555</a>	Refer to <a href="#">Application Note 1891</a>

# MAX14591

## High-Speed, Open-Drain Capable Logic-Level Translator

### *Revision History*

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	5/11	Initial release	—
1	12/14	Updated <i>Ordering Information</i> and <i>Package Information</i>	12



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**Maxim Integrated 160 Rio Robles, San Jose, CA 95134 USA 1-408-601-1000**

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