LDC1312, LDC1314, LDC1612, LDC1614 Sensor Status Monitoring

Application Report

TEXAS INSTRUMENTS

Contents

LDC1312, LDC1314, LDC1612, LDC1614 Sensor Status Monitoring

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ABSTRACT

TI's multichannel inductance-to-digital converters (LDCs) LDC1612, LDC1614, LDC1312 and LDC1314 feature three different methods for reporting conversion status information including errors, warnings, and completed conversion results. Information is available through the data registers, the status registers, and the INTB pin of the device. This application note explains usage and interpretation of the information that the LDC reports in detail.

1   Reporting Mechanisms

The LDC can detect and report on several device conditions. It provides flexibility in the error reporting mechanism.

Errors can be reported in the following ways:

* by the four MSBs in the conversion output registers DATA_MSB_CHx.
* by the STATUS register.
* by asserting the INTB pin.

Summary tables with the DATA_CHx, STATUS and ERROR_CONFIG registers are shown in section Section 4 for reference.

Table 1 summarizes which reporting options are available for each error and status condition.

Table 1. Error and Status Condition Reporting Options

Condition Reported	DATA_CHx Reporting Section 1.1	Status Register Reporting Section 1.2	INTB Reporting Section 1.3
Data ready (DRDY) Section 2.2	N/A	Reported	Set DRDY_2INT=1
Unread conversion Section 2.1	N/A	Reported	N/A
Under-range error Section 3.1	Set UR_ERR2OUT=1	Reported	Set UR_ERR2INT=1
Over-range error Section 3.2	Set OR_ERR2OUT=1	Reported	Set OR_ERR2INT=1
Watchdog timeout error Section 3.3	Set WD_ERR2OUT=1	Reported	Set WD_ERR2INT=1
Amplitude high error Section 3.4	Set AH_ERR2OUT=1 [1]	Reported	Set AH_ERR2INT=1
Amplitude low warning Section 3.4	Set AL_ERR2OUT=1 [1]	Reported	Set AL_ERR2INT=1
Zero count error Section 3.5	N/A	Reported	Set ZC_ERR2INT=1

[1]   If both ERROR_CONFIG.AH_ERR2OUT=1 and AL_ERR2OUT=1, the amplitude warning bit in CHx_ERR_AE will report a logic OR of the amplitude warnings.

1.1   Conversion Output Register Behavior and Available Reports

This reporting method supports the following functions:

- Under-range errors
- Over-range errors
- Watchdog timeout errors
- Amplitude warnings

Any error bit set in the DATA_CHx register will be cleared by reading DATA_CHx. If that channel bit caused the error or warning bit in STATUS to be set and INTB to be asserted, then the STATUS error bit is cleared.

The error bits set in the DATA_CHx register are not sticky. An error or warning bit will be cleared if the subsequent conversion of the corresponding channel completes without the particular condition.

If both ERROR_CONFIG.AH_ERR2OUT=1 and AL_ERR2OUT=1, the amplitude warning bit in CHx_ERR_AE will report a logic OR of the amplitude warnings.

Table 2 shows the output of the DATA_CHx register for each error and status condition.

Table 2. Error and Status Condition Reporting Through the Output Data Register

Condition Reported	DATA_CHx Reporting	DATA_CHx Output [1] [2]
Data ready (DRDY)	N/A	0x0XXX[3]
Unread conversion	N/A	0x0XXX[3]
Under-range error	Set UR_ERR2OUT=1	0x8000
Over-range error	Set OR_ERR2OUT=1	0x4FFF
Watchdog timeout error	Set WD_ERR2OUT=1	0x2000
Amplitude high error	Set AH_ERR2OUT=1 [4]	0x1XXX [4]
Amplitude low warning	Set AL_ERR2OUT=1 [4]	0x1XXX [4]
Zero count error	N/A	0x0000 or 0x8000

[1]   This table uses the LDC1312 DATA_CHx register as an example. Refer to the LDC161x datasheet for the listing of the equivalent DATA_CHx_MSB and DATA_CHx_LSB registers.

[2]   Assuming only the indicated error occurs. If multiple error flags occur, then the leading four bits may be different

[3]   If both ERROR_CONFIG.AH_ERR2OUT=1 and AL_ERR2OUT=1, the amplitude warning bit in CHx_ERR_AE will report a logic OR of the amplitude warnings.

[4]   Valid conversion data exists in DATAx

1.2   Status Register Behavior and Available Reports

This reporting method supports the following functions:

- Under-range errors
- Over-range errors
- Watchdog timeout errors
- Amplitude high errors
- Amplitude low warnings
- Zero count errors
- Data ready (DRDY)
- Unread conversion notification

The STATUS.ERR_CHAN records the channel that reported the error. If more than one channel reported an error, the ERR_CHAN bit reports the first channel in which the error occurred. If errors from multiple channels occur while using this technique, subsequent errors will not be reported, as shown in Figure 1.
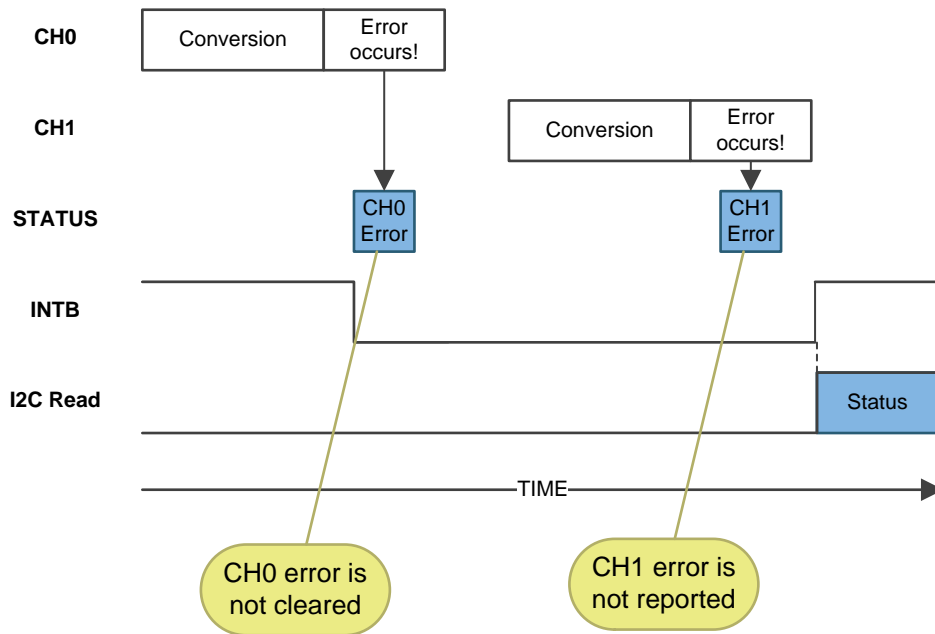
Figure 1. CH0 Error is Not Cleared; Subsequent Error is Not Reported

To avoid missing errors from multiple channels, it is recommended to use INTB reporting in addition to status reporting. This way, INTB will assert when an error occurs, the user can read it, and then INTB will report again if another error occurs, as shown in Figure 2.
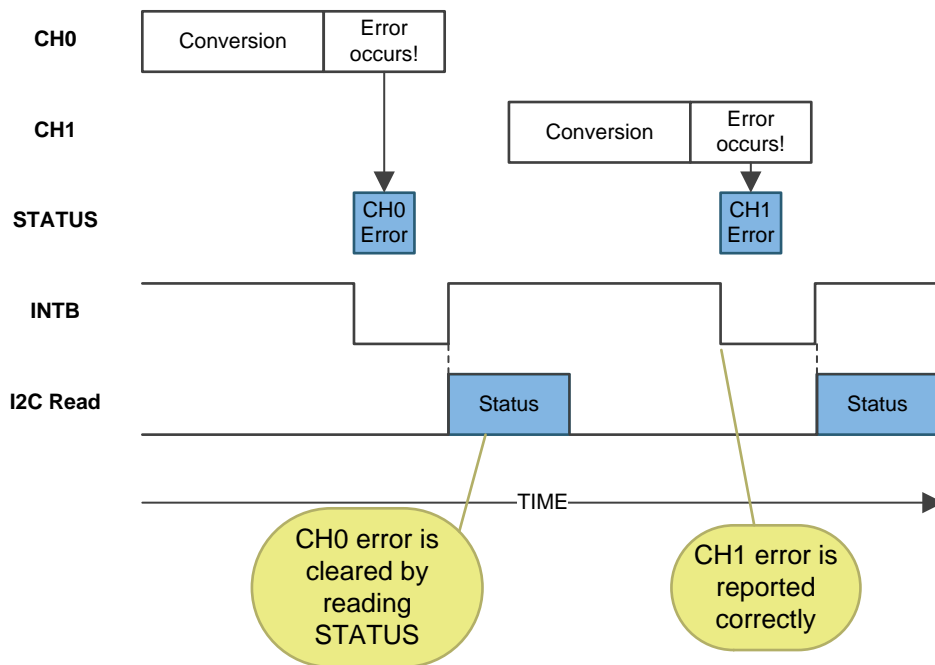
Figure 2. CH0 Error is Cleared; Subsequent Error is Reported Correctly

All bits in the STATUS register except for the Unread Conversion notification are sticky. The bits need to be cleared by reading the STATUS register. Reading from the STATUS register also de-asserts INTB.

1.3   *Reporting Errors and Status on the INTB Pin*

Error and status registers can trigger an interrupt on the INTB pin. The following conditions must be met:

1. The error or status register must be unmasked by enabling the appropriate register bit in the ERROR_CONFIG register
2. The INTB function must be enabled by setting CONFIG.INTB_DIS to 0

Reporting through the INTB pin supports the following functions:

- Under-range errors
- Over-range errors
- Watchdog timeout errors
- Amplitude high errors
- Amplitude low warnings
- Zero count errors
- Data ready (DRDY)

Interrupts are cleared by the following events:

1. Entering Sleep Mode
2. Power-on reset (POR)
3. Device enters Shutdown Mode (SD is asserted)
4. Software reset
5. I2C read of the STATUS register: Reading the STATUS register will clear any error status bit set in STATUS along with the ERR_CHAN field and de-assert INTB

Setting register CONFIG.INTB_DIS to b1 disables the INTB function and holds the INTB pin high.

2   Reporting of Completed Conversions

2.1   Unread Conversion

The LDC reports when a conversion has completed and the conversion result is available and can be read from the DATA_CHx registers. The status register bit STATUS.CHx_UNREADCONV shows when a conversion has occurred on a particular channel that has not been read yet. The register is cleared when either the corresponding DATAx register or the Status register is read.

In multi-channel mode, this register can be used to identify a completed conversion result on a particular channel without having to wait until the last conversion in the sequence is complete, as shown in Figure 3.
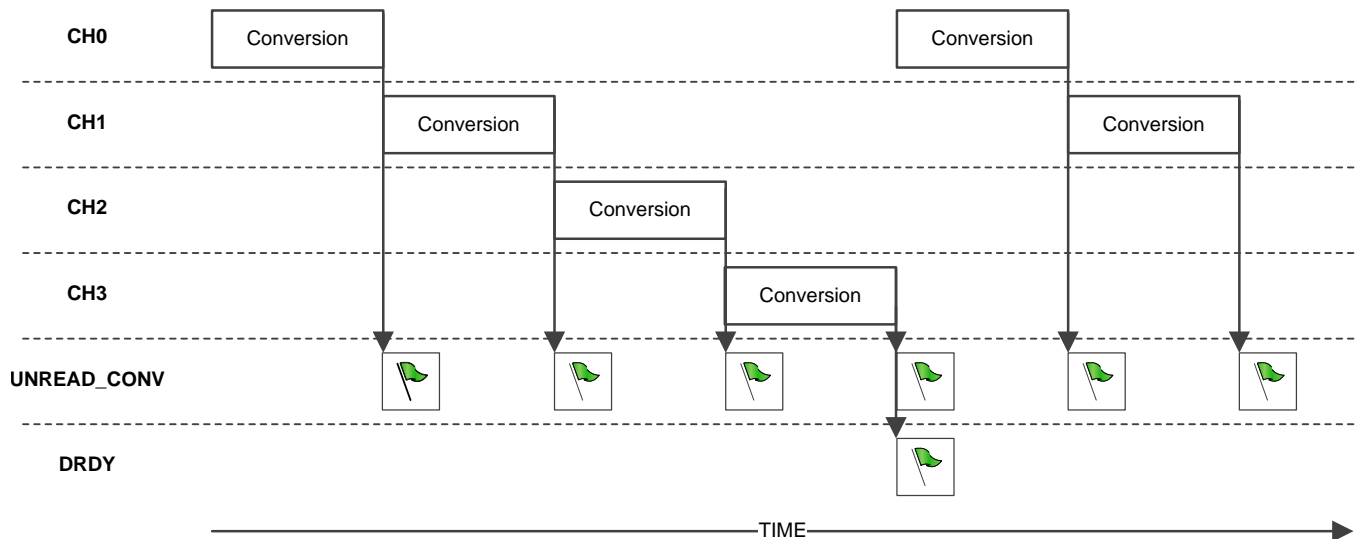

Figure 3. UNREAD_CONV Flags Completed Conversions Without Waiting Until the End of the Cycle

2.2   Data Ready Reporting

When the device is in single-channel continuous conversion mode, which is set by MUX_CONFIG.AUTOSCAN_EN = 0, data ready will occur upon the completion of each conversion.

When the device is in multi-channel (sequential) mode, which is set by MUX_CONFIG.AUTOSCAN_EN = 1, the data ready will occur on completion of the last conversion in a sequence. For example, if MUX_CONFIG.RR_SEQUENCE=0, then data ready will occur when both Channel 0 and Channel 1 conversions are complete.

Data ready is reported:
• in the STATUS.DRDY field if ERROR_CONFIG.DRDY_2INT is set to b1.
• by asserting the INTB pin if ERROR_CONFIG.DRDY_2INT is set to b1.

Summary tables with the STATUS and ERROR_CONFIG registers are shown in section Section 4 for reference.

2.3   Reading Data Without Using DRDY or CHx_UNREADCONV

The deterministic conversion time also allows data polling at a fixed interval instead of using DRDY. As long as the microcontroller and the LDC are clocked from the same clock source, the conversion time can be calculated as shown in section *'Multi-Channel and Single Channel Operation"* in the LDC161x datasheet and the LDC131x datasheet

If it is not feasible to share clocks between the LDC and the microcontroller, repeated data reads may occur unless the LDC conversion time is faster than the I2C read operation.

3 Reporting of Errors and Warnings

3.1 Frequency Under-Range Errors

Frequency Under-range errors occur when the output code (DATAx) would be a negative number after subtracting the offset value in the CHx_OFFSET register. If Frequency Under-range errors are occurring on a specific channel, reducing the offset value for the channel applied by the OFFSET_CHx register can resolve them. Under-range errors may also be addressed in some applications by increasing the value in the CHx_RCOUNT.

When a Frequency Under-range error occurs:

- the LDC1312 and LDC1314 report a DATA[11:0] output of 0x000 for the channel which caused the violation.
- the LDC1612 and LDC1614 report a DATA[27:0] output of 0x0000000 for the channel which caused the violation.

Frequency Under-range errors are reported:

- the output register DATA_CHx of the appropriate channel if ERROR_CONFIG.UR_ERR2OUT is set to b1.
- in the STATUS.ERR_UR field (bit 13) if ERROR_CONFIG.UR_ERR2INT is set to b1.
- by asserting the INTB pin if ERROR_CONFIG.UR_ERR2INT is set to b1.

3.2 Frequency Over-Range Errors

Frequency Over-range errors occur when the sensor frequency exceeds the reference frequency. When a Frequency Over-range error occurs on a channel, the output code for the channel will be limited full-scale. If Frequency Over-range errors are occurring on a specific channel, increasing the reference frequency or decreasing the sensor frequency will resolve this issue. Frequency Over-range errors can also be addressed by increasing specific channel's sensor divider in CLOCK_DIVIDERS_CHx.CHx_FIN_DIVIDER or by decreasing the specific channel's reference divider setting in CLOCK_DIVIDERS_CHx.CHx_FREF_DIVIDER.

When a Frequency Over-range error occurs:

- the LDC1312 and LDC1314 report a DATA[11:0] output of 0xFFF for the channel which caused the violation.
- the LDC1612 and LDC1614 report a DATA[27:0] output of 0xFFFFFFF for the channel which caused the violation.

Frequency Over-range errors are reported:

- in the output register DATA_CHx of the appropriate channel if ERROR_CONFIG.OR_ERR2OUT is set to b1.
- in the STATUS.ERR_OR field (bit 12) if ERROR_CONFIG.OR_ERR2INT is set to b1.
- by asserting the INTB pin if ERROR_CONFIG.OR_ERR2INT is set to b1.

3.3 Watchdog Timeout Errors

Watchdog Timeout errors occur in continuous conversion mode when the sensor is no longer oscillating, or if it is oscillating at a frequency lower than 250Hz. If a Watchdog timeout occurs, the sensor is reset. The LDC will abort the current conversion, and attempt to restart the sensor on the active channel. If the sensor resumes oscillation, then the data conversion will resume, and INTB will be de-asserted (if reporting Watchdog errors is enabled in ERROR_CONFIG.WD_ERR2INT). If the sensor does not restart, the LDC will issue repeated Watchdog timeout errors.

If a watchdog event occurs, the data read from DATA registers is invalid and must be ignored.

The sensor recovery time which is controlled by the watchdog is approximately 5.2ms – the LDC requires that the sensor generate at least one oscillation in that time. If the conversion time is less than 5.2ms, then one or many Zero Count errors will be generated before the Watchdog timeout error.

Watchdog Timeout errors are reported:

- in the output register DATA_CHx of the appropriate channel if ERROR_CONFIG.WD_ERR2OUT is set to b1.
- in the STATUS.ERR_WD field (bit 11) if ERROR_CONFIG.WD_ERR2INT is set to b1.
- by asserting the INTB pin if ERROR_CONFIG.WD_ERR2INT is set to b1.

Watchdog timeout errors only occur in continuous mode. In sequential mode, zero-count errors and amplitude warnings should be used to detect a stopped oscillation instead.

3.4 Amplitude Warnings

Amplitude warnings occur when the sensor amplitude is not within the required range when the conversion begins. There are two types of amplitude warnings - a low amplitude warning and a high amplitude error. This can be caused by an incorrect setting of the channel IDRIVE, or if the sensor impedance is outside of the specified driving range of the LDC.

Refer to the application note Setting LDC1312/4, LDC1612/4, and LDC1101 Sensor Drive Configuration for information on configuring the sensor oscillation amplitude correctly and avoiding Amplitude warnings.

The reporting of amplitude warnings is more useful during the development of a system rather than during the normal operation. However, in certain circumstances, an amplitude warning may indicate that a hardware fault with the sensor occurred, such as a physically disconnected sensor capacitor.

Amplitude High Errors are reported:

- in the output register DATA_CHx of the appropriate channel if ERROR_CONFIG.AH_ERR2OUT is set to b1. Amplitude Low Warning and Amplitude High Errors are OR-ed together in this register bit.
- in the STATUS.ERR_AHE field (bit 10) if ERROR_CONFIG.AH_ERR_2INT is set to b1.
- by asserting the INTB pin if ERROR_CONFIG.AH_ERR2INT is set to b1 .

Amplitude Low Warnings are reported:

- in the output register DATA_CHx of the appropriate channel if ERROR_CONFIG.AL_ERR2OUT is set to b1. Amplitude Low Warnings and Amplitude High Errors are OR-ed together in this register bit.
- in the STATUS.ERR_ALE field (bit 9) if ERROR_CONFIG.AL_ERR_2INT is set to b1.
- by asserting the INTB pin if ERROR_CONFIG.AL_ERR2INT is set to b1.

3.5 Zero Count Errors

A Zero Count error occurs when no oscillations are recorded for either the sensor channel or on the reference input. A Zero Count error can indicate that the sensor has stopped oscillating or the external clock input has stopped. A Zero Count error can also occur if:

1. The conversion time is less than one oscillation period of the sensor. Increase the value of CHx_RCOUNT or increase the reference clock divider (CLOCK_DIVIDERS_CHx.CHx.FREF.DIVIDER); note that this will reduce the sample rate.
2. The channel input divider is too large. Reduce the value of CLOCK_DIVIDERS_CHx.CHx.FIN_DIVIDER.
3. The sensor resonant frequency is too low for the desired measurement. Increase the sensor frequency to address this issue.

Zero Count Errors are reported:

- in the STATUS.ERR_ZC field (bit 8) if the ERROR_CONFIG.ZC_ERR2INT field is set to b1.
- by asserting the INTB pin if the ERROR_CONFIG.ZC_ERR2INT field is set to b1.

4 Summary of Relevant Register Tables

4.1 Address 0x00, DATA_CH0 (LDC1312)

The following table uses the LDC1312 DATA_CH0 register as an example. Refer to the LDC161x datasheet and the LDC131x datasheet for a complete listing of the DATA registers of the appropriate LDC device.

Figure 4. Address 0x00, DATA_CH0

15	14	13	12	11	10	9	8
CH0_ERR_UR	CH0_ERR_OR	CH0_ERR_WD	CH0_ERR_AE	DATA0[11:0]			

7	6	5	4	3	2	1	0
DATA0[11:0]							

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 3. Address 0x00, DATA_CH0 Field Descriptions

Bit	Field	Type	Reset	Description
15	CH0_ERR_UR	R	0	Channel 0 Conversion Under-range Error Flag. Cleared by reading the bit.
14	CH0_ERR_OR	R	0	Channel 0 Conversion Over-range Error Flag. Cleared by reading the bit.
13	CH0_ERR_WD	R	0	Channel 0 Conversion Watchdog Timeout Error Flag. Cleared by reading the bit.
12	CH0_ERR_AE	R	0	Channel 0 Amplitude Warning. Cleared by reading the bit
11:0	DATA0[11:0]	R	0000 0000 0000	Channel 0 Conversion Result

4.2 Address 0x18, STATUS

Figure 5. Address 0x18, STATUS

15	14	13	12	11	10	9	8
ERR_CHAN		ERR_UR	ERR_OR	ERR_WD	ERR_AHE	ERR_ALE	ERR_ZC

7	6	5	4	3	2	1	0
RESERVED	DRDY	RESERVED		CH0_UNREADCONV	CH1_UNREADCONV	CH2_UNREADCONV	CH3_UNREADCONV

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 4. Address 0x18, STATUS Field Descriptions

Bit	Field	Type	Reset	Description
15:14	ERR_CHAN	R	00	Warning or Error Channel Indicates which channel has generated a Warning or Error. Once flagged, any reported warning or error is latched and maintained until either the STATUS register or the DATA_MSB_CHx (LDC161x) or DATA_CHx (LDC131x) register corresponding to the Warning or Error Channel is read. b00: Channel 0 is source of warning or error. b01: Channel 1 is source of warning or error. b10: Channel 2 is source of warning or error (LDC1614 and LDC1314 only). b11: Channel 3 is source of warning or error (LDC1614 and LDC1314 only).

Table 4. Address 0x18, STATUS Field Descriptions (continued)

Bit	Field	Type	Reset	Description
13	ERR_UR	R	0	Conversion Under-range Error b0: No Conversion Under-range error was recorded since the last read of the STATUS register. b1: An active channel has generated a Conversion Under-range error. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this error.
12	ERR_OR	R	0	Conversion Over-range Error. b0: No Conversion Over-range error was recorded since the last read of the STATUS register. b1: An active channel has generated a Conversion Over-range error. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this error.
11	ERR_WD	R	0	Watchdog Timeout Error b0: No Watchdog Timeout error was recorded since the last read of the STATUS register. b1: An active channel has generated a Watchdog Timeout error. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this error.
10	ERR_AHE	R	0	Amplitude High Error b0: No Amplitude High error was recorded since the last read of the STATUS register. b1: An active channel has generated an Amplitude High error. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this error.
9	ERR_ALE	R	0	Amplitude Low Warning b0: No Amplitude Low warning was recorded since the last read of the STATUS register. b1: An active channel has generated an Amplitude Low warning. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this warning.
8	ERR_ZC	R	0	Zero Count Error b0: No Zero Count error was recorded since the last read of the STATUS register. b1: An active channel has generated a Zero Count error. Refer to STATUS.ERR_CHAN field to determine which channel is the source of this error.
6	DRDY	R	0	Data Ready Flag. b0: No new conversion result was recorded in the STATUS register. b1: A new conversion result is ready. When in Single Channel Conversion, this indicates a single conversion is available. When in sequential mode, this indicates that a new conversion result for all active channels is now available.
3	CH0_UNREADCONV	R	0	Channel 0 Unread Conversion b0: No unread conversion is present for Channel 0. b1: An unread conversion is present for Channel 0. Read Register DATA_CH0 to retrieve conversion results.
2	CH1_ UNREADCONV	R	0	Channel 1 Unread Conversion b0: No unread conversion is present for Channel 1. b1: An unread conversion is present for Channel 1. Read Register DATA_CH1 to retrieve conversion results.
1	CH2_ UNREADCONV	R	0	Channel 2 Unread Conversion b0: No unread conversion is present for Channel 2. b1: An unread conversion is present for Channel 2. Read Register DATA_CH2 to retrieve conversion results (LDC1614 and LDC1314 only)
0	CH3_ UNREADCONV	R	0	Channel 3 Unread Conversion b0: No unread conversion is present for Channel 3. b1: An unread conversion is present for Channel 3. Read Register DATA_CH3 to retrieve conversion results (LDC1614 and LDC1314 only)

4.3 Address 0x19, ERROR_CONFIG

Figure 6. Address 0x19, ERROR_CONFIG

15	14	13	12	11	10	9	8
UR_ERR2OUT	OR_ERR2OUT	WD_ ERR2OUT	AH_ERR2OUT	AL_ERR2OUT	RESERVED		

7	6	5	4	3	2	1	0
UR_ERR2INT	OR_ERR2INT	WD_ERR2INT	AH_ERR2INT	AL_ERR2INT	ZC_ERR2INT	Reserved	DRDY_2INT

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 5. Address 0x19, ERROR_CONFIG

Bit	Field	Type	Reset	Description
15	UR_ERR2OUT	R/W	0	Under-range Error to Output Register b0: Do not report Under-range errors in the DATA_CHx registers. b1: Report Under-range errors in the DATA_CHx.CHx_ERR_UR register field corresponding to the channel that generated the error.
14	OR_ERR2OUT	R/W	0	Over-range Error to Output Register b0: Do not report Over-range errors in the DATA_CHx registers. b1: Report Over-range errors in the DATA_CHx.CHx_ERR_OR register field corresponding to the channel that generated the error.
13	WD_ ERR2OUT	R/W	0	Watchdog Timeout Error to Output Register b0: Do not report Watchdog Timeout errors in the DATA_CHx registers. b1: Report Watchdog Timeout errors in the DATA_CHx.CHx_ERR_WD register field corresponding to the channel that generated the error.
12	AH_ERR2OUT	R/W	0	Amplitude High Error to Output Register b0:Do not report Amplitude High errors in the DATA_CHx registers. b1: Report Amplitude High errors in the DATA_CHx.CHx_ERR_AE register field corresponding to the channel that generated the error.
11	AL_ERR2OUT	R/W	0	Amplitude Low Warning to Output Register b0: Do not report Amplitude High warnings in the DATA_CHx registers. b1: Report Amplitude Low warnings in the DATA_CHx.CHx_ERR_AE register field corresponding to the channel that generated the warning.
7	UR_ERR2INT	R/W	0	Under-range Error to INTB b0: Do not report Under-range errors by asserting INTB pin and STATUS register. b1: Report Under-range errors by asserting INTB pin and updating STATUS.ERR_UR register field.
6	OR_ERR2INT	R/W	0	Over-range Error to INTB b0: Do not report Over-range errors by asserting INTB pin and STATUS register. b1: Report Over-range errors by asserting INTB pin and updating STATUS.ERR_OR register field.
5	WD_ERR2INT	R/W	0	Watchdog Timeout Error to INTB b0: Do not report Watchdog Timeout errors by asserting INTB pin and STATUS register. b1: Report Watchdog Timeout errors by asserting INTB pin and updating STATUS.ERR_WD register field.
4	AH_ERR2INT	R/W	0	Amplitude High Error to INTB b0: Do not report Amplitude High errors by asserting INTB pin and STATUS register. b1: Report Amplitude High errors by asserting INTB pin and updating STATUS.ERR_AHE register field.

Table 5. Address 0x19, ERROR_CONFIG (continued)

Bit	Field	Type	Reset	Description
3	AL_ERR2INT	R/W	0	Amplitude Low Warning to INTB b0: Do not report Amplitude Low warnings by asserting INTB pin and STATUS register. b1: Report Amplitude Low warnings by asserting INTB pin and updating STATUS.ERR_ALE register field.
2	ZC_ERR2INT	R/W	0	Zero Count Error to INTB b0: Do not report Zero Count errors by asserting INTB pin and STATUS register. b1: Report Zero Count errors by asserting INTB pin and updating STATUS. ERR_ZC register field.
1	Reserved	R/W	0	Reserved (set to b0)
0	DRDY_2INT	R/W	0	Data Ready Flag to INTB b0: Do not report Data Ready Flag by asserting INTB pin and STATUS register. b1: Report Data Ready Flag by asserting INTB pin and updating STATUS. DRDY register field.

5 Conclusion

The extensive error reporting that the LDC1612, LDC1614, LDC1312 and LDC1314 provide an effective means to diagnose sensor issues or device configuration errors. This summary of the various reporting methods and error conditions can greatly simplify an LDC system design.

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