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## MAX14912/MAX14913

# Octal High-Speed, High-Side Switch/Push-Pull Driver

### General Description

The MAX14912/MAX14913 have eight 640mA smart high-side switches that can also be configured as push-pull drivers for high-speed switching. The propagation delay from input to switching of the high-side/low-side drivers is 1 $\mu$ s (max). Each high-side driver has a low on-resistance of 230m $\Omega$  (max) at 500mA load current at  $T_A = 125^\circ\text{C}$ .

The device is configured and controlled either through pins or the SPI interface. The SPI interface is daisy-chainable, which allows efficient cascading of multiple devices. SPI also supports command mode, for the highest detailed diagnostic information. The MAX14912 allows configuration through SPI in parallel and serial setting modes, while the MAX14913 only supports configuration through SPI in serial setting mode.

Open-load detection in high-side mode detects both open-wire conditions in the switch on/off states, and LED drivers provide indication of per-channel fault and status conditions. Internal active clamps accelerate the shutdown of inductive loads fast in high-side mode.

The MAX14912/MAX14913 are available in a 56-pin QFN 8mm x 8mm package.

### Applications

- Industrial Digital Outputs
- PLC Systems
- Building Automation

### Benefits and Features

- Low Power and Heat Dissipation
  - 230m $\Omega$  (max) High-Side  $R_{ON}$  at  $T_A = 125^\circ\text{C}$
  - High-Efficiency 5V/100mA Buck Regulator
- Fast Switching Ideal for High-Speed Control Systems
  - 0.1 $\mu$ s (typ.) Propagation Delay (High-Side Mode)
  - 0.5 $\mu$ s (typ.) Propagation Delay (Push-Pull Mode)
  - 200kHz Switching-Rate Capability in Push-Pull Mode
  - Fast Inductive Load Demagnetization
- Robust Operation
  - 60V Abs Max  $V_{DD}$  Rating
  - Safe-Demagnetization with Maxim Integrated's patented SafeDemag™: Turn-Off of Unlimited Inductance
  - IEC61000-4-2 12kV Air Gap/8kV Contact ESD Protection
  - $\pm 1\text{kV}/42\Omega$  Surge Protection with TVS on  $V_{DD}$
  - Robust SPI Interface with Watchdog and CRC
  - $-40^\circ\text{C}$  to  $+125^\circ\text{C}$  Ambient Operating Temperature Range
- Extensive Diagnostics Reduces System Downtime
  - Per Driver and Chip Thermal Shutdown
  - Open-Wire Detection in High-Side Mode
  - Low Supply Voltage Warning
  - Undervoltage Detection
  - Overvoltage Detection on OUT
  - Overcurrent Detection
  - LED Drivers for Visual Fault and Output State Indication
- Flexible Interface for Ease of Design
  - Serial and/or Parallel Control Interface
  - Per-Channel Configuration and Monitoring
  - Wide Logic Voltage Range (1.6V to 5.5V)
- Small Package and High Integration Enables Compact High-Density I/O Modules
  - 56-Pin QFN 8mm x 8mm Package
  - Eight High-Side Switches/Push-Pull Drivers
  - Daisy-Chainable SPI Interface

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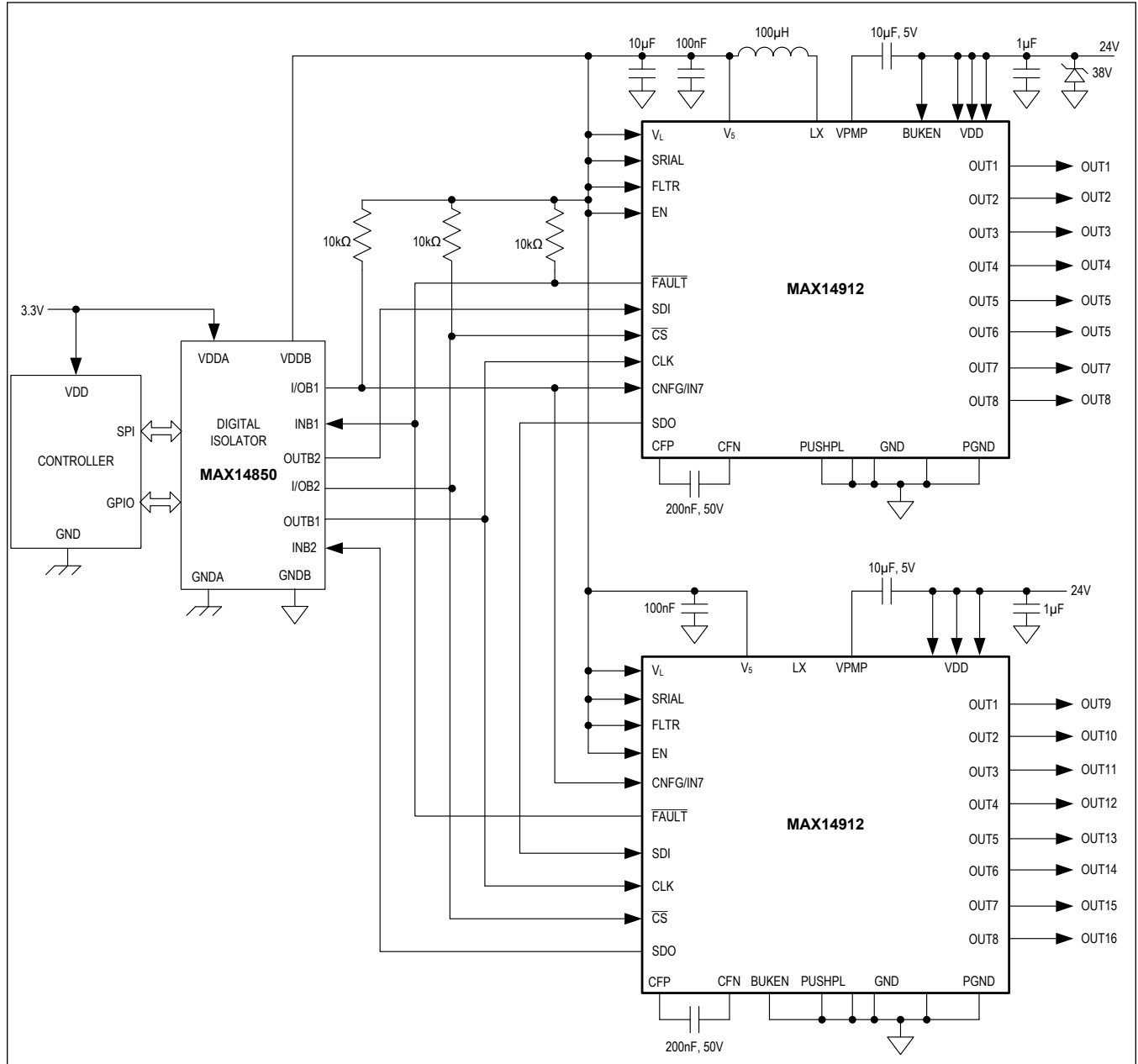
[Ordering Information](#) appears at end of data sheet.

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Typical Application Circuit: Isolated 16 Channel DO with Daisy Chained SPI



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## Absolute Maximum Ratings

(All voltages relative to GND.)		IN <sub>-</sub> , PUSHPL, FLTR, SRIAL, EN, $\overline{\text{FAULT}}$ , $\overline{\text{CERR}}$ /IN4, WDFLT/ IN6	-0.3V to +6V
V <sub>DD</sub>	-0.3V to +60V	LED <sub>-</sub> , LD <sub>-</sub>	-0.3V to (V <sub>5</sub> + 0.3V)
PGND	-0.3V to +0.3V	Inductive Kickback Energy OUT <sub>-</sub> pins: I <sub>L</sub> < 0.6A	Unlimited
BUKEN, LX	-0.3V to (V <sub>DD</sub> + 0.3V)	OUT <sub>-</sub> Load Current	Internally Limited
V <sub>PMP</sub>	(V <sub>DD</sub> - 0.3V) to (V <sub>DD</sub> + 6V)	Continuous-Current (any other terminal)	±100mA
OUT <sub>-</sub> (continuous voltage)	(V <sub>DD</sub> - 49V) to (V <sub>DD</sub> + 0.3V)	Continuous Power Dissipation (T <sub>A</sub> = +70°C) QFN (derate 47.6mW/°C above 70°C)	3800mW
V <sub>5</sub> , V <sub>L</sub>	-0.3V to +6V	Junction Temperature	Internally Limited
CFP	(V <sub>DD</sub> - 0.3V) to (V <sub>PMP</sub> + 0.3V)	Storage Temperature Range	-65°C to +150°C
CFN	-0.3V to (V <sub>PMP</sub> + 0.3V)	Lead Temperature (Soldering, 10sec)	+300°C
SDO	-0.3V to (V <sub>L</sub> + 0.3V)		
SDI, CLK, $\overline{\text{CS}}$	-0.3V to +6V		

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 Information

### 56 QFN

Package Code	K5688+1
Outline Number	<a href="#">21-100026</a>
Land Pattern Number	<a href="#">90-100006</a>
<b>THERMAL RESISTANCE, FOUR-LAYER BOARD</b>	
Junction to Ambient ( $\theta_{JA}$ )	21°C/W
Junction to Case ( $\theta_{JC}$ )	1.0°C/W

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 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).

**DC Electrical Characteristics**

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>SUPPLY</b>						
$V_{DD}$ Supply Voltage	$V_{DD}$		10.5		36	V
$V_{DD}$ Supply Current	$I_{DD}$	HS mode, EN = high, OUT_ outputs high (no switching), no load, $V_5$ and $V_L$ supplied externally		1.1	1.5	mA
		PP mode, EN = high, 100kHz switching on all OUT_, $V_5$ and $V_L$ supplied externally, no load		15	25	
$V_{DD}$ Undervoltage-Lockout Threshold	$V_{DD\_UV}$	$V_5 = 5V$ , $V_{DD}$ rising	8.5		9.5	V
$V_{DD}$ Undervoltage-Lockout Hysteresis	$V_{DD\_UVHYST}$	$V_5 = 5V$		1		V
$V_{DD}$ Low-Voltage Warning Threshold	$V_{DD\_LV}$	$V_{DD}$ falling	12	13	14	V
$V_{DD}$ Low-Voltage Warning Hysteresis	$V_{DD\_LVHYST}$	$V_5 = 5V$		2		V
<b><math>V_5/V_L</math> Supplies</b>						
$V_5$ Supply Voltage (Supplied Externally)	$V_5$		4.5		5.5	V
$V_5$ Supply Current ( $V_5$ Supplied Externally)	$I_{V5}$	HS mode, EN = high, OUT_ outputs high, no load, no LEDs connected		2.2	3.2	mA
		PP mode, EN = high, OUT_ switching at 100kHz, no load, no LEDs connected		8.5	11	
$V_5$ Undervoltage-Lockout Threshold	$V_{V5\_UV}$	$V_{DD} = 24V$ , $V_5$ rising	3.8		4.2	V
$V_5$ Undervoltage-Lockout Hysteresis	$V_{V5\_UVHYST}$	$V_{DD} = 24V$		0.3		V
$V_L$ Supply Voltage	$V_L$		1.6		5.5	V
$V_L$ Supply Current	$I_{V_L}$	All logic inputs high or low		24	35	$\mu A$
$V_L$ Undervoltage-Lockout Threshold	$V_{L\_UV}$	$V_L$ falling	1.12	1.27	1.52	V
<b>5V DC-DC REGULATOR</b>						
Undervoltage-Lockout Threshold of the DC-DC Regulator	$V_{DCDC\_UVLO}$	$V_{DD}$ rising			6.6	V
Undervoltage-Lockout Threshold of the DC-DC Regulator Hysteresis	$V_{DCDC\_UVLOHY}$			0.5		V
Output Regulated Voltage	$V_{DCDC}$	0mA to 90mA external load current	4.85	5.0	5.15	V
Current Limit	$I_{CL\_DCDC}$		100			mA
Turn-On Time	$T_{ON\_DCDC}$	Delay from $V_{DD}$ crossing the UVLO threshold until the DC-DC regulator finishes soft-start	3.0	3.4	3.8	ms
Switching Frequency	$f_{DCDC}$		540	600	660	kHz



**DC Electrical Characteristics (continued)**

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>DRIVER OUTPUTS (OUT<sub>-</sub>)</b>						
HS Mode On-Resistance	$R_{OUT\_HS}$	HS mode, HS = on, $I_{OUT\_} = -500mA$ (Note 1)		110	230	m $\Omega$
HS Mode Current Limit	$I_{LIM}$	EN = high, HS = on, $V_{OUT\_} = V_{DD} - 1V$	0.64	0.87	1.2	A
HS Mode Current-Limit V/I Slope		(See Overcurrent and Short-Circuit Protection section)		150		$\Omega$
HS Mode Weak Pulldown Current	$I_{LKG}$	High-side mode, OL detect = off, HS = off, $7V < V_{OUT\_} < V_{DD}$	65	100	180	$\mu A$
Push-Pull Mode HS On-Resistance	$R_{OUT\_PP}$	PP mode, HS = on, EN = high, $I_{OUT\_} = -500mA$ (Note 1)		110	230	m $\Omega$
Push-Pull Mode LS On-Resistance	$V_{OL\_PP}$	PP mode, LS = on, EN = high, $I_{OUT} = 500mA$		1	2.5	$\Omega$
Push-Pull Mode Current Limit	$I_{LIM\_PP}$	PP mode, EN = High, $OUT\_ =$ high, $V_{OUT\_} = V_{DD} - 1V$	0.64	0.87	1.2	A
		PP mode, EN = High, $OUT\_ =$ low, $3V < V_{OUT\_} < V_{DD}$	0.44	0.68	0.81	
<b>OPEN-LOAD DETECT (OUT<sub>-</sub>)</b>						
Open-Load Pullup Current, High-Side Off	$I_{OL\_HSOFF}$	OL detect = on, high-side mode, HS = off, $7V < V_{OUT\_} < V_{DD} - 1V$	40	65	110	$\mu A$
Open-Load Detect Threshold, High-Side Off	$V_{OL\_T}$	OL detect = on, high-side mode, HS = off, LED turns off/on	6.4	6.7	7.35	V
Open-Load Detect Threshold Current, High-Side On	$I_{OL\_HSON}$	OL detect = on, high-side mode, HS = on, $0V < V_{OUT\_} < (V_{DD} - 1V)$	1	2	3	mA
Debounce Filter	$T_{DEB\_OL}$	Reliable open-load detection reading is obtained only if both the switch input state and the load level do not change for $T_{DEB\_OL}$ , high-side = on/off		100		ms
<b>LOGIC (I/O)</b>						
Input Voltage High	$V_{IH}$	$V_L < 2.5V$	$0.8 \times V_L$			V
		$V_L \geq 2.5V$	$0.7 \times V_L$			
Input Voltage Low	$V_{IL}$	$V_L < 2.5V$	$0.16 \times V_L$			V
		$V_L \geq 2.5V$	$0.3 \times V_L$			
Input Threshold Hysteresis	$V_{IHYST}$		$0.1 \times V_L$			V
Input Pulldown Resistor	$R_I$	All logic input pins, except $\overline{CS}$ (Note 2)	140	200	275	k $\Omega$
Input Pullup Resistor	$R_I$	$\overline{CS}$ input (Note 2)	140	200	275	k $\Omega$
Output Logic-High (SDO)	$V_{OH}$	$I_L = -5mA$	$V_L - 0.33V$			V
Output Logic-Low	$V_{OL}$	$I_L = +5mA$	0.33			V
SDO Pulldown Resistor	$R_{L\_SDO}$	$\overline{CS} =$ high	140	200	275	k $\Omega$

**DC Electrical Characteristics (continued)**

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>OPEN-DRAIN OUTPUTS (<math>\overline{FAULT}</math>, <math>\overline{CERR/IN4}</math>, <math>WDFLT/IN6</math>)</b>						
Output Logic-Low	$V_{ODL}$	$I_L = +5mA$			0.58	V
Leakage	$I_{ODL}$	Open-drain output off, pins are at 5.5V	-1		+1	$\mu A$
<b>LED DRIVERS (<math>LEDH_+</math>, <math>LDL_+</math>)</b>						
Output Voltage High	$V_{OH\_LED}$	$LEDH = on$ , $I_{LED} = 5mA$	$V_5 - 0.3$			V
Output Leakage Current High	$I_{LH}$	$LEDH_+ = off$ , $V = 0V$	-50			$\mu A$
Output Voltage Low	$V_{OL\_LED}$	$LDL = on$ , $I_{LED} = 5mA$			0.3	V
Output Leakage Current Low	$I_{LL}$	$LDL = off$ , $V = 5V$			50	$\mu A$
LED Driver Scan Rate	FLED	Update rate for each LED	1.07	1.18	1.31	kHz
Fault-LED Minimum On-Time	$t_{FAULT\_ON}$	Fault LED is turned on for at least $t_{FAULT\_ON}$		200		ms
<b>PROTECTION</b>						
OUT_ Clamp Negative Voltage	$V_{CL}$	Relative to $V_{DD}$ . EN = high	49	56	64.5	V
Channel Thermal-Shutdown Temperature	$T_{JSHDN}$	Junction temperature rising. Per channel		167		$^\circ C$
Channel Thermal-Shutdown Hysteresis	$T_{JSHDN\_HYST}$			17		$^\circ C$
Chip Thermal Shutdown	$T_{CSHDN}$	Temperature rising		150		$^\circ C$
Chip Thermal-Shutdown Hysteresis	$T_{CSHDN\_HYS}$ T			8		$^\circ C$

**Note 1:** Excludes bond wire resistance.

**Note 2:** All units are production tested at  $T_A = +25^\circ C$ . Specifications over temperature are guaranteed by design.

**Note 3:** Specification is guaranteed by design; not production tested.

**Note 4:** Channel-to-channel skew is defined as the difference in propagation delays between channels on the same device with the same polarity.

**Note 5:** X - means do not care.

**Note 6:** All logic input pins except  $\overline{CS}$  have a pulldown resistor.  $\overline{CS}$  has a pullup resistor.

**Note 7:** Bypass each  $V_{DD}$  pin to GND with a  $1\mu F$  capacitor as close as possible to the device for high-ESD protection.

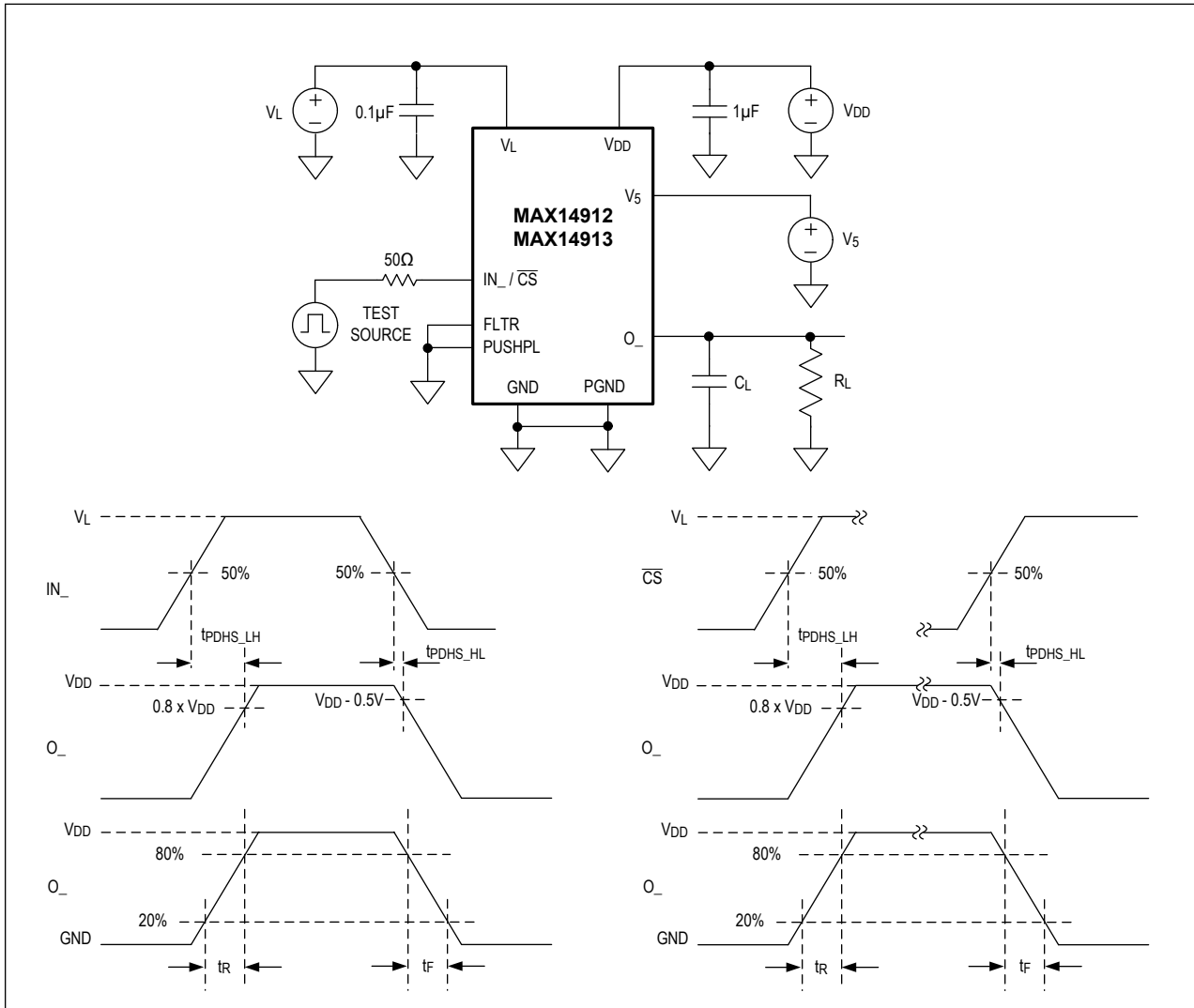


Figure 1. High-Side Mode Timing Characteristics

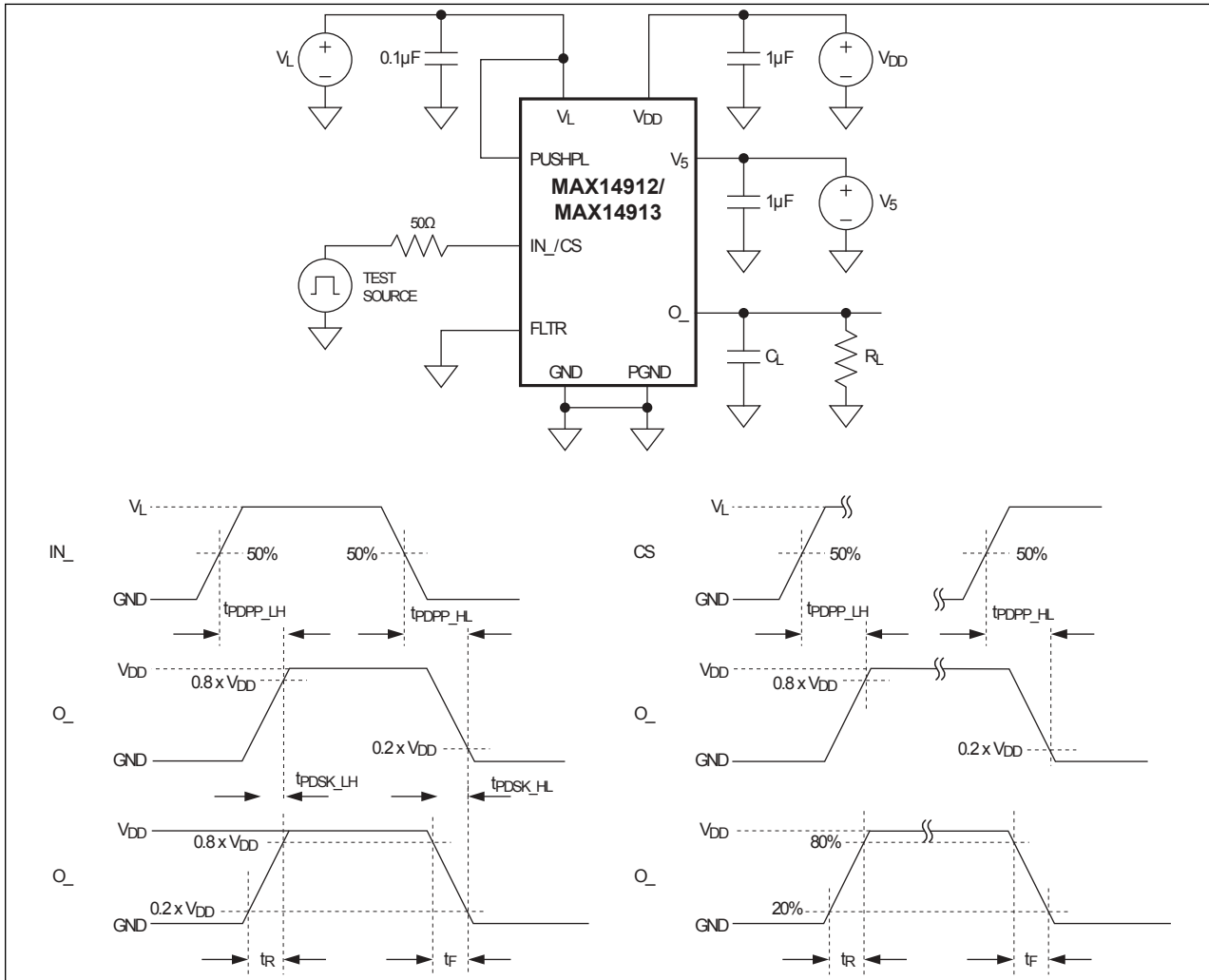


Figure 2. Push-Pull Mode Timing Characteristics

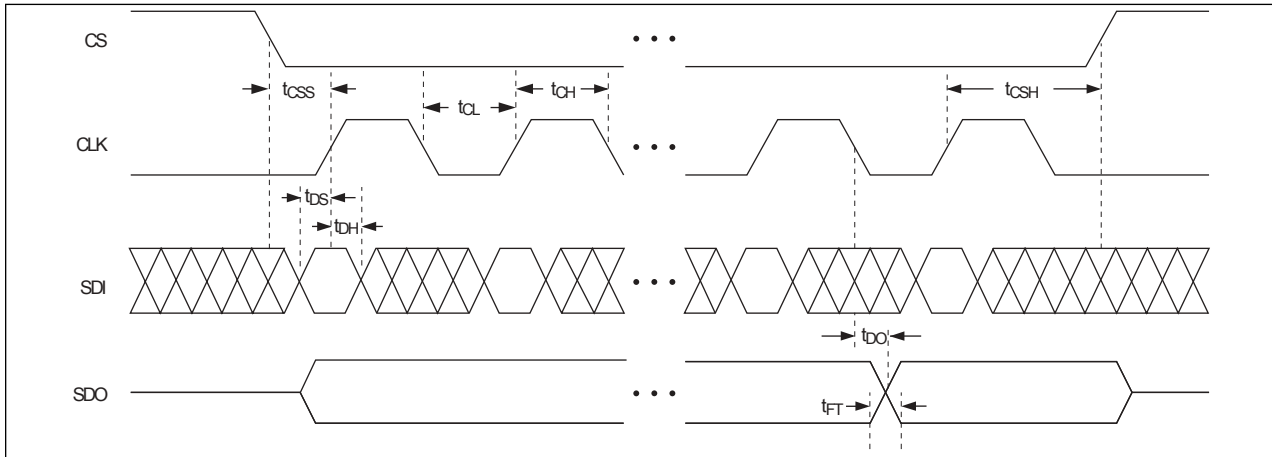


Figure 3. SPI Timing Diagram

### AC Electrical Characteristics

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>OUT_ OUTPUTS</b>						
Power-Up Delay	$t_{POWERUP}$	EN = high time from $V_{DD} > V_{DD\_UV}$ to switches turned-on, $V_{HVBUCKEN} = 0V$ or $V_{DD}$		5.5		ms
Enable Delay	$t_{ENABLE}$	All power supplies above UVLO thresholds; time from EN positive edge to switches turned on		0.1		$\mu s$
Push-Pull Switchover Delay	$t_{D\_PPMODE}$	Delay from high-side to push-pull switchover		45		$\mu s$
Output Propagation Delay LH	$t_{PD\_LH}$	High-side mode, delay from $IN_+$ or positive CS edge to $OUT_+$ to $0.8 \times V_{DD}$ . $C_L = 100pF$ , FLTR = low (Figure 1, Note 3)		0.35	0.7	$\mu s$
		Push-pull mode, delay from $IN_+$ or CS positive edge to $OUT_+$ rising to $0.8 \times V_{DD}$ . $C_L = 100pF$ , FLTR = low (Figure 2)		0.40	0.7	
Output Propagation Delay HL	$t_{PD\_HL}$	High-side mode, delay from $IN_+$ negative edge or CS switching high to $OUT_+$ falling by $0.5V$ . $R_L = 48\Omega$ , FLTR = low (Figure 1, Note 3)		0.1		$\mu s$
		Push-pull mode, delay between $IN_+$ switching low or CS switching high to $OUT_+$ falling to $0.2 \times V_{DD}$ . $C_L = 100pF$ , FLTR = low (Figure 2)		0.35	0.7	
Output-to-Output Propagation Skew LH	$t_{PD\_SK\_LH}$	Push-pull modes, $C_L = 1nF$ , FLTR = X (Note 4, Note 5)	-100	0	100	ns

**AC Electrical Characteristics (continued)**

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output-to-Output Propagation Skew HL	$t_{PD\_SK\_HL}$	Push-pull modes, $R_L = 5k\Omega$ , $C_L = 1nF$ , FLTR = X (Note 5)	-100	0	100	ns
Output Rise Time	$t_R$	Push-pull mode, 20% to 80% $V_{DD}$ , $C_L = 100pF$ , FLTR = X (Note 5)		0.3		$\mu s$
		High-side mode, 20% to 80% $V_{DD}$ , FLTR = X (Note 5)		0.3		
Output Fall Time	$t_F$	Push-pull mode, 80% to 20% $V_{DD}$ , $V_{DD} < 30V$ , $C_L = 100pF$ , FLTR = X (Note 5)		0.05		$\mu s$
<b>CRC ERROR DETECTION (CERR/IN4)</b>						
Propagation Delay	$t_{PDL\_CERR}$	SRIAL = high, CRC/IN3 = high, OUT_ detects a CRC error on SDI data, $I_{SOURCE} = 5mA$		14.5		ns
	$t_{PDH\_CERR}$	SRIAL = high, CRC/IN3 = high, OUT_ clears/CERR/IN4, $I_{SOURCE} = 5mA$		17		
<b>WATCHDOG TIMER</b>						
Watchdog Timeout Accuracy	$t_{WD\_ACC}$	SRIAL = high, WDEN/IN5 = high. See Table 5 for watchdog timeout selection.	-10		+10	%
<b>GLITCH FILTERS</b>						
Pulse Length of Rejected Glitch	$t_{FPL\_GF}$	FLTR = high, on EN, CS, _IN_ pins			80	ns
		FLTR = X, SRIAL and PUSHPL pins			170	
Passes Pulse Length	$t_{FD\_GF}$	FLTR = high, on EN, CS, _IN_ pins	260			ns
		FLTR = X, SRIAL and PUSHPL pins	550			
Glitch Filter Delay Time	$t_{D\_GF}$	FLTR = high, on EN, CS, _IN_ pins		140		ns
		FLTR = X, SRIAL and PUSHPL pins		320		
<b>SPI TIMING CHARACTERISTICS / <math>2.5V \leq V_L &lt; 5.5V</math></b>						
CLK Clock Period	$t_{CH+CL}$		50			ns
CLK Pulse-Width High	$t_{CH}$		10			ns
CLK Pulse-Width Low	$t_{CL}$		10			ns
$\overline{CS}$ Fall-to-CLK Rise Time	$t_{CSS}$	FLTR = low (Note 3)	12			ns
		FLTR = high	260			
SDI Hold Time	$t_{DH}$		5			ns
SDI Setup Time	$t_{DS}$		5			ns
Output Data Propagation Delay	$t_{DO}$	$C_L = 10pF$ . CLK falling-edge to SDO stable			30	ns
SDO Rise-and-Fall Times	$t_{FT}$			1		ns
$\overline{CS}$ Hold Time	$t_{CSH}$		40			ns
$\overline{CS}$ Pulse Width High	$t_{CSPW}$	FLTR = low (Note 3).	15			ns
		FLTR = high	260			

**AC Electrical Characteristics (continued)**

( $V_{DD} = +10V$  to  $+36V$ ,  $V_5 = +4.5V$  to  $+5.5V$ ,  $V_L = +1.6V$  to  $+5.5V$ ,  $T_A = -40^\circ C$  to  $+125^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$  and  $V_{DD} = +24V$ ,  $C_{DCDC} = 10\mu F$ ,  $L_{DCDC} = 100\mu H$ ,  $C_{FLY} = 200nF$ ,  $C_{PUMP} = 10\mu F$ , unless otherwise noted.)

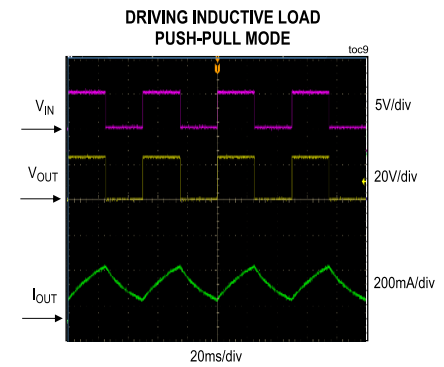
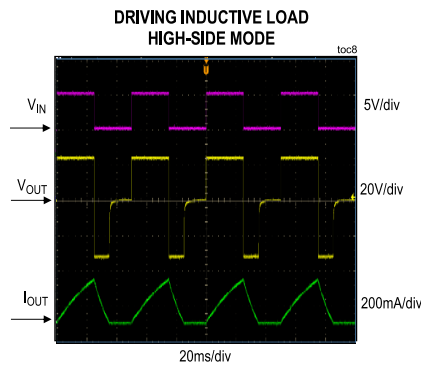
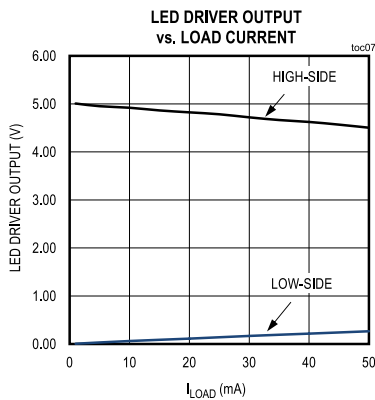
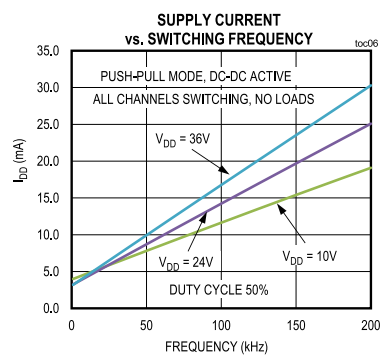
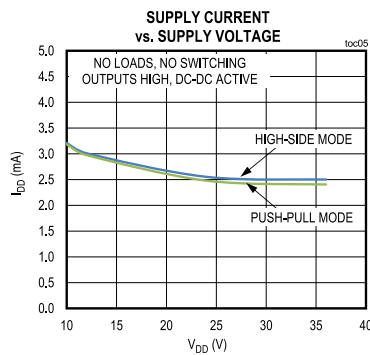
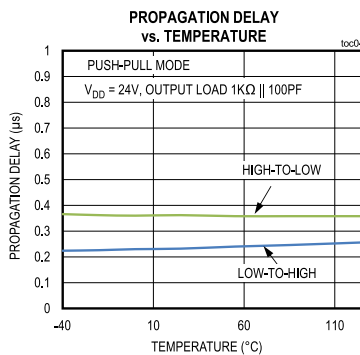
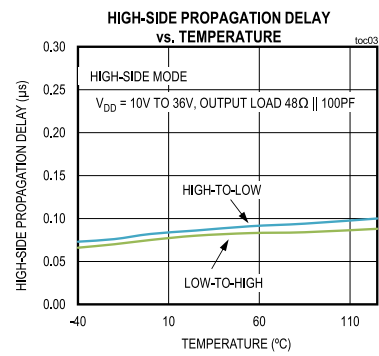
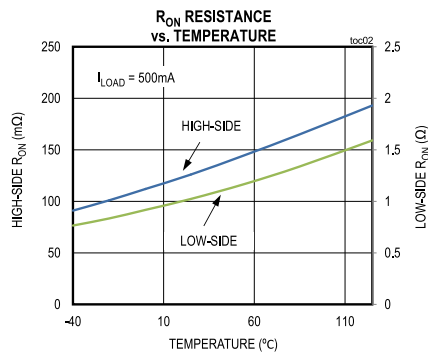
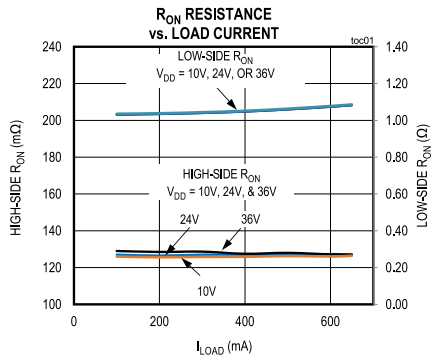
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b><math>1.6V \leq V_L &lt; 2.5V</math></b>						
CLK Clock Period	$t_{CH+CL}$		60			ns
CLK Pulse-Width High	$t_{CH}$		13			ns
CLK Pulse-Width Low	$t_{CL}$		13			ns
$\overline{CS}$ Fall to CLK Rise Time	$t_{CSS}$	FLTR = low (Note 3)	15			ns
		FLTR = high	260			
SDI Hold Time	$t_{DH}$		10			ns
SDI Setup Time	$t_{DS}$		10			ns
Output Data Propagation Delay	$t_{DO}$	$C_L = 10pF$ . CLK falling-edge to SDO stable			40	ns
SDO Rise-and-Fall Times	$t_{FT}$			2.5		ns
$\overline{CS}$ Hold Time	$t_{CSH}$		40			ns
$\overline{CS}$ Pulse-Width High	$t_{CSPW}$	FLTR = low (Note 3)	20			ns

**ESD Characteristics**

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
ESD	$V_{ESD}$	OUT_ pins. Contact (Note 7)		$\pm 8$		kV
		OUT_ pins. Air Discharge		$\pm 12$		
		All other pins. Human Body Model		$\pm 2$		

Typical Operating Characteristics

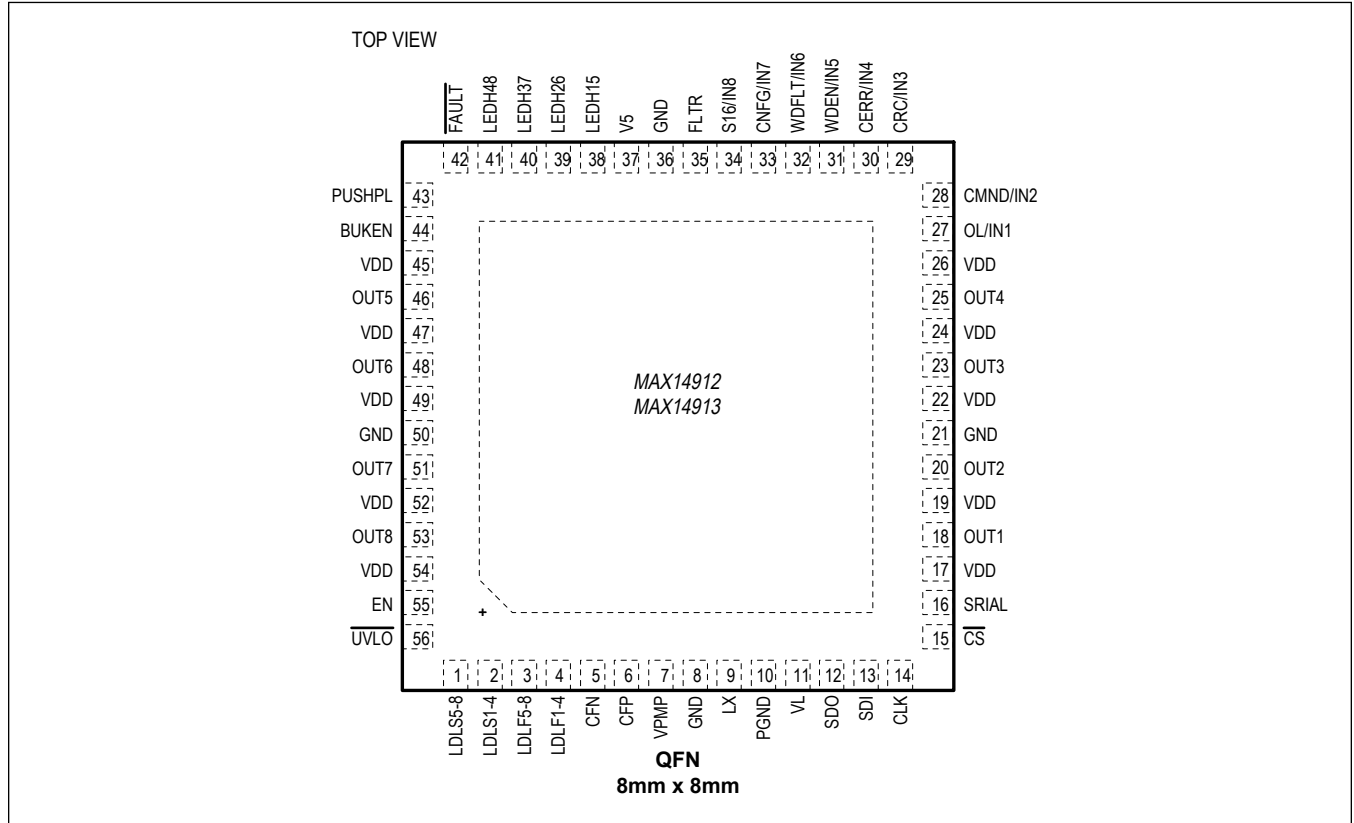
( $V_{DD} = 24V$ ;  $V_5 = 5V$ ,  $V_L = 3.3V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)





Pin Configuration

MAX14912/MAX14913



## Pin Description

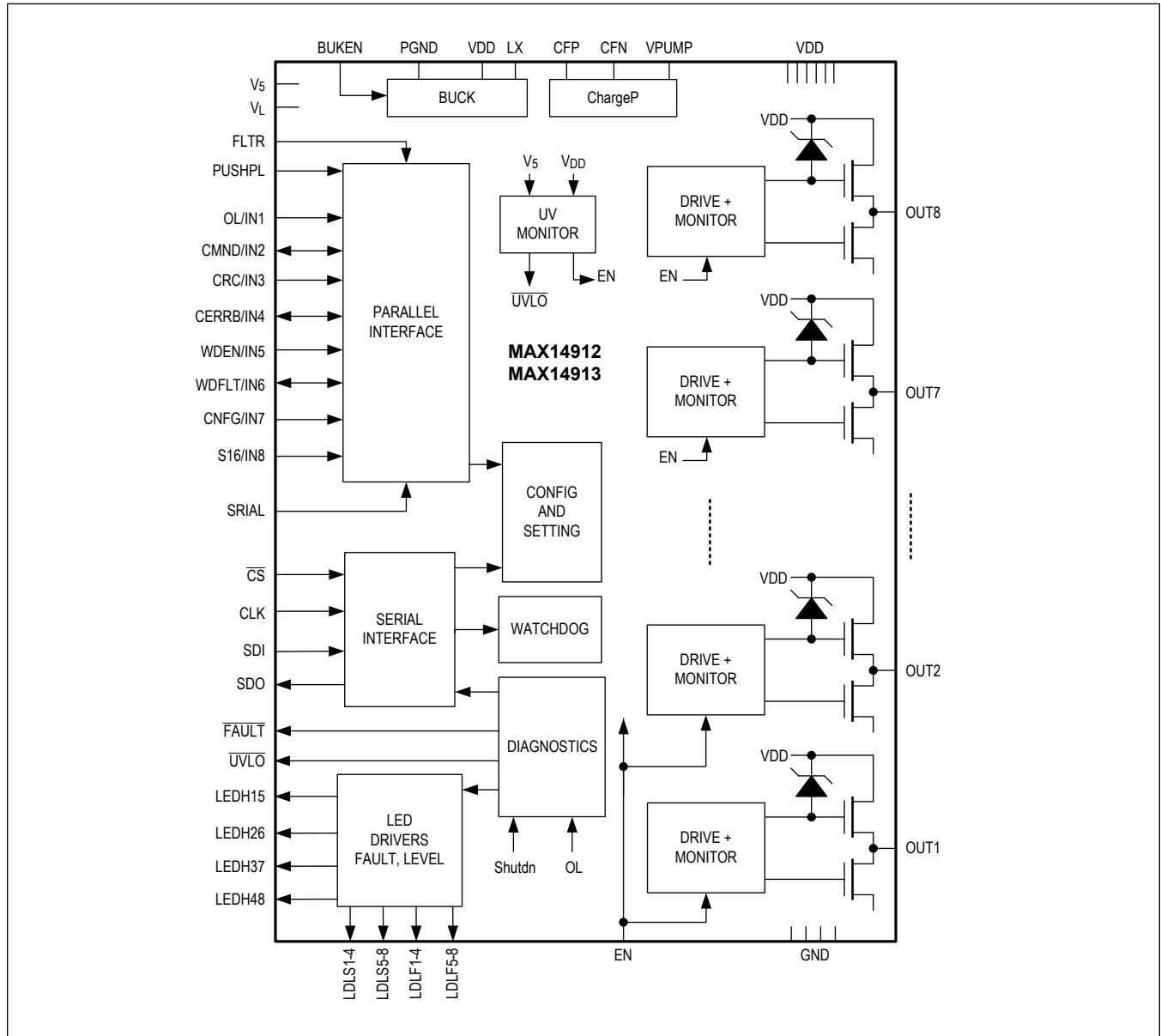
PIN	NAME	FUNCTION
<b>LED DRIVERS</b>		
1, 2	LDLS5-8, LDLS1-4	Status LED Cathode Outputs (Open-Drain Low-Side)
3, 4	LDLF5-8, LDLF1-4	Fault LED Cathode Outputs (Open-Drain Low-Side)
38–41	LEDH15, LEDH26, LEDH37, LEDH48	LED Anode Connections (Open-Drain High-Side). Connect a resistor in series to set the diode current.
<b>POWER SUPPLY</b>		
5	CFN	Charge-Pump Flying Capacitor
6	CFP	Charge-Pump Flying Capacitor. Connect a 200nF/50V capacitor to CFN.
7	VPMP	Charge-Pump Output. Connect a 10µF/5V capacitor between VPMP and V <sub>DD</sub> . VPMP is not intended for use as a power supply for other devices.
8, 21, 36, 50	GND (4x)	Ground. Connect all GND pins together.
9	LX	DC-DC Converter Switching Output. Connect LX to the switching-side of the inductor.
10	PGND	Ground for the DC-DC Converter. Connect to GND.
11	V <sub>L</sub>	Logic Supply Input. V <sub>L</sub> defines the levels on all I/O logic interface pins. Bypass V <sub>L</sub> to GND through a 100nF ceramic capacitor.
17, 19, 22, 24, 26, 45, 47, 49, 52, 54	V <sub>DD</sub> (10x)	Supply Voltage, Nominally 24V. Connect all V <sub>DD</sub> together. Bypass V <sub>DD</sub> to GND through a 1µF capacitor.
37	V <sub>5</sub>	5V Supply Input. V <sub>5</sub> can be powered by an external 5V supply or the internal 5V buck. Bypass V <sub>5</sub> to GND through a 10µF ceramic capacitor.
44	BUKEN	Enable Input for Buck Regulator. BUKEN should be permanently connected to either V <sub>DD</sub> or GND—do not switch BUKEN. Connect BUKEN to GND if not using the internal buck. Connect BUKEN to V <sub>DD</sub> to use the internal buck.
56	$\overline{\text{UVLO}}$	$\overline{\text{UVLO}}$ is an Open-Drain, Undervoltage Indicator of the V <sub>DD</sub> Supply.
<b>SERIAL INTERFACE</b>		
12	SDO	Serial-Data Output. SPI MISO data output to controller.
13	SDI	Serial-Data Input. SPI MOSI data from controller.
14	CLK	Serial-Clock Input from SPI Controller
15	$\overline{\text{CS}}$	Chip-Select Input from Controller
<b>LOGIC INTERFACE</b>		
16	SRIAL	Serial/Parallel Select Input. Drive SRIAL high to set the MAX14912/MAX14913 outputs through the serial interface. Drive SRIAL low to set the MAX14912/MAX14913 outputs through the parallel ( $\_/\text{IN}$ ) pins. SRIAL does not affect serial readback of diagnostic/status information.
27	OL/IN1	Open-Load Select Input/IN1 Input. In serial mode (SRIAL = high), drive OL/IN1 = high to enable open-load detection on all eight OUT_ outputs when in high-side operation. In parallel mode (SRIAL = low), OL/IN1 sets OUT1 on/off/high/low.
28	CMND/IN2	Command Mode SPI Input/IN2 Logic Input. In serial mode (SRIAL = high), CMND/IN2 enables command-based SPI access (see <a href="#">Detailed Description</a> section for details). In parallel mode (SRIAL = low), CMND/IN2 sets OUT2 on/off/high/low.
29	CRC/IN3	CRC Select Input/IN3 Input. In serial mode (SRIAL = high), drive CRC/IN3 = high to enable CRC error detection on serial data. In parallel mode (SRIAL = low), CRC/IN3 sets OUT3 on/off/high/ low.

## Pin Description (continued)

PIN	NAME	FUNCTION
30	CERR/IN4	CRC Error Detection Output/IN4 Input. In serial mode (SRIAL = high) with error checking enabled (CRC/IN3 = high), CERR/IN4 is an open-drain output whose transistor turns on when the device detects an error on SDI data. In parallel mode (SRIAL = low), CERR/IN4 sets OUT4 on/off/high/low.
31	WDEN/IN5	Watchdog Enable Input/ IN5 Input. In serial mode (SRIAL= high), WDEN/IN5 enables the watchdog timer. In parallel mode (SRIAL= low), WDEN/IN5 sets OUT5 on/off/high/low.
32	WDFLT/IN6	Watchdog Fault Output/IN6 Input. In serial mode (SRIAL = high), WDFLT/IN6 is the open-drain watchdog fault output, which turns on when a watchdog fault is detected while WDEN/IN5 is high. In parallel mode (SRIAL = low), WDFLT/IN6 sets OUT6 on/off/high/low.
33	CNFG/IN7	Configure Input/IN7 Input. In serial mode (SRIAL = high), drive CNFG/IN7 high to enable per-channel configuration through the serial interface. In serial mode, drive CNFG/IN7 low to allow setting the OUT_ outputs through the serial interface. In parallel mode (SRIAL = low), CNFG/IN7 sets OUT7 on/off/high/low.
34	S16/IN8	16-Bit Serial Select/IN8 Input. In serial mode (SRIAL = high), drive S16/IN8 high to select 16-bit serial-interface operation. Drive S16/IN8 low in serial mode for 8-bit serial operation. In parallel mode (SRIAL = low), S16/IN8 sets OUT8 on/off/high/low.
35	FLTR	Glitch Filter Enable Input. Set FLTR high to enable glitch filtering on all parallel logic inputs and CS.
42	$\overline{\text{FAULT}}$	Open-Drain Fault Output. The $\overline{\text{FAULT}}$ transistor turns on low when a fault condition (driver shutdown or open-load detect) occurs.
43	PUSHPL	Push-Pull, High Slew-Rate Configuration Input. When PUSHPL is set high, all OUT_ pins operate in push-pull mode. When PUSHPL is set low, all OUT_ pins operate in high-side mode.
55	EN	Output Enable Input. Driving EN low turns all high-side OUT_ switches off, and three-states all push-pull OUT_ drivers and turns all LED drivers off. Driving EN high enables normal operation.
<b>SWITCH/DRIVER OUTPUTS</b>		
18, 20, 23, 25, 46, 48, 51, 53	OUT1–OUT8	Driver Output N. May be configured as a high-side switch or push-pull output.

Functional Diagram

Functional Diagram



## Detailed Description

### High-Side Mode

The high-side drivers (HS) have 230mΩ (max) on-resistance when sourcing 500mA at  $T_A = +125^\circ\text{C}$ . The OUT\_ output voltage can go below ground, as can occur during inductive load turn-off/demagnetization. Internal clamping diodes limit the negative excursion to ( $V_{DD} - V_{CL}$ ) and allow free-wheeling currents to demagnetize the inductive loads quickly.

Low-side transistors (LS) can be switched in to provide push-pull operation. Fast discharge of ground-connected RC loads is achieved by push-pull drive. In push-pull mode, the OUT\_ outputs are clamped to GND.

### Output Parallelization

The devices support paralleling of channels in high-side mode to provide higher current. The channels can be paired (1-2, 3-4, 5-6, and 7-8) by setting two bits of the SPI register 3: joinUP and joinDW (see [Table 6](#)).

When joinDW = 1, OUT1 and OUT2 are connected together, and OUT3 and OUT4 are connected together, and:

- Input signals related to channels 2 and 4 are neglected;
- Output status is determined by inputs 1 and 3;
- Push-pull mode is disabled.

When joinUP = 1, OUT5 and OUT6 are connected together, and OUT7 and OUT8 are connected together, and:

- Input signals related to channels 6 and 8 are neglected;
- Output status is determined by inputs 5 and 7;
- Push-pull mode is disabled.

The above configuration can be used without any additional external zener clamping.

Besides pairing of drivers through internal configuration, multiple OUTs can be operated in parallel by tying the OUT\_ together and driving the inputs simultaneously. In this case, an external zener clamp is required per output set for absorbing the energy during inductive load turn-off. The external clamp voltage of this zener diode must be lower than the minimum internal clamp voltage ( $V_{CL}(\text{min})$ ). The reason is that there is channel-to-channel variation between the internal clamp voltages. Without an external zener diode, during turn-off of channels connected in parallel, the internal clamp with the lowest clamp voltage turns on and dissipates all the energy. Channel diagnostics for fault detection remains independent in case of paralleling the outputs.

### Open-Load/Wire Detection

Detection of an open-load condition can be enabled on a per-channel basis through serial configuration, or globally in serial mode through the OL/IN1 input. Open-load detection works in high-side mode only. It operates with the HS driver either on or off.

When the HS switch is off, a current source is enabled, which pulls OUT\_ to  $V_{DD}$  when the wire is open. If the OUT\_ voltage is above  $V_{OL\_T}$ , an open load is signaled.

When the HS switch is on, the voltage across the HS switch is monitored. If this drop is below a load current of  $I_{OL\_HSON}$ , an open-load fault is reported.

The switch input state and the load condition must both be stable for at least  $t_{DEB\_OL}$  to get a reliable reading.

When an open-load condition is detected on an output:

1. The F\_ bit is set for that output in the serial diagnostic data.
2. The fault LED is turned on for at least 200ms for that channel.
3. The open-drain global FAULT transistor is turned on for at least 200ms.

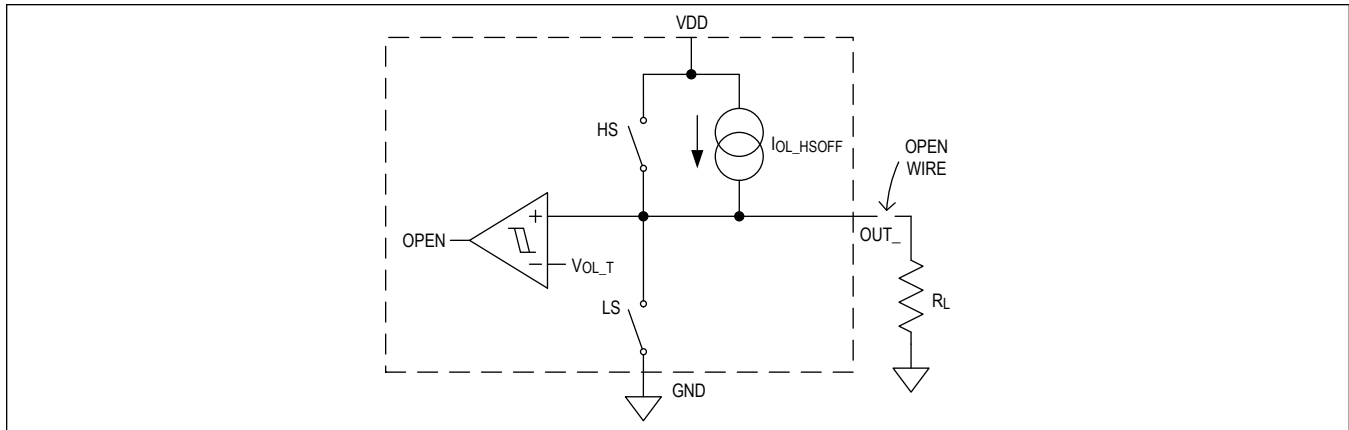


Figure 4. Open-Wire Load Detection

## Watchdog

The watchdog timer allows monitoring activity on the  $\overline{\text{CS}}$  input in serial mode ( $\text{SRIAL} = \text{high}$ ). Drive  $\text{WDEN}/\text{IN5}$  high to enable the watchdog function. The watchdog monitors and expects activity on the  $\overline{\text{CS}}$  input. The WD timer is reset at every  $\overline{\text{CS}}$  falling edge. If the timer is not reset after the timeout delay, see [Table 8](#), all  $\text{OUT}_n$  outputs are turned off and the watchdog fault output ( $\text{WDFLTB}/\text{IN6}$ ) transitions low until the next  $\overline{\text{CS}}$  falling edge. The watchdog timeout can be selected in SPI command mode (see the Configuration and Monitoring section). Bits selection in Register 3:  $\text{WD}[1:0] = 00$  for 0.9s,  $\text{WD}[1:0] = 01$  for 0.45s and  $\text{WD}[1:0] = 10$  for 0.15s. The default value is 0.9s.

## Thermal Management

Every driver's temperature is constantly monitored while  $V_{\text{DD}} > V_{\text{DD\_UV}}$ . If the temperature of a driver rises above the thermal-shutdown threshold of  $T_{\text{JSHDN}}$ , that channel is automatically turned off for protection. The drivers are turned on again once the temperature drops by a hysteresis margin of  $T_{\text{JSHDN\_HYST}}$ .

Both high and low-side drivers are thermally protected with a per-driver protection circuit. When a driver turns off due to thermal shutdown:

1. A fault is indicated through the global  $\overline{\text{FAULT}}$  output.
2. The F\_ bit of that channel is set in the diagnostic byte in the SPI interface.
3. The fault LED driver turns on for that channel.

The device also has a chip thermal shutdown that triggers a  $\overline{\text{FAULT}}$  output and all the channels shut down if the temperature rises above  $T_{\text{CSDN}}$ .

## Overcurrent and Short-Circuit Protection

In the event of a short-circuit or high current at an  $\text{OUT}_n$  output, the load current is limited on a per-channel basis to  $I_{\text{LIM\_HS}}$  for the high-side (HS) driver and to  $I_{\text{LIM\_PP}}$  for the low-side (LS) driver. Whenever a short circuit is detected on any  $\text{OUT}_n$  pin, the  $\overline{\text{FAULT}}$  open-drain output is activated for 100 $\mu\text{s}$  (typ). This  $\overline{\text{FAULT}}$  pulse generation can be disabled by setting bit 04 of register 03 (SPI Command Mode is necessary). A measure to prevent damages in case of short-circuit conditions is that the affected channel is put in a safe Slow mode. While in Slow mode, the low-to-high and high-to-low transitions at  $\text{OUT}_n$  are slew-rate limited to around 3V/ $\mu\text{s}$ . In HS mode the normal (i.e., fast) slew-rate mode is automatically restored after 10-20ms. In PP mode, the user needs to keep the IN signal of the affected channel in the low state for at least 20ms in order to restore the normal slew-rate. Normal slew-rate can be restored at once for all channels by setting EN pin low. The user can determine whether any channel is in Slow mode in one of the following ways. 1) SPI 16-bit mode or in Command mode: When CNFG pin is held high, any SPI cycle will return the status of the Slow mode register in the 8 least significant bits (instead of the level information). 2) Command mode: Register 07 is Slow mode or overvoltage. While the device is in Slow mode, the current rises in a controlled way up to the current limit.

A short-circuit or overcurrent generally creates a temperature rise in the chip; both the HS and LS FETs' temperatures are continuously monitored. When any switch temperature exceeds  $T_{JSHDN}$ , the corresponding OUT\_ output is put in a high-impedance state and the corresponding bit(s) is set in Register 5 until the temperature falls by the hysteresis.

If the case temperature is below  $T_{CSHDN}$ , a short circuit on one output will allow the other outputs to operate normally.

The HS current-limit circuit features a controlled dV/dI slope that improves stability with inductive loads. In other words, the current is limited to a nonconstant value that increases with  $(V_{DD} - V_{OUT})$  with a slope of  $1A/150V$ .

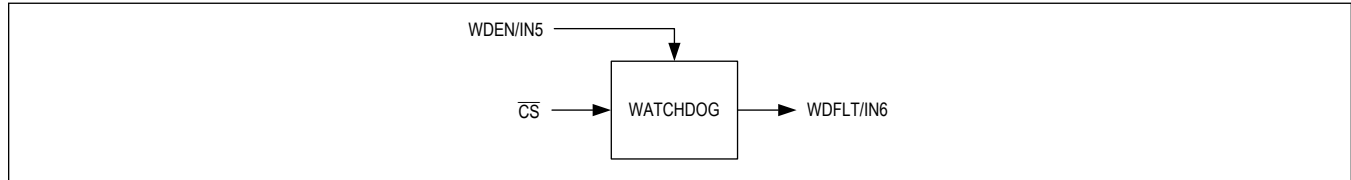


Figure 5. Watchdog Timer

### Undervoltage Lockout

When the  $V_L$ ,  $V_{DD}$ , or  $V_5$  supply voltages are under their respective UVLO thresholds, all OUT\_ outputs are turned off (three-stated) and the open-load detect current sources are turned off; they automatically turn back on once the  $V_{DD}/V_5$  rises to above the UVLO thresholds.

Undervoltage conditions can be read out through SPI.

The UVLO open-drain output pin indicates whether  $V_{DD}$  is below the  $V_{DD\_UV}$  threshold.

### LED Drivers

The 4 x 4 LED driver crossbar matrix offers a pin-optimized configuration for driving 16 LEDs. Per-channel output status and the fault conditions are indicated by individual LEDs. If a FAULT LED is turned on for an output, the corresponding LEVEL LED is always turned off. This mitigates false information about the status of the affected OUT\_ pin.

Note: When  $SRIAL = 1$  and  $CNFG = 1$ , the LEVEL LEDs do not indicate the state of OUT\_, but Slow mode status instead. The LEVEL LED is turned on if the channel is in Slow mode; otherwise, it is turned off.

For every current-limiting resistor (R), each of the four LEDs in the vertical string are pulsed so that current only flows through one LED at any given time. Therefore, the resistors (R) determine the LED current through one LED and should be chosen according to the LED's current/light-intensity requirements. Every LED that is on, is pulsed on with a 25% duty cycle.

### Configuration and Monitoring

The MAX14912/MAX14913 can be configured, set, and monitored through either a parallel or serial interface. The serial interface allows greater configuration flexibility and provides more monitoring information. For the MAX14913, in parallel setting mode ( $SRIAL = low$ ), the SPI cannot be used for configuring the device, SPI is only available for monitoring.

### Global Configuration

Pin-based configuration does not require the use of the SPI interface. It is global and allows for the configuration of all OUT\_ as high-side outputs, push-pull outputs, and enables open-load detection. See [Table 1](#) for details.

In cases where configuration is possible through the parallel and/or serial interface, [Table 2](#) documents the priority.

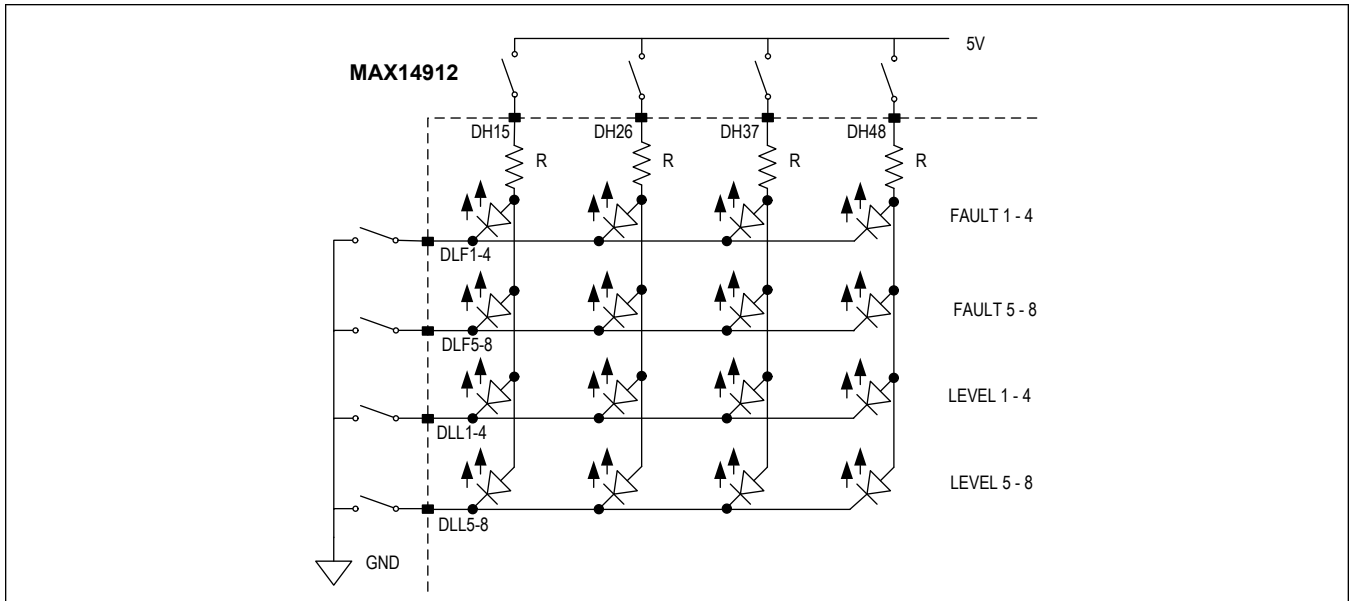


Figure 6. LED Output Status and Fault-Detection Matrix

Table 1. Global Configuration Pins

INPUT	SRIAL	CONFIGURATION
PUSHPL	X	Configures all OUT_ outputs as push-pull or high-side. 0 = All drivers in high-side mode unless configured as push-pull by serial interface. 1 = All drivers in push-pull mode.
OL/IN1	1	Enables global open-load detection in serial mode. 0 = Open-load detection disabled unless enabled by serial interface. 1 = Open-load detection enabled for all high-side mode switches.
CRC/IN3	1	Enables CRC generation and error detection on the serial interface. 0 = CRC error detection disabled. 1 = CRC error detection enabled.
FLTR	X	Enables anti-glitch filtering on all logic input pins except SDI and CLK. (Note 1) 0 = Glitch filtering disabled. 1 = Glitch filtering enabled.
WDEN/IN5	1	Enables watchdog on the SPI interface. 0 = Watchdog disabled. 1 = Watchdog enabled.

Note 1: PUSHPL and SRIAL are always filtered, independent of FLTR logic.



**Table 2. Configuration Priority**

CONFIGURATION	SRIAL	PRIORITY	
Push-Pull/ High-Side	1	PUSHPL	RESULT
		Low	OUT_ drivers in high-side mode, unless configured individually as push-pull through the serial interface.
		High	All OUT_ drivers in push-pull mode, independent of serial configuration.
Open-Load Detection	1	OL/IN1	RESULT
		Low	Open-load detection off, unless configured individually through the serial interface.
		High	Open-load detection enabled on all OUT_ outputs that operate in high-side mode.

**Parallel Interface: Setting the OUT\_ Output Driver**

The parallel mode (SRIAL = low) uses one input pin (IN\_) to set each output (OUT\_). [Table 3](#) shows the settings that depend on the configured mode.

In parallel setting mode (SRIAL = low), the MAX14913 can only be configured via the global configuration inputs: PUSHPL and FLTR, not on a per-channel basis through SPI. This means that all high-side drivers are either in high-side or push-pull operation. Open-load detection is enabled and cannot be disabled in parallel setting mode.

The MAX14912 can be configured with full flexibility in parallel setting mode.

**Serial Controller Interface**

The serial interface can be used in all setting modes. It is based on CPOL = low and CPHA = low, meaning that the SDO data is latched-in on the rising edge of CLK and new SDO data is written on the falling edge of CLK. The default idle CLK state needs to be low. The SDO output is only actively driven when the SPI master drives  $\overline{CS}$  low, it is otherwise weakly pulled down by an internal 200k $\Omega$  resistor when  $\overline{CS}$  is high.

The SPI interface provides per channel and detailed global diagnostics. In serial setting mode (SRIAL = high), the outputs are set on/off/high/low by the serial interface. Serial mode also allows per channel and global configuration. In parallel setting mode (SRIAL = low), the MAX14913 does not allow configuration through SPI, while the MAX14912 can be configured per channel and globally.

The SPI interface can be operated in either command mode or direct mode. Command mode is available in both parallel and serial modes and provides higher information content and supports more configuration options. See [Table 4](#) for details. Direct mode SPI is only available in serial setting mode (SRIAL = high). In direct SPI mode, output setting and per-channel configuration is written directly (without a command byte) and diagnostics data is provided either in an 8 or 16-bit SPI cycle.

In both command and direct SPI modes, when the high-side/push-pull drivers are set on/off/high/low via SPI, the outputs change state at the end of the SPI cycle, on the rising  $\overline{CS}$  edge, with a sub 1 $\mu$ s propagation delay, as defined in the Electrical Properties Table. In direct and command mode SPI, diagnostic and status information is sampled at the beginning of each SPI cycle, initiated by the falling  $\overline{CS}$  edge and is then sequentially written out on SDO on each falling CLK edge. Command SPI mode allows reading back the chip configuration and status and diagnostics, as selected via the command byte. This information is then written out on the following SPI cycle.

**Table 3. SRIAL = Low**

DRIVER MODE	IN_	OUT_ STATE
High-Side	0	High-side off
High-Side	1	High-side on
Push-Pull	0	Push-pull output low
Push-Pull	1	Push-pull output high

**Table 4. SPI Interface Modes Selection and Description**

PIN					RESULT			
SPI MODE	SRIAL	CMND /N2	CNFG /IN7	S16 /IN8	BITS	SDI	SDO	NOTES
DIRECT SPI 8-BIT/16-BIT OPERATION	1	0	0	0	8	Per-channel OUT_ setting	Per-channel fault	OUT set by SPI. FAULT is the real-time status of the fault (driver shutdown or open- load)
				1	16	Per-channel OUT_ setting and HS/PP selection	Per-channel fault and level	
	1	0	1	0	8	Per-channel config: HS/PP	Per-channel fault	OUT level does not change. LEVEL LEDs indicate Slow mode
				1	16	Per-channel config: HS/PP and OL detection on/ off	Per-channel fault and Slow mode	
COMMAND MODE	1	1	0	X	16	8-bit-command + 8-bit data	Previous command per-channel fault and level	OUT level may or may not change depending on command. LEVEL LEDs indicate OUT level
	1	1	1	X	16	8-bit-command + 8-bit data	Previous command per-channel fault and Slow mode	OUT level may or may not change depending on command. LEVEL LEDs indicate Slow mode
	0	X	X	X	16	8-bit-command + 8-bit data	Previous command output	OUT set by INx pins. MAX14912 allows SPI configuration. MAX14913 does not allow SPI configuration.

**Daisy-Chain SPI Operation**

The device supports daisy-chain operation, allowing control/monitoring of multiple MAX14912/MAX14913 devices from a single serial interface with one common chip-select signal. The identical data that is clocked into SDI, is clocked out of SDO with a one SPI cycle delay. This is illustrated in [Figure 7](#).

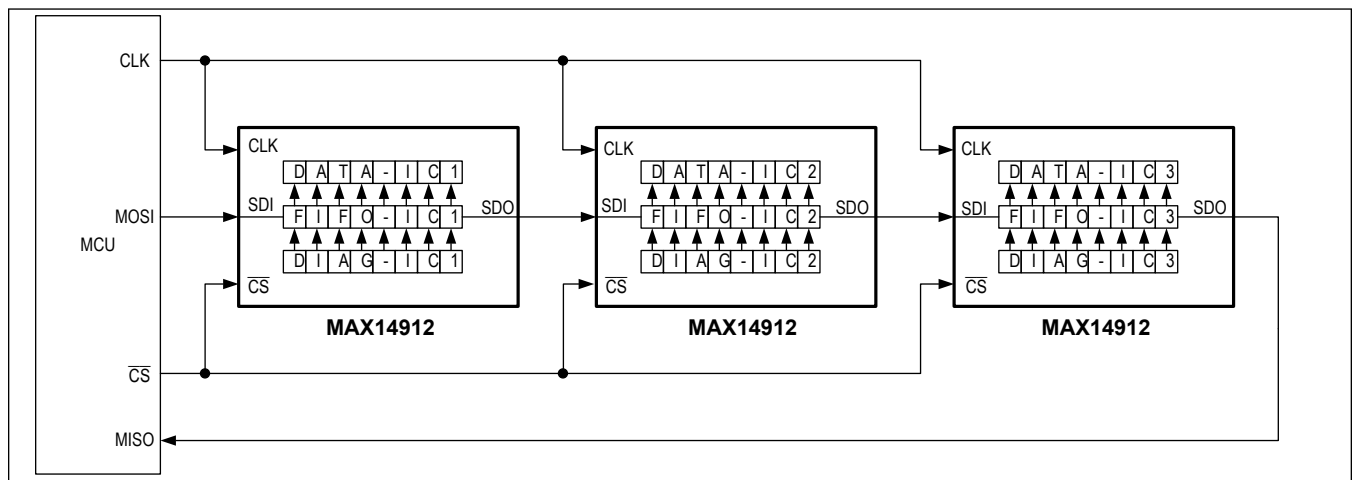


Figure 7. Daisy-Chain Connection

**Direct SPI Serial Interface: 8-bit Mode**

SRIAL = high, CMND = low, S16 = low.

Figure 8 shows an 8-bit cycle that reads the per-channel diagnostic data and sets/configures the outputs in a single 8-bit cycle. Table 5 illustrates the meaning of the SPI bits.

The data returned on SDO is the per-channel fault status.

Pin CNFG is used to select whether the SDI input bits set the output level or the output mode (high-side or push-pull).

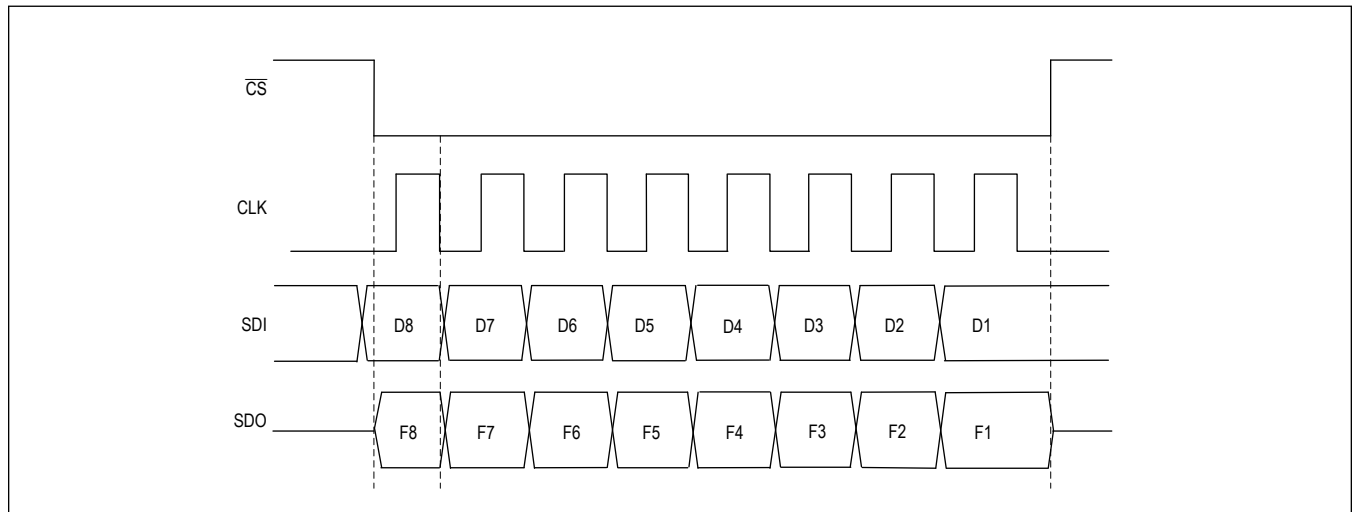


Figure 8. SPI Cycle in 8-Bit Direct SPI Mode

**Direct SPI Serial Interface: 16-Bit Mode**

SRIAL = High, CMND = Low, S16 = High Figure 9 shows a 16-bit read/write cycle that reads the per-channel diagnostic data and configures/sets the outputs in a single 16-bit cycle.

The data returned on SDO is the per-channel fault status.

The CNFG pin is used to select whether the input bits sent to SDI set the output level or the output mode (high-side or push-pull). Moreover, in 16-bit mode, the open-load detection can be enabled on a per-channel basis.

**Table 5. 8-Bit SPI Direct Mode Bit Definition**

BIT	BIT VALUE	CNFG	DEFINITION
D_	0	Low	In high-side mode: set HS off In push-pull mode: HS off, LS on
	1	Low	In high-side mode: set HS switch on In push-pull mode: set HS switch on, LS off
	0	High	Configure high-side mode
	1	High	Configure push-pull mode
F_	0	X	No fault
	1	X	Fault (thermal protection or open load)

**Table 6. 16-Bit SPI Direct Mode Bit Definition**

BIT	BIT VALUE	CNFG	DEFINITION
D_	0	Low	In high-side mode: HS off, LS off In push-pull mode: HS off, LS on
	1	Low	HS on, LS off
C_	0	Low	High-side mode
	1	Low	Push-pull mode
D_C_	00	High	High-side mode; open-load detection defined by OL/IN1 pin
	01	High	Push-pull mode
	10	High	High-side mode with open-load detection
	11	High	<i>Not used</i>
F_	0	X	No fault
	1	X	Fault status (thermal protection or open-load)
L_	0	0	Output level < 7V
	1	0	Output level > 7V
	0	1	Slow mode disabled
	1	1	Slow mode enabled

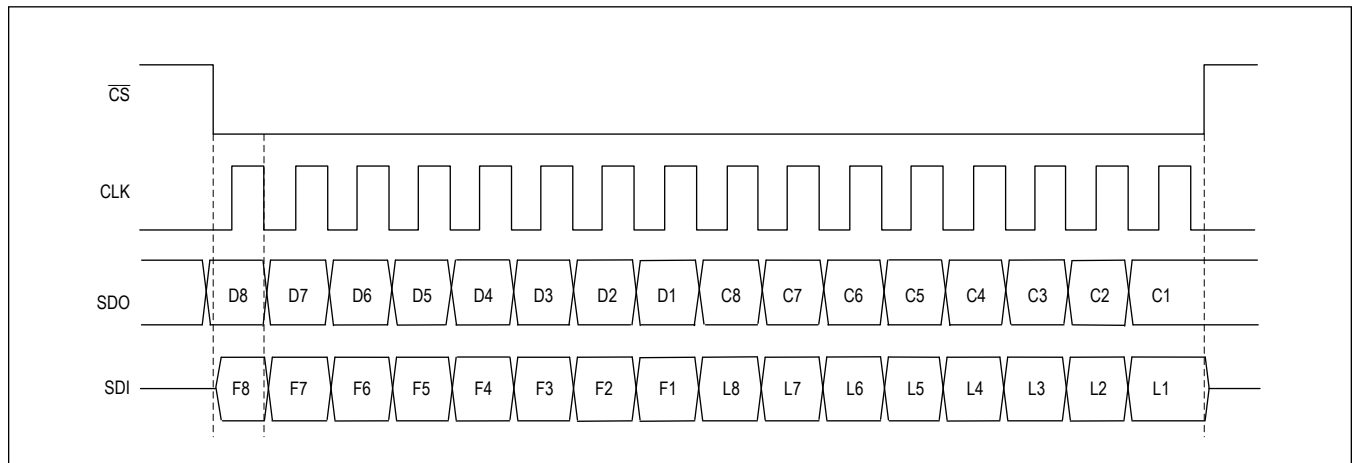


Figure 9. SPI Cycle in 16-Bit Direct SPI Mode

## Command Mode SPI

CMND = High

In serial setting mode (SRIAL = high), command SPI mode allows setting, configuration and monitoring. In parallel setting mode (SRIAL = low) command mode allows monitoring. While the MAX14912 supports SPI configuration in parallel mode, configuration is not supported in the MAX14913. In command mode, the input is always a command + data word; pins S16 and OL are ignored. The output word returns the information requested during the previous SPI cycle.

[Table 7](#) lists the registers accessible in command mode, while [Table 8](#) lists the commands and their effect.

In command mode, a latched version of all faults is available. In other words, the device keeps any fault in memory until the user decides to clear the fault registers. Each bit of fault registers 4, 5, and 6 is set as soon as its corresponding real-time fault signal goes high. At the end of any SPI cycle during which the SDI MSB (the Z bit) has been set to 1, all fault registers are cleared at once (see [Table 8](#)). If [SRIAL = high and CMND = high], the global FAULT signal is latched as well (see [Table 9](#) for more details on the global FAULT signal). Otherwise, it is a real-time global fault status.

In command mode, both the latched and the real-time faults can be read out. All commands except #4 returns the same real-time data as in the 16-bit mode. Command #4 can be used to read any register and, for fault registers 4, 5, and 6, it returns both the latched and real-time value of any fault signal.

**Table 7. SPI REGISTERS (Accessible Only in COMMAND Mode)**

REG	R/W	PURPOSE	7	6	5	4	3	2	1	0
0	R/W	Switch/Driver Settings (Note 10)	IN8	IN7	IN6	IN5	IN4	IN3	IN2	IN1
		Default	0	0	0	0	0	0	0	0
1	R/W	Push-Pull/High-Side Configuration (Note 11)	PP8	PP7	PP6	PP5	PP4	PP3	PP2	PP1
		Default	0	0	0	0	0	0	0	0
2	R/W	Open Load Detect Enable (Note 11)	OL_EN8	OL_EN7	OL_EN6	OL_EN5	OL_EN4	OL_EN3	OL_EN2	OL_EN1
		Default	0	0	0	0	0	0	0	0
3	R/W	Watchdog Config. And Channel Paralleling (Note 11)	—	—	—	Short-Circuit Pulse Off	joinUP	joinDW	WD1	WD0
		Default	0	0	0	0	0	0	0	0
4	R	Per-Channel Open-Load Condition	OL8*	OL7*	OL6*	OL5*	OL4*	OL3*	OL2*	OL1*
5	R	Per-Channel Thermal Shutdown	THSD8*	THSD7*	THSD6*	THSD5*	THSD4*	THSD3*	THSD2*	THSD1*
6	R	Global Faults	WDfault	CRCfault	DCDC Current-Limit	8CKmult Error*	THSDglob*	5V UVLO	VDD UVLO	VDD WARN
7	R	OUT Overvoltage Detection or Slow Mode (Note 9)	OV8	OV7	OV6	OV5	OV4	OV3	OV2	OV1

**Note 9:** Bits are set when the OUT\_ voltage is higher than  $V_{DD}$ . These bits are real-time.

**Note 10:** Register 0 can be written to, but will not change the output states in Parallel (SRIAL = low) setting mode, since the outputs are then only set through the IN\_ pins.

**Note 11:** Registers 1, 2, 3 can be written to in the MAX14913, but will not change the configuration in Parallel (SRIAL = low) setting mode.

\* Faults are stretched in time to a minimum duration of 200ms.

Table 8. COMMAND MODE Protocol

COMMAND NO.	FUNCTION	SDI		SDO VALID ON NEXT CYCLE	COMMENT
		COMMAND	DATA		
0	Set OUT State (Reg 0) (Note 15)	Z0000000	DDDDDDDD	FFFFFFFF.LLLLLLLL	D = 0 : HS off; LS on (in PP) D = 1 : HS on; LS off L: Output Level or Slow-Mode (CNFG = 1) F: Fault (Real-Time) <sup>12</sup> Z = 1: Clear Fault Registers <sup>13</sup>
1	Set HS/PP Mode (Reg 1) (Note 16)	Z0000001	DDDDDDDD	FFFFFFFF.LLLLLLLL	D = 0 : HS Mode D = 1 : PP Mode
2	Set OL Detection (Reg 2) (Note 16)	Z0000010	DDDDDDDD	FFFFFFFF.LLLLLLLL	D = 0 : OL Detection Off D = 1 : OL Detection On (HS Mode)
3	Set Configuration (Reg 3) (Note 16)	Z0000011	000SJJAB	FFFFFFFF.LLLLLLLL	AB: Watchdog 00 = 0.90s 01 = 0.45s 10 = 0.15s J = 1: Channels are Coupled (PP Disabled) S = 1: FAULT Not Asserted When Short Circuit is Detected
4	Read Register (Note 14)	Z0100000	00000NNN	AAAAAAAA.QQQQQQQQ	NNN = 0,1,2,3: Q = Reg value, A = 0 NNN = 4,5,6: Q = Reg value, A = Real_time NNN = 7: Q = 0, A = Real_time
5	Read Real-Time Status (Note 12)	Z0110000	—	FFFFFFFF.LLLLLLLL	F-L Status Readout (Real-Time). No Data is Written

**Note 12:** F bits are the logical OR of thermal protection and open-load detection real-time signals.

**Note 13:** Any fault bit inside registers 4, 5, and 6 are set as soon as its corresponding event happens. All fault registers are cleared only by setting Z = 1 (this is possible during any command cycle). The registers get cleared at  $\overline{CS}$  rising edge. If Z = 1 the registers are not cleared in case of SPI communication error (CRC, 8-CK).

If SRIAL = 1 and CMND = 1, the Z bit clears also the  $\overline{FAULT}$  IRQ signal.

**Note 14:** The Q bits are the value of the fault registers (that need to be cleared by means of the Z bit).

The A bits are the corresponding real-time values (i.e., the real-time fault signals). The real-time values are stretched by 200ms. Therefore, they have a time resolution of ~200ms.

**Note 15:** In parallel setting mode (SRIAL = low), writing to this registers does not change the real-time values or settings. These can only be changed through pins.

**Note 16:** For the MAX14913 only, in parallel setting mode (SRIAL = low), writing to these registers does not change the configuration.

Table 9. FAULT SUMMARY

FAULT NAME	WHAT IT CHECKS	EFFECT ON FAULT	PIN		REG BIT(S)
			NAME	BEHAVIOR	
Per-Channel Thermal Shutdown (Note 17)	Temp (HS) > 170°C or Temp (LS) > 170°C	Single-channel HS and LS are turned off immediately.	$\overline{\text{FAULT}}$ (Note 18)	Pin goes low on any fault; if command-mode: pin goes high when Z bit is set, else: pin goes high when no faults	Reg 5
Global Thermal Shutdown	Die-Center Temperature > 150°C	All channels HS and LS are turned off.	$\overline{\text{FAULT}}$		Reg 6 bit 3
Channel Open-Load Detection (If Enabled)	HS Mode Only. HS On: Current < 2mA HS Off: Current < 80μA		$\overline{\text{FAULT}}$		Reg 4
V <sub>DD</sub> Undervoltage-Lockout	V <sub>DD</sub> < V <sub>DD_UV</sub>	All channels HS and LS are turned off; all LEDs off	$\overline{\text{UVLO}}$	Goes low	Reg 6 bit 1
V <sub>5</sub> Undervoltage-Lockout	V <sub>5</sub> < V <sub>V5_UV</sub>	All channels HS and LS are turned off; all LEDs off			Reg 6 bit 2
V <sub>DD</sub> Warning	V <sub>DD</sub> < V <sub>VDD_WARN</sub>				Reg 6 bit 0
Watch-Dog (If Enabled)	Activity on $\overline{\text{CS}}$ : Fault if no falling-edge for more than 1.2s (or 600ms or 200ms)		$\overline{\text{WDFLT}}$	Goes high; goes low at next $\overline{\text{CS}}$ falling-edge	Reg 6 bit 7
No 8-Multiple CK Pulses	Number of CK pulses during a $\overline{\text{CS}}$ low period not a multiple of 8	SPI input data is discarded	$\overline{\text{FAULT}}$	Goes low on $\overline{\text{CS}}$ rise;	Reg 6 bit 4
CRC Error Detection (If Enabled)	Received data does not match the FCS word	SPI input data is discarded	$\overline{\text{CERR}}$	Goes high; goes high on next $\overline{\text{CS}}$ rise if fault does not happen again	Reg 6 bit 6
Short Circuit	HS or LS current exceed ~3A	Channel goes in Slow mode	$\overline{\text{FAULT}}$	Pin goes low for ~100μs	Reg 7

**Note 17:** The HS or LS FETs are turned on/off according to the thermal protection signal generated by the analog circuit. On the other hand, inside the logic circuit the thermal-protection signal is maintained high for at least 200ms (to filter out the ~10ms hysteretic cycling of the FET temperature).

**Note 18:** In command mode the  $\overline{\text{FAULT}}$  pin behaves as an IRQ latched signal and can be cleared only by setting the Z bit to 1 (as for any other fault register). In all other modes,  $\overline{\text{FAULT}}$  is the logical OR of the real-time faults.

## Error Detection on the Serial Interface

### CRC Detection

In serial mode (SRIAL = high), error-detection of the serial data can be enabled to minimize incorrect operation/misinformation due to data corruption of the SDI/SDO signals. If enabled, the devices performs error detection on SDI data received from the controller, calculates a CRC on the SDO data sent to the controller, and appends a check byte to the SDO diagnostics/status data it sends to the controller. This ensures that the data it receives from the controller (setting/configuration), as well as the data that it sends to the controller (diagnostics/status), has a low likelihood of undetected errors.

Setting the CRC/IN3 input high enables CRC error detection. A CRC frame-check sequence (FCS) is then sent along with each serial transaction. The 7-bit FCS is based on the generator polynomial  $(x^7 + x^5 + x^4 + x^2 + x + 1)$ . The CRC initialization condition is 0x7F. When CRC is enabled, the device expects a check byte appended to the 8 or 16-bit SDI program/configuration data it receives. The check byte has the format shown in [Figure 10](#).

The 7-bit FCS bits (CRI\_) are calculated on the 8/16-bit data, including the 1 in the first position of the check byte. Therefore, the CRC is calculated on 9 or 17 bits. CRI1 is the LSB of the FCS.

The device verifies the received FCS. If no error is detected, it sets the OUT\_ outputs and/or changes configuration per the SDI data. If a CRC error is detected, the device does not change the OUT\_ outputs and/or does not change its configuration. Instead, it sets the CERRB/IN4 output low (i.e., the open-drain CERRB/IN4 nMOS output transistor is turned on) and sets the CERR (CRC error) bit in the check byte that it appends to the 8/16-bit SDO diagnostic/status data returned to the controller during the following serial communication cycle. In command SPI mode, register 6 also reflects an CRC error condition. The check byte the device appends to the 8/16-bit diagnostics/status data has the format shown in [Figure 11](#).

CERR is the error-feedback bit that it sends back to the controller to signal that a CRC error was detected on the previous SDI data reception. Note that CERR is one state delayed (i.e., it indicates if an error was detected in the previous SPI data reception). The reason for the one-cycle delay is due to the daisy-chain scheme.

CRO\_ are the CRC bits that the device calculates on the 8/16-bit diagnostics and/or status data, including the CERR bit (i.e., calculated on 9/17 bits). This allows the controller to check for errors on the SDO data received from the device.

**Clock Count for Multiples of 8**

For each SPI cycle (between  $\overline{CS}$  going low to  $\overline{CS}$  going high), the device counts the number of CLK pulses. The 8CKmult error flag (see [Table 7](#)) is asserted (goes high) and the FAULT pin is asserted (goes low) if the counted CLK pulses are not a multiple of 8. In this case, the SDI data is ignored.

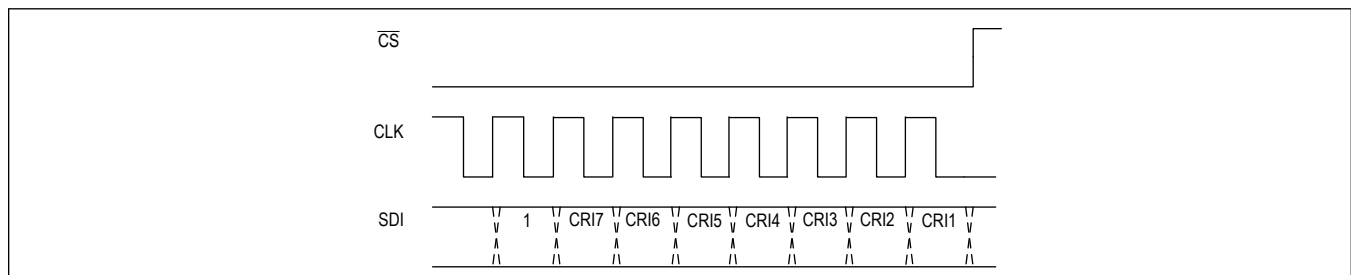


Figure 10. SDI Check Byte Expected from Controller

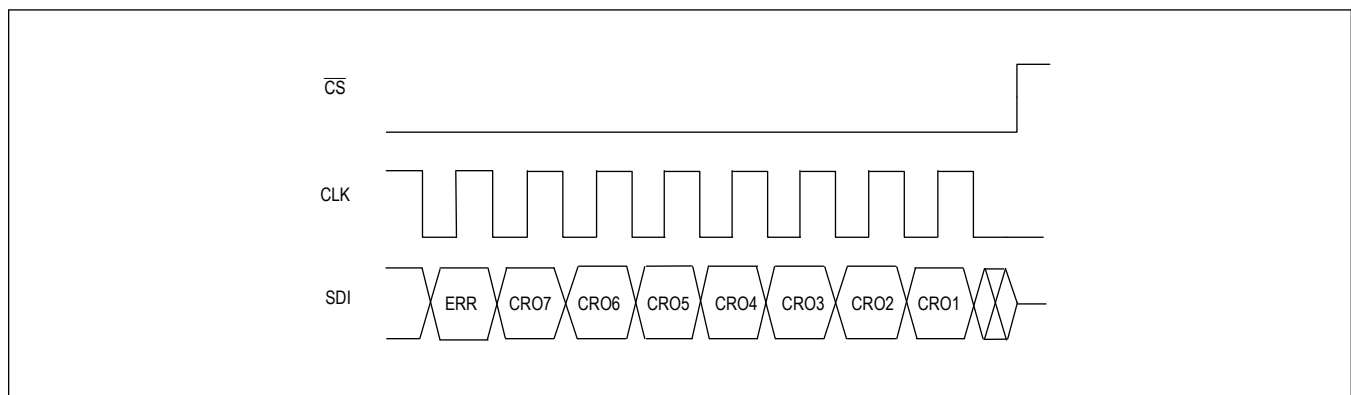


Figure 11. SDO Check Byte Sent by Device



## Applications Information

### PCB Layout and Circuit Recommendations

- Capacitor between VPMP and V<sub>DD</sub>: 10μF 5V;
- Capacitor between CFN and CFP: 200nF 50V;
- Capacitor on V<sub>5</sub>: only one 10μF plus a ceramic 100nF as fast bypass capacitor close to each chip.
- A 1206 footprint 10μF cap is recommended;
- LX trace must be as short as possible;
- Connection between the inductor and V<sub>5</sub> can be long;
- Inductor is 100μH: I<sub>SAT</sub> > 0.35A, DCR ~1Ω (e.g., the Coilcraft LPS4018-104ML);
- GND and V<sub>DD</sub> connections: Dedicated PCB planes for GND and another for V<sub>DD</sub> are recommended.

### Driving Capacitive Loads

When charging/discharging purely capacitive loads with a push-pull driver, the driver dissipates power that is proportional to the switching frequency. The power can be estimated by  $P_D \sim C \times V_{DD}^2 \times f_{SW}$ , where C is the load capacitance, V<sub>DD</sub> is the supply voltage, and f<sub>SW</sub> is the switching frequency. For example, in an application with a 1nF load and 100kHz switching frequency, each driver dissipates 130mW at V<sub>DD</sub> = 36V. When driving purely capacitive loads, consider a maximum capacitance of approximately 10nF.

### Driving Inductive Loads

During turn-off of inductive loads by the high-side switch, the kickback voltage generated by the inductance is clamped by the internal clamp to a voltage of -56V (typ) relative to V<sub>DD</sub>.

Large load inductance L<sub>L</sub>, combined with high load current I<sub>L</sub>, means high inductive energy is present in the inductive load ( $E_L = 1/2 \times L_L \times I_L^2$ ). The energy dissipated in the internal inductive clamp E<sub>CL</sub> during load turn-off depends on the load resistance R<sub>L</sub> and the V<sub>DD</sub> supply voltage. E<sub>CL</sub> is higher than the inductive load energy E<sub>L</sub>, and can even be as high as double the inductive load energy. Based on constant load resistance R<sub>L</sub> and load inductance L<sub>L</sub>, the energy dissipated in the clamp E<sub>CL</sub> can be estimated by:

$$E_{CL} = V_{CL} \times L_L / R_L \times [I_L - (V_{CL} - V_{DD}) / R_L \times \ln(1 + (R_L \times I_L) / (V_{CL} - V_{DD}))]$$

The standard high-side switch would be damaged if it cannot dissipate E<sub>CL</sub> energy, but the SafeDemag feature allows it to dissipate unlimited inductive energy.

The MAX14912/MAX14913 feature [Safe Demagnetization](#), which allows inductive loads of any value to be turned off in high-side or push-pull modes.

### Board Layout

High-speed switches require proper layout and design procedures for optimal performance. Ensure that power-supply bypass capacitors are placed as close as possible to the device. Connect all V<sub>DD</sub> pins to a V<sub>DD</sub> plane. Ensure that all pins have no more than 10mΩ between them. In this case, a 1μF capacitor should be placed as close as possible to the V<sub>DD</sub> pins. In case low-resistance paths are not possible between the V<sub>DD</sub> pins, bypass each pin to GND through a 100nF capacitor.

### Surge Protection

The MAX14912/MAX14913 OUT<sub>-</sub> pins achieve ±1kV/(42Ω + 0.5μF) IEC-61000-4-5 1.2μs/50μs surge ratings by using only a TVS protection diode on V<sub>DD</sub>, as shown in the Typical Application Circuit.

A suppressor/TVS diode should be used between V<sub>DD</sub> and GND to clamp high-surge transients on the V<sub>DD</sub> supply input and surges from the O<sub>-</sub> outputs. The standoff voltage should be higher than the rated operating voltage of the equipment, while the breakdown voltage should be below 75V.

**Reverse Currents Into OUT**

If currents flow into the OUT\_ pins, the device will heat up due to internal currents that flow through the device to PGND. The allowed reverse currents thus depend on  $V_{DD}$ , the ambient temperature and the thermal resistance. At 25°C ambient temperature the reverse current into one OUT should be limited to 1A at  $V_{DD} = 36V$  and 2A at  $V_{DD} = 24V$ . Driving higher currents into OUT can destroy the device thermally.

**Ordering Information**

PART	TEMP RANGE	PACKAGE	PACKAGE CODE	PACKAGE BODY SIZE	LEAD PITCH
MAX14912AKN+	-40°C to +125°C	QFN56	K5688+1	8mm x 8mm	0.5mm
MAX14912AKN+T	-40°C to +125°C	QFN56	K5688+1	8mm x 8mm	0.5mm
MAX14913AKN+	-40°C to +125°C	QFN56	K5688+1	8mm x 8mm	0.5mm
MAX14913AKN+T	-40°C to +125°C	QFN56	K5688+1	8mm x 8mm	0.5mm

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

T = Tape and reel.

## Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	12/15	Initial release	—
1	5/16	Updated <a href="#">Electrical Characteristics</a> table	1, 3–5, 7, 9, 23, 29
2	6/16	Updated $V_{PMP}$ abs max limit	3
3	8/16	Updated text and diagrams	2, 3, 9–11, 14, 18, 19, 24–26, 28
4	12/16	General updates to reflect ESD levels, explained Slow mode behavior, and removed future product asterisks in <a href="#">Ordering Information</a> table	1, 4, 9, 18, 19, 23–26, 28, 29
5	1/19	Updated <a href="#">Benefits and Features</a> , <a href="#">Electrical Characteristics</a> , <a href="#">Overcurrent and Short-Circuit Protection</a> sections, and corrected typo in the <a href="#">Serial Controller Interface</a> section	1, 3–5, 18, 21
6	11/20	Updated the LED Driver section and replaced Table 4	19, 21
7	12/21	Updated <a href="#">Benefits and Features</a> , <a href="#">Electrical Characteristics</a> , <a href="#">Timing Diagrams</a> , and <a href="#">Driving Inductive Loads</a> section, and added TOC 8 and TOC 9	1, 8, 11, 13, 16, 33