CrossLinkPlus I2C Hardened IP Usage Guide

Technical Note

FPGA-TN-02112-1.0

August 2019
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Contents

Acronyms in This Document ........................................................................................................... 4
1. Introduction ........................................................................................................................................ 5
2. I²C IP Core Overview ....................................................................................................................... 5
3. Generating I²C Module with Clarity Designer ................................................................................ 6
   3.1. Enabling Hardened IP ............................................................................................................... 6
3.2. I²C Settings ................................................................................................................................... 7
   3.2.1. General Settings ..................................................................................................................... 8
   3.2.2. Master Clock Rate ................................................................................................................ 9
   3.2.3. FIFO Mode .......................................................................................................................... 10
   3.2.4. I²C Addressing .................................................................................................................... 10
   3.2.5. PMU Wake Options .............................................................................................................. 10
3.3. I²C Interrupts ............................................................................................................................. 11
   3.3.1. System Bus Interrupts .......................................................................................................... 11
   3.3.2. FIFO Interrupts ..................................................................................................................... 12
4. SB_I2C Hardened IP Macro Ports and Wrapper Connections ...................................................... 13
5. I²C Usage Cases ............................................................................................................................. 15
References .......................................................................................................................................... 16
Technical Support Assistance ............................................................................................................ 17
Revision History ............................................................................................................................... 18

Figures

Figure 3.1. I²C Module in Clarity Designer ......................................................................................... 6
Figure 3.2. Enabling Hardened I²C IP Blocks .................................................................................... 7
Figure 3.3. I²C Settings ....................................................................................................................... 8
Figure 3.4. I²C I/O Buffer ................................................................................................................ 9
Figure 3.5. I²C I/O Connections ...................................................................................................... 9
Figure 3.6. I²C Interrupts .................................................................................................................. 11
Figure 5.1. I²C Circuit ..................................................................................................................... 15

Tables

Table 4.1. Pins for I²C Hardened IP ................................................................................................. 13
### Acronyms in This Document

A list of acronyms used in this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIC</td>
<td>Application-Specific Integrated Circuit</td>
</tr>
<tr>
<td>FIFO</td>
<td>First In First Out</td>
</tr>
<tr>
<td>I²C</td>
<td>Inter-Integrated Circuit</td>
</tr>
<tr>
<td>SCL</td>
<td>Serial Clock Line</td>
</tr>
<tr>
<td>SDA</td>
<td>Serial Data Line</td>
</tr>
</tbody>
</table>
1. Introduction

CrossLinkPlus™ from Lattice Semiconductor is a programmable video bridging device that supports a variety of protocols and interfaces for mobile image sensors and displays. The device is based on Lattice mobile FPGA technology. It combines the extreme flexibility of an FPGA with the low power, low cost, and small footprint of an ASIC. CrossLinkPlus devices include integrated I2C blocks to interface with virtually all mobile sensors and application processors. CrossLinkPlus devices provide two I2C IP cores. The I2C0 core has dedicated I/O pins, called USER_SCL and USER_SDA, on the CrossLinkPlus device. This is in order to support the device sleep mode wakeup over I2C function. The SCL and SDA pins from the I2C1 core may be connected to any pin on the device.


2. I2C IP Core Overview

The I2C hardened IP provides industry standard two-pin communication interface that conforms to the I2C Bus Specification version 2.1. It may be configured in either Master or Slave mode.

In Master mode, the I2C hardened IP supports configurable data transfer rate and performs arbitration detection so as to allow the hardened IP to operate in multi-master systems. The hardened IP supports clock stretching in both Master and Slave modes with enable/disable capability.

The I2C hardened IP supports both seven bits and ten bits addressing in Slave mode with configurable Slave address. It supports general call address detection in both Master and Slave mode.

The I2C hardened IP provides interrupt logic for easy communication with host. It also provides configurable digital delay at SDA output for generating start/stop conditions reliably.

The key I2C IP core features of CrossLinkPlus devices:
- Configurable Master and Slave mode
- Support for 7-bit or 10-bit configurable Slave address
- Multi-master arbitration support
- Clock stretching to ensure data setup time
- Up to 1000 kHz data transfer speed, also supports 400 kHz, 100 kHz, and 50 kHz modes
- General call support
- Optional delaying input or output data, or both
- Optional FIFO mode
- Transmit FIFO size is 10 bits x 16 bytes, receive FIFO size is 10 bits x 32 bytes
- I2C0 core supports sleep mode wakeup over I2C. Refer to Power Management and Calculation for CrossLinkPlus Devices (FPGA-TN-02111) for more details.
3. Generating I²C Module with Clarity Designer

The Clarity Designer tool of Lattice Diamond is used to configure the I²C hardened IP functions and generate the I²C module.

3.1. Enabling Hardened IP

To enable the hardened user I²C blocks, perform the following steps:

1. On the Lattice Diamond top menu, click Tools, and then Clarity Designer. With a CrossLinkPlus device targeted for the Diamond project, the Clarity Designer window appears and the I²C module is listed under Module > Architecture_Modules, as shown in Figure 3.1.

![Figure 3.1. I²C Module in Clarity Designer](image)

2. Click i2c. The Lattice FPGA module – I2C window appears, as shown in Figure 3.2.

3. On the Hard IP Enables tab, select the desired I²C core (I2C0 or I2C1, or both), and enter your System Bus clock frequency. The I2C Settings and I2C Interrupts tabs are enabled when at least one of the Enable Hard Users I²C block is selected.
3.2. I²C Settings

This section describes the I²C Settings tab of Lattice FPGA Module – I²C window, as shown in Figure 3.3.
3.2.1. General Settings

3.2.1.1. General Call Enable
Select this checkbox to enable I2C General Call response (addresses all devices on the bus using the I2C address 0) in Slave mode. This setting can be modified dynamically by enabling the GCEN bit in the I2C Control Register I2CCR1. Refer to Advanced CrossLinkPlus I2C Hardened IP Reference Guide (FPGA-TN-02135) for register descriptions.

3.2.1.2. Include I/O Buffers
Select this checkbox to include buffers for the I2C pins. Note that I2C0 pins are hard-routed through I/O buffer to the dedicated pins on the device. These buffers need to be included with I2C0.

Figure 3.4 and Figure 3.5 show the I2C I/O buffer and connections, respectively.
3.2.1.3. **SDA Input Delay**
Select SDA Input Delay between 0 ns and 50 ns.

3.2.1.4. **SDA Output Delay**
Select SDA Output Delay between 0 ns and 350 ns.

3.2.2. **Master Clock Rate**

3.2.2.1. **Master Clock Desired**
In the Master Clock Desired field, you can specify a desired Master clock frequency in kHz. A calculation is then made to determine a divider value to generate a clock close to this value from the input clock. The frequency of the input System Bus clock is specified on the **Hard IP Enables** tab. The divider value is rounded to the nearest integer after dividing the input System Bus clock by the value entered in this field.

3.2.2.2. **Master Clock Actual**
This is a read-only field. It is not always possible to divide the input System Bus clock to the exact value you requested, therefore the actual value in kHz is returned in this field. When both the desired I2C clock and System Bus clock fields contain valid data and either is updated, the Master Clock field returns the value (FREQ_SB/L2C_CLK_DIVIDER),
rounded to an integer, as shown in the example below. FREQ_SB is the System Bus clock frequency that has been entered on the Hard IP Enables tab. I2C_CLK_DIVIDER is a factor to be calculated as in the example below.

Master Clock calculation example:
- Divider = I2C_CLK_DIVIDER = FREQ_SB/I2C_CLK_FREQ
- Master Clock (Actual) = FREQ_SB/Divider Integer

For example, if FREQ_SB = 42.5 MHz and I2C_BUS_PERF = 400 kHz.

Divider = 42500/400 = 106.25
Therefore, ROUND Divider Integer = 106
Actual frequency = 42500/106 = 400.9 kHz

The tool automatically calculates and displays the Actual I2C Master clock rate value based on the System Bus Frequency and Desired Master Clock rate selected.

In this example, if an I2C_CLK_FREQ of 400 kHz cannot be generated, you may use the actual value or change the System Bus clock frequency.

### 3.2.3. FIFO Mode

#### 3.2.3.1. Enable FIFO Mode
Select this option to enable FIFO mode operation.

#### 3.2.3.2. CLK Stretch Enable
Select this checkbox to enable Clock Stretching for FIFO mode. This setting may be used to ensure valid data is transmitted from the FIFO. If disabled, then overflow and underflow error flag must be monitored.

The Clock Stretch for Register mode is a separate control and can be enabled or disabled through the CKSDIS (bit2) inside I2CCMDR register. The I2CCMDR register can be directly accessed through the System Bus.


#### 3.2.3.3. RxFIFO Almost Full
Select the value from the drop down list to set the trigger for the RxFIFO Almost Full Flag. The maximum FIFO size of the RxFIFO is 32 bytes.

#### 3.2.3.4. TxFIFO Almost Empty
Select the value from the drop down list to set the trigger for the TxFIFO Almost Empty Flag.

### 3.2.4. I2C Addressing

In the I2C Address box, you can choose between 7-bit or 10-bit addressing, and define the Hardened I2C address.

The lower two significant bits of the I2C address are fixed for each core. You can set the upper five significant bits in case of 7-bit addressing, or the upper eight significant bits in case of 10-bit addressing.

### 3.2.5. PMU Wake Options

This option is available for I2C0 only to enable the Wakeup port. The WKUPEN bit in the I2CCR1 can be modified dynamically allowing the Wake Up function to be enabled or disabled.

#### 3.2.5.1. Address Match
Select this checkbox to turn on the I2C wakeup on address match.

#### 3.2.5.2. RxFIFO Almost Full
Select this checkbox to turn on the I2C wakeup on RxFIFO Almost Full Flag assertion.
3.3. **I²C Interrupts**

This section describes the I²C Interrupts tab of Lattice FPGA Module – I²C window, as shown in **Figure 3.6**.

![Image of I²C Interrupts tab](image)

**Figure 3.6. I²C Interrupts**

3.3.1. **System Bus Interrupts**

System Bus interrupts enable the interrupt port when any of the interrupts are enabled. Refer to **Advanced CrossLinkPlus I²C Hardened IP Reference Guide (FPGA-TN-02135)** for more details on the interrupt registers described below.

3.3.1.1. **Arbitration Lost**

This interrupt indicates I²C lost arbitration. This interrupt is bit 3 (ARBL) of register I2CINTSR. When enabled, it indicates that ARBL is asserted. Writing 1 to this bit clears the interrupt.

This option can be changed dynamically by modifying bit ARBLEN in register I2CINTCR.

3.3.1.2. **Tx/Rx Ready**

This interrupt indicates that the I²C transmit data register (I2CTXDR) is empty or that the receive data register (I2CRXDR) is full. This interrupt is bit 2 (TRRDY) of register I2CINTSR. When enabled, it indicates that TRRDY is asserted. Writing 1 to this bit clears the interrupt.
This option can be changed dynamically by modifying bit TRRDYEN in register I2CINTCR.

### 3.3.1.3. Overrun or NACK
This interrupt indicates that the I2CRXDR received new data before the previous data. This interrupt is bit TROE of register I2CINTSR. When enabled, it indicates that TROE is asserted. Writing 1 to this bit clears the interrupt.

This option can be changed dynamically by modifying bit I2CINTSR in register I2CINTCR.

### 3.3.1.4. General CallIRQ Enable
This interrupt indicates that a general call has occurred. This interrupt is bit 0 (HGC) of register I2CINTSR. When enabled, it indicates that HGC is asserted. Writing 1 to this bit clears the interrupt.

This option can be changed dynamically by modifying bit HGCEN in register I2CINTCR.

### 3.3.2. FIFO Interrupts

#### 3.3.2.1. General Call
This interrupt indicates that a general call has occurred. This interrupt is bit HGC of register I2CFIFOINTSR.

This bit can be changed by modifying bit HGCEN in register I2CFIFOINTCR.

#### 3.3.2.2. Receive NACK
This interrupt indicates that a NACK has been received. This interrupt is bit RNACK of register I2CFIFOINTSR.

This bit can be changed by modifying bit RNACKEN in register I2CFIFOINTCR.

#### 3.3.2.3. Master Read Complete
A transaction is considered complete when:
- the specified number of data bytes from the Slave have been received in the RX FIFO, or
- the Master terminates the read transaction before the specified number of data bytes received.

This is bit MRDCMPL of register I2CFIFOINTSR. This bit can be changed by modifying bit MRDCMPLEN in register I2CFIFOINTCR.

#### 3.3.2.4. Arbitration Lost
This interrupt indicates I2C lost arbitration. This interrupt is bit ARBL of register I2CFIFOINTSR. When enabled, it indicates that ARBL is asserted. Writing 1 to this bit clears the interrupt.

This option can be changed dynamically by modifying bit ARBLEN in register I2CFIFOINTCR.

#### 3.3.2.5. TX FIFO Sync
This interrupt indicates I2C TXFIFO synchronization error. Synchronization error happens when there are back-to-back commands in the FIFO. The previous command is overwritten. This interrupt is bit TXSERR of register I2CFIFOINTSR.

This option can be changed dynamically by modifying bit TXSERREN in register I2CFIFOINTCR.

#### 3.3.2.6. TX FIFO Underflow
This interrupt is mutually exclusive with clock stretching function. This interrupt is bit TXUNDERF of register I2CFIFOINTSR.

This option can be changed dynamically by modifying bit TXUNDERFEN in register I2CFIFOINTCR.

#### 3.3.2.7. RX FIFO Overflow
This interrupt is mutually exclusive with clock stretching function. This interrupt is bit RXOVERF of register I2CFIFOINTSR.

This option can be changed dynamically by modifying bit RXOVERFEN in register I2CFIFOINTCR.
4. SB_I2C Hardened IP Macro Ports and Wrapper Connections

When the I2C Hardened IP is enabled, the necessary signals are included in the generated module. Table 4.1 lists the pins for the I2C hardened IP.

Table 4.1. Pins for I2C Hardened IP

<table>
<thead>
<tr>
<th>Port Name</th>
<th>I2C Wrapper Name</th>
<th>Pin Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBCSi</td>
<td>i2cXcsi*</td>
<td>Input</td>
<td>Chip select signal. Activates the IP to allow the System Bus or fabric interface to communicate with the IP.</td>
</tr>
<tr>
<td>SBCLKi</td>
<td>i2cXclkki*</td>
<td>Input</td>
<td>System clock input.</td>
</tr>
<tr>
<td>SBWRi</td>
<td>i2cXwe*</td>
<td>Input</td>
<td>System read/write input. R=0, W=1</td>
</tr>
<tr>
<td>SBSTBi</td>
<td>i2cXstbi*</td>
<td>Input</td>
<td>System strobe signal. When asserted, indicates that the Slave component is selected.</td>
</tr>
<tr>
<td>SBADRI[3:0]</td>
<td>i2cXadri[3:0]*</td>
<td>Input</td>
<td>System bus control registers address.</td>
</tr>
<tr>
<td>SBACKo</td>
<td>i2cXacko*</td>
<td>Output</td>
<td>System acknowledgement</td>
</tr>
<tr>
<td>SBSRWo</td>
<td>i2cXsrdwr*</td>
<td>Output</td>
<td>Slave read/write signal. A 1 indicates a Slave transmitting (external Master receiving). A 0 means Slave receiving (external Master transmitting).</td>
</tr>
<tr>
<td>I2CPIRQ</td>
<td>i2cXicirq*</td>
<td>Output</td>
<td>Interrupt request output signal of the I2C core – The intended use of this signal is for it to be connected to a Master controller (such as a microcontroller or state machine) and request an interrupt when a specific condition is met.</td>
</tr>
<tr>
<td>I2CPWKUP</td>
<td>i2cXicwkup*</td>
<td>Output</td>
<td>Wake-up signal – The signal is enabled only if the Wakeup Enable feature is set.</td>
</tr>
<tr>
<td>FIFO_RST</td>
<td>i2cXififorst*</td>
<td>Input</td>
<td>Reset for the FIFO logic.</td>
</tr>
<tr>
<td>TXFIFO[AE]</td>
<td>i2cXtxfifoa<em>e</em></td>
<td>Output</td>
<td>TXFIFO almost empty status signal coming from TXFIFO, indicating user-defined almost empty threshold value is reached.</td>
</tr>
<tr>
<td>TXFIFO_E</td>
<td>i2cXtxfifoe*</td>
<td>Output</td>
<td>TXFIFO empty signal coming from TXFIFO.</td>
</tr>
<tr>
<td>TXFIFO_F</td>
<td>i2cXtxfifof*</td>
<td>Output</td>
<td>TXFIFO full signal.</td>
</tr>
<tr>
<td>RXFIFO_E</td>
<td>i2cXrxfifoe*</td>
<td>Output</td>
<td>RXFIFO is empty. It can be served as an active low DATA RDY signal.</td>
</tr>
<tr>
<td>RXFIFO_AF</td>
<td>i2cXrxfifoa<em>f</em></td>
<td>Output</td>
<td>RXFIFO almost full signal, indicating user-defined almost full threshold value is reached.</td>
</tr>
<tr>
<td>RXFIFO_F</td>
<td>i2cXrxfifof*</td>
<td>Output</td>
<td>RXFIFO full signal.</td>
</tr>
</tbody>
</table>
| MRDCMPL   | i2cXmrdcmpl*     | Output        | Master Read Complete – This is only valid for Master Read Mode. A transaction is considered complete when:  
- The specified number of data bytes from the Slave has been received in the RX FIFO, or  
- The Master terminates the read transaction before the specified number of data bytes received |
<p>| I2CX_SCL* | i2cXscl*         | Bi-directional| Open drain clock line of the I2C core – The signal is an output if the I2C core is performing a Master operation. The signal is an input for Slave operations. The i2c1scl signal (Right I2C) uses dedicated I/O pin only. The i2c0scl signal (Left I2C) can use any of the available GPIOs on the device. |</p>
<table>
<thead>
<tr>
<th>Port Name</th>
<th>I2C Wrapper Name</th>
<th>Pin Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2C_SDA*</td>
<td>i2cXsda*</td>
<td>Bi-directional</td>
<td>Open drain data line of the I2C core – The signal is an output when data is transmitted from the I2C core. The signal is an input when data is received into the I2C core. The i2c1sda signal (Right I2C) uses dedicated I/O pin only. The i2c0sda signal (Left I2C) can use any of the available GPIOs on the device.</td>
</tr>
</tbody>
</table>

*Note: X indicates the I2C: X=0 for the hard I/O pin I2C; X=1 for the selectable I/O pin I2C.*
5. **I²C Usage Cases**

The I²C usage cases are described below (Figure 5.1).

- The CrossLinkPlus device is used as I²C Master accessing Slave I²C devices.
  - A System Bus Master is implemented in the CrossLinkPlus logic.
  - I²C devices 1, 2, and 3 are all Slave devices.
  - The Master performs bus transactions to the I2C0 I²C controller to access external Slave I²C Device 1 on Bus A.
  - The Master performs bus transactions to the I2C1 I²C controller to access the external Slave I²C Device 2 or Device 3 on Bus B.
- External Master I²C device accessing Slave CrossLinkPlus I²C.
  - The I²C Devices 1, 2, and 3 are I²C Master devices.
  - The external Master I²C Device 1 on Bus A performs I²C memory cycles to access the I2C0 I²C controller using address yyyxxxxx01.
  - The external Master I²C Device 2 or Device 3 on Bus B performs I²C memory cycles to access the I2C1 I²C user with the address yyyxxxxx10.
- The System Bus Master in the CrossLinkPlus fabric must manage data reception and transmission. The System Bus Master can use interrupts or polling techniques to manage data transfer, and to prevent data overrun conditions.

![Figure 5.1. I²C Circuit](image)
References
For more information, refer to the following documents:

- CrossLinkPlus Family Data Sheet (FPGA-DS-02054)
- CrossLinkPlus High-Speed I/O Interface (FPGA-TN-02102)
- CrossLinkPlus Hardware Checklist (FPGA-TN-02105)
- CrossLinkPlus sysCLOCK PLL/DLL Design and Usage Guide (FPGA-TN-02109)
- CrossLinkPlus sysI/O Usage Guide (FPGA-TN-02108)
- CrossLinkPlus Memory Usage Guide (FPGA-TN-02110)
- Power Management and Calculation for CrossLinkPlus Devices (FPGA-TN-02111)
Technical Support Assistance
Submit a technical support case through www.latticesemi.com/techsupport.
## Revision History

**Revision 1.0, August 2019**

<table>
<thead>
<tr>
<th>Section</th>
<th>Change Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Production release.</td>
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</table>