LogiCORE IP ECC v1.1

Product Guide

PG092 October 16, 2012

XILINX®

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Introduction

The Xilinx LogiCORE IP ECC core is ideal for robust data transmission with error correction and checking capabilities. The adaptable core supports Hamming and Hsiao algorithms for Single Error Correction and Double Error Detection (SEC-DED) error correction codes (ECC). The ECC core supports data widths between 4 and 128 bits and can be used with internal and external memories and with high speed Multi Gigabit transceivers.

Features

- Supports Single Bit Error correction and double bit error detection functions
- Supports hamming algorithm for 4 to 64 data widths
- Supports Hsiao algorithm for 4 to 128 data widths
- Supports encode only, decode only and encode/decode modes
- Supports clock enable and synchronous active high reset
- Provides option to add input/output registering stages
- Provides optional internal pipelining stage for high frequency operations
- Supports dynamically enabling or disabling error correction function
- Provides Single Bit Error corrected and two bit error detected status outputs

LogiCORE IP Facts Table	
Core Specifics	
Supported Device Family(1)	Virtex®-7, Kintex™-7, Artix™-7
Supported User Interfaces	Native
Resources	See Table 2-3 and Table 2-4.
Provided with Core	
Design Files	Encrypted RTL
Example Design	Not Provided
Test Bench	Not Provided
Constraints File	Not Provided
Simulation Model	Not Provided
Supported S/W Driver	N/A
Tested Design Flows(2)	
Design Entry	Vivado Design Suite v2012.3
Simulation	Mentor Graphics ModelSim
Synthesis	Vivado Synthesis
Support	
Provided by Xilinx @ www.xilinx.com/support	

Notes:

1. For a complete listing of supported devices, see the release notes for this core.
2. For the supported versions of the tools, see the Xilinx Design Tools: Release Notes Guide.

Overview

Single Error Correction and Double Error Detection (SEC-DED) error correction codes (ECC) are used to increase reliability against soft errors from random noise. As technology has scaled, the decreasing supply voltages and increasing interface speeds has resulted in reduced noise margins. This margin reduction increases the probability of soft errors introduced in both on-chip and off-chip FPGA components. For FPGA internal memory and external memories, error correction codes are needed to reduce radiation induced soft errors or single event upsets (SEU). For maintaining signal integrity, high-speed off-chip interfaces such as multi-gigabit transceivers also require increased protection against bit errors introduced due to the clock jitter or random noise. The ECC core increases system reliability under these random error conditions by detecting and correcting all single-bit errors. In addition, it detects double-bit errors in the data.

Feature Summary

This section summarizes the functionality of the all three ECC functions: encoder, decoder, encoder/decoder.

ECC Encoder

The ECC encoder operation calculates check (or protection) bits for the input data. For each 4 to 128 bits of data input, it generates between 4 and 9 check bits. These bits are used during each ECC decoder operation to correct any single-bit errors, or to detect any double-bit errors. The data along with the calculated check bits are provided as an output of ECC encoder function, as shown in Figure 1-1. The data and check bits output of the ECC encoder is called an ECC codeword. For more details on the number of check bits required for the configured data width, see GUI in Chapter 4.

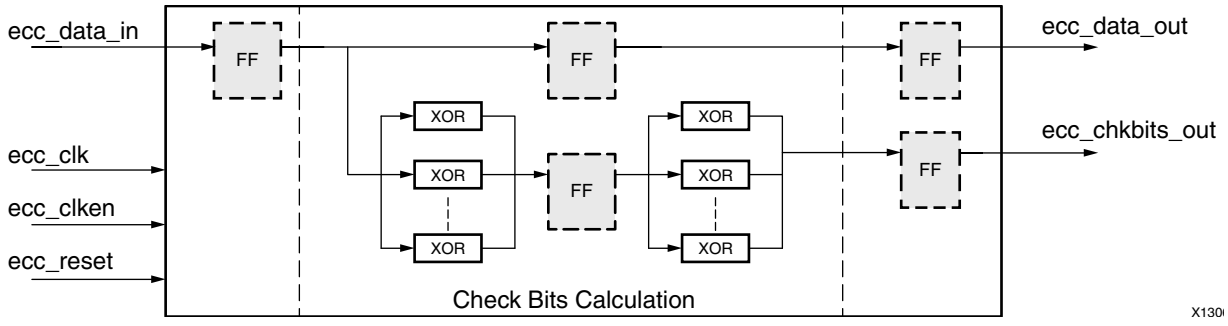

Figure 1-1: **ECC Encoder Block Diagram**

ECC Decoder

The ECC decoder operation generates error correction syndrome bits for the input data and check bits. These syndrome bits are used to correct any single-bit errors, or to detect (but not correct) any double-bit errors in the input data. The single bit error corrected data, along with the `ecc_sbit_err` status or the uncorrected data with `ecc_dbit_err` status, are provided as an output of the ECC decoder function, as shown in Figure 1-2. If no errors are detected, input data is forwarded at the output, and both `ecc_sbit_err` and `ecc_dbit_err` status outputs are kept de-asserted.

The ECC decoder operations can also be bypassed by asserting the `ecc_correct_n` input. When the operations are bypassed, the input data is forwarded at the output, and both `ecc_sbit_err` and `ecc_dbit_err` status outputs are kept deasserted. The ECC bypass function can be applied when error protection/correction is not required for portions of data or payload provided to the ECC core.

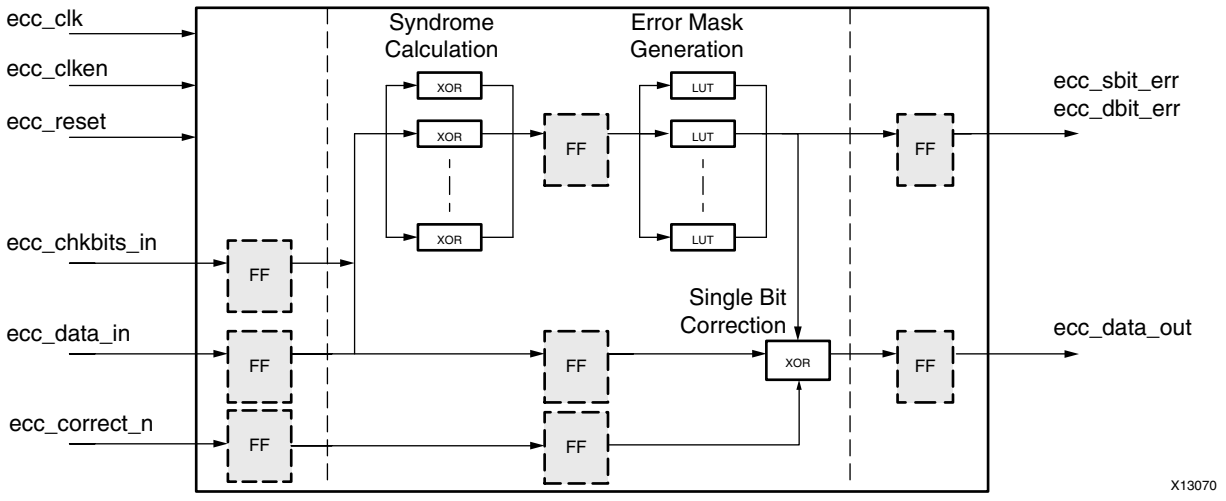

Figure 1-2: **ECC Decoder Block Diagram**

ECC Encoder/Decoder

The ECC encoder/decoder combines both encoder and decoder operations in a single module and is most suited for applications requiring either encoding or decoding but not both at the same time. The ECC encoder/decoder function provides an additional `ecc_encode` input. When this input is asserted, ECC encoder operations are performed on the input data. When `ecc_encode` input is not asserted, ECC decoder operations are performed on input codeword (data and check bits). When `ecc_correct_n` input is asserted during ECC decoder operation, the decoding operation is bypassed and input data is forwarded at the output with error status outputs kept deasserted.

The ECC encoder/decoder function provides an optimized solution for Single Port Memory operations or for extending ECC function over byte enabled data with an external read-modify-write operation.

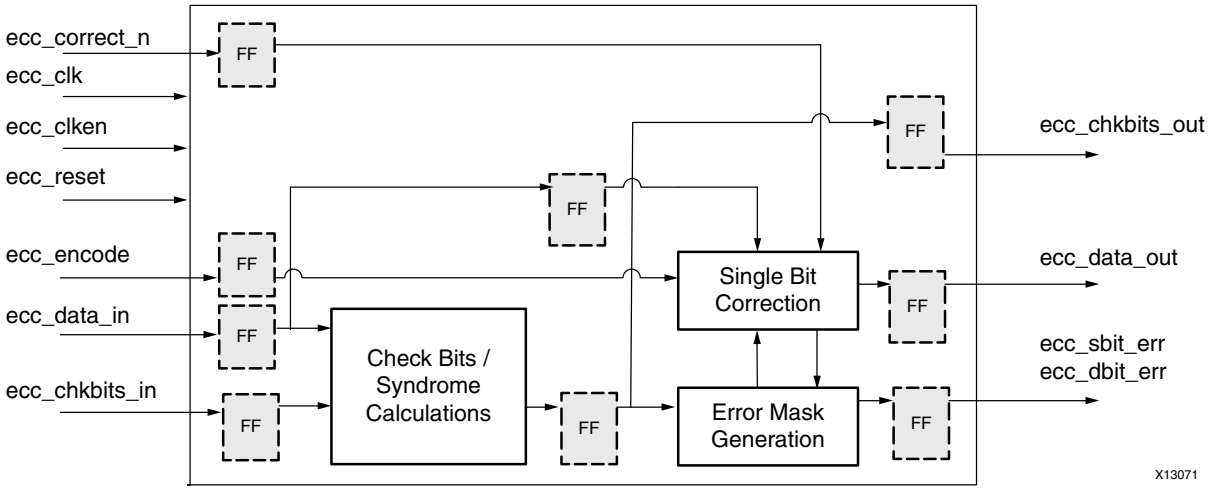

Figure 1-3: **ECC Encoder/Decoder Block Diagram**

ECC Clock Enable and Registering Options

The ECC core supports multiple registering options. These options include input registering, output registering and an optional internal pipeline registering stage. Each registering stage can be independently enabled. The internal pipeline registering stage breaks the computation logic into two parts and can be used for higher data widths for frequency optimization. In addition, the clock enable can be used to save power. When one or more registering stages are enabled and when clock enable is used, the ECC core pipelines the data with respect to the clock enable.

Applications

Figure 1-4 shows an example of the ECC Encoder and ECC Decoder use case. In this use case, ECC Encoder and ECC Decoder functions are used along with Internal Memories for single bit error correction function. The error correction function here increases reliability against radiation induced soft errors or Single Event upsets [SEU].

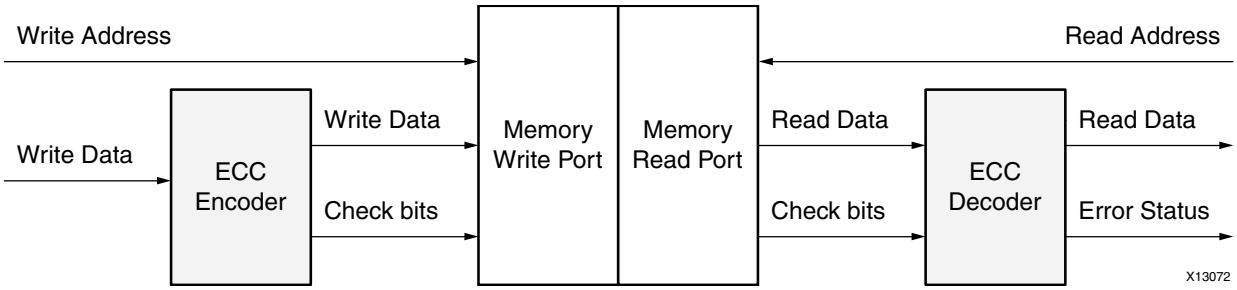

Figure 1-4: **ECC Encoder and ECC Decoder Application Example**

In Figure 1-5, ECC Encoder/Decoder function is used with the off chip DDR memory. The write operations to the memory are considered to be performed using data byte enables or data strobes. ECC functions inherently do not support byte enables, to perform data writes with byte enables a read-modify-write operation is used here.

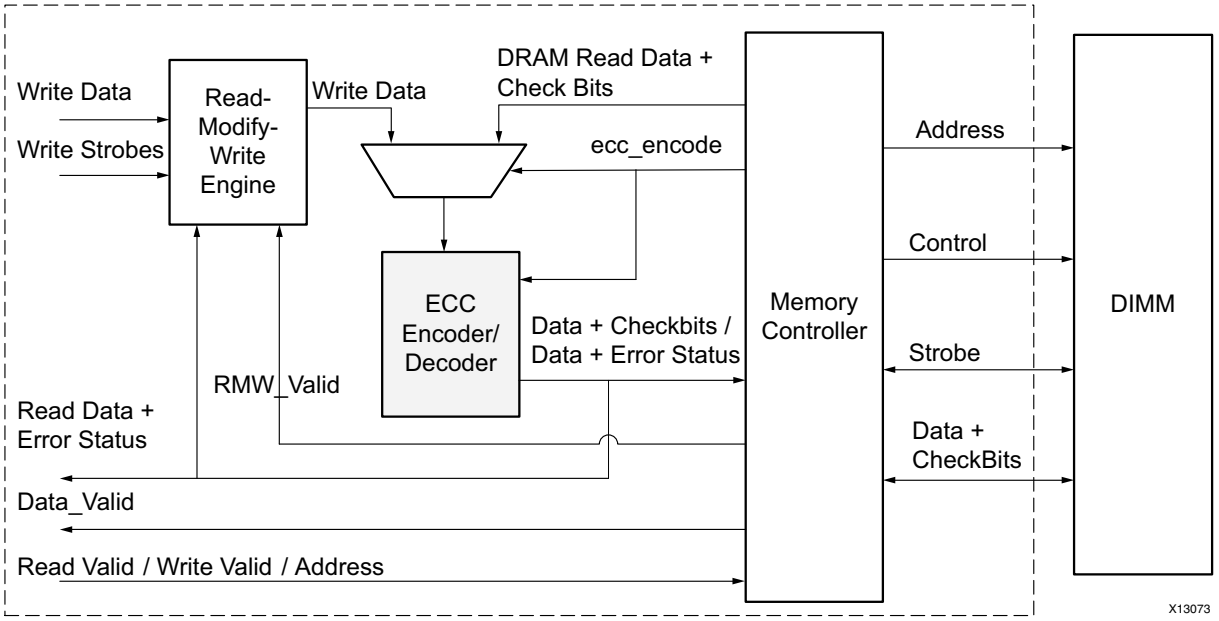

Figure 1-5: **ECC Encoder/Decoder Application Example**

For DDR memory writes, first a read is performed to the memory. The codeword received from DDR memory is checked for single bit errors and then the corrected data is provided to read-modify-write operation. The output of read-modify-write operation is again provided to ECC core to generate the write codeword to the DDR Memory. For DDR memory

reads, the codeword read from DDR Memory is checked for single bit errors by the ECC function. The corrected data along with error status is then provided at the user interface. A single instance of ECC encoder/decoder function is used here for both reads from the DDR memory to perform Read-Modify-Write to the DDR memory.

Note: The ECC functions supported are suited for applications requiring random bit error conditions and are not suited for applications requiring burst error detection or correction. For more than 2-bits in error, the supported ECC function does not guarantee a robust error detection operation and may even result in an incorrect single bit error correction operation.

Licensing and Ordering Information

This Xilinx LogiCORE IP module is provided at no additional cost with the Xilinx Vivado Design Suite under the terms of the Xilinx End User License. Information about this and other Xilinx LogiCORE IP modules is available at the Xilinx Intellectual Property page. For information about pricing and availability of other Xilinx LogiCORE IP modules and tools, contact your local Xilinx sales representative.

Product Specification

The Xilinx LogiCORE IP ECC core is ideal for robust data transmission with error correction and checking capabilities. The adaptable core supports Hamming and Hsiao algorithms for Single Error Correction and Double Error Detection (SEC-DED) error correction codes (ECC).

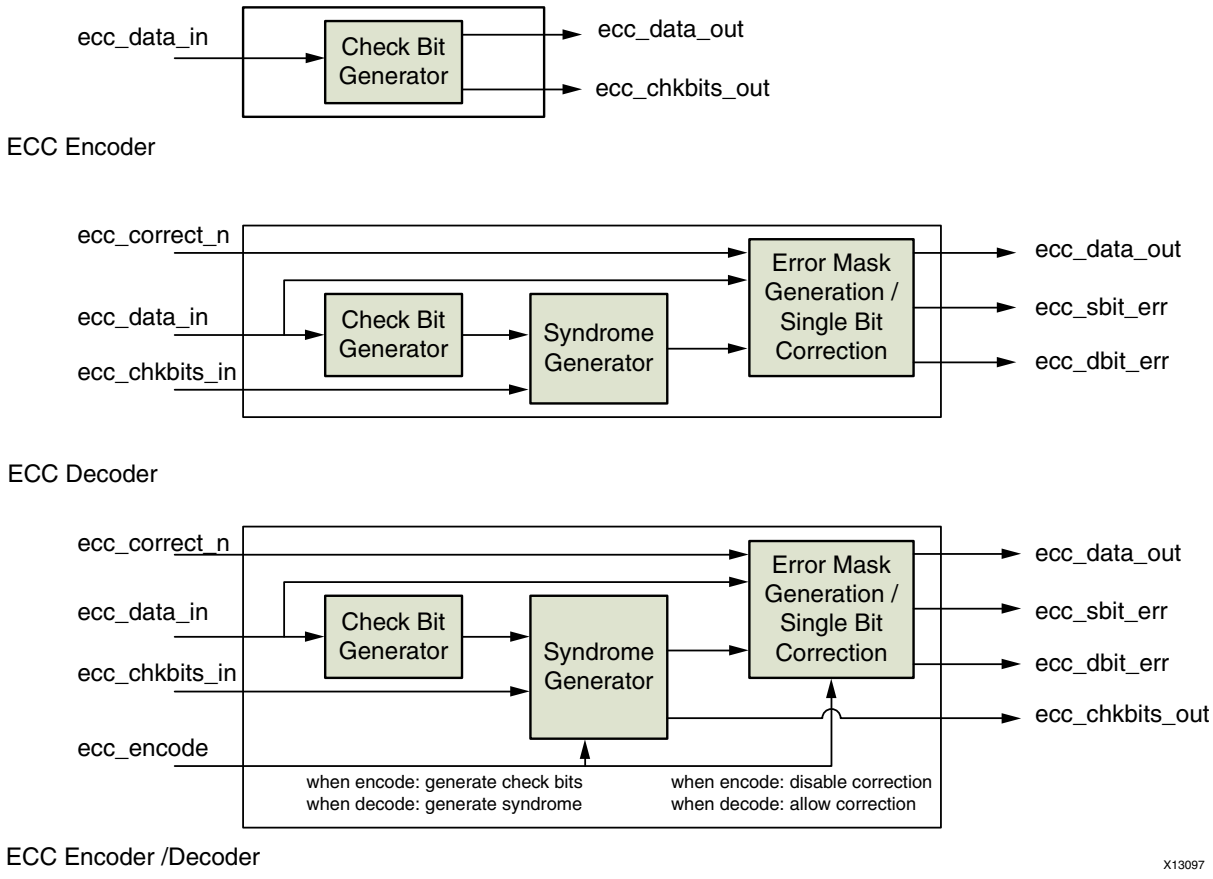

Figure 2-1: **ECC Block Diagram**

Performance

This section details the performance information for various core configurations.

Maximum Frequencies

Table 2-1 and Table 2-2 show the performance numbers for the ECC core for the Kintex™-7 family and -1 speed grade of FPGAs. Benchmark values have been generated using the Xilinx® Vivado™ Design Suite for version 2012.3. In the benchmark designs, the core is encased in a wrapper with input and output registers to remove the effects of I/O delays from the results.

Table 2-1: **Frequency Table for Hamming Algorithm**

Features				Frequency
Data Width	**Mode**	**Input / Output Registering**	**Internal Pipeline**	**MHz**
32-bit	Encoder	1	0	550
	Decoder	1	0	350
	Encoder/Decoder	1	0	325
	Encoder	1	1	550
	Decoder	1	1	500
	Encoder/Decoder	1	1	475
64-bit	Encoder	1	0	500
	Decoder	1	0	290
	Encoder/Decoder	1	0	270
	Encoder	1	1	500
	Decoder	1	1	440
	Encoder/Decoder	1	1	420

Table 2-2: **Frequency Table for Hsiao Algorithm**

Features				Frequency
Data Width	**Mode**	**Input / Output Registering**	**Internal Pipeline**	**MHz**
64-bit	Encoder	1	0	500
	Decoder	1	0	320
	Encoder/Decoder	1	0	270
	Encoder	1	1	500
	Decoder	1	1	480
	Encoder/Decoder	1	1	440

Table 2-2: **Frequency Table for Hsiao Algorithm *(Cont'd)***

Features				Frequency
Data Width	**Mode**	**Input / Output Registering**	**Internal Pipeline**	**MHz**
128-bit	Encoder	1	0	425
	Decoder	1	0	250
	Encoder/Decoder	1	0	210
	Encoder	1	1	425
	Decoder	1	1	400
	Encoder/Decoder	1	1	360

Latency

ECC core supports Input Registering, Output Registering and Internal Pipeline Registering options. Each of these registering stages can be independently enabled during core generation. The clock cycle latency of the core equals the number of registering stages selected for the core. There is no clock cycle latency in case none of the registering stages are selected; in this case the core latency is determined by logical delay of the core. For more details on ECC Core delays, see Maximum Frequencies.

When Clock Enable is used with the registering stages, ECC core operations are synchronous to both ECC clock and ECC Clock Enable. In this case, clock cycle latency of the core equals the number registering stages only when both clock and clock enable are asserted.

Figure 2-2 provides timing diagram for ECC Encoder function with a single stage of registering. With the clock-enable signal set to high, the calculated check bits and data appear here at the next rising edge of the clock. The clock enable feature when enabled allows to control when encoded data should appear on the output port.

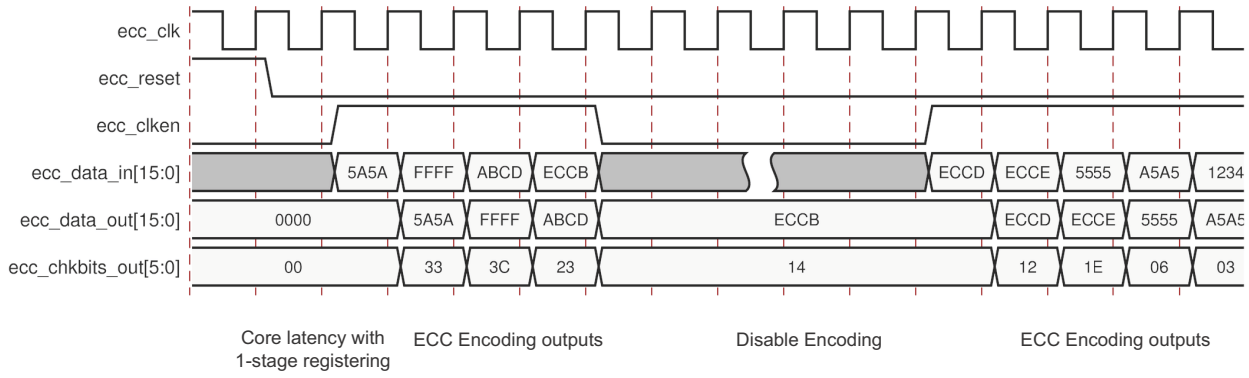

Figure 2-2: **ECC Encoder Timing Diagram**

Figure 2-3 provides timing diagram for ECC Decoder function with two stages of registering. The data corrected for any single bit error and status outputs here appears after two rising edges of the clock. The clock enable feature here is used to perform each ECC operation in two clock cycles.

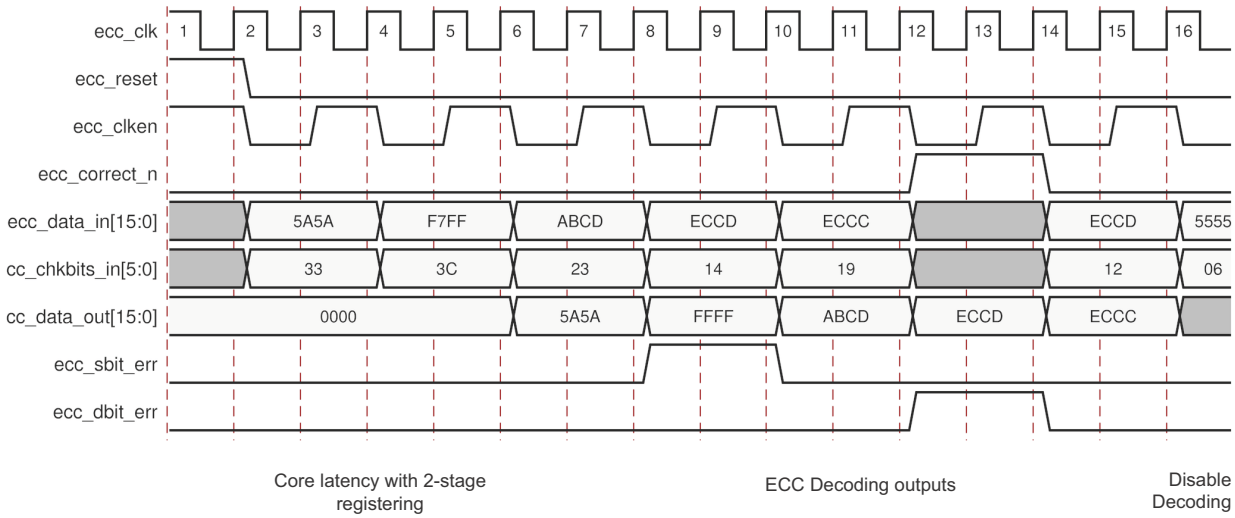

Figure 2-3: **ECC Decoder Timing Diagram**

Figure 2-4 provides timing diagram for ECC Encoder/Decoder function with three stages of registering. When ecc_encode input is asserted, ECC Encoder operations are performed on the input data and the calculated check bits and data appear after three rising edges of the clock. When ecc_encode input is not asserted ECC Decoder operations are performed on input data and check bits, the data corrected for any single bit error and status outputs appears here after three rising edge of the clock.

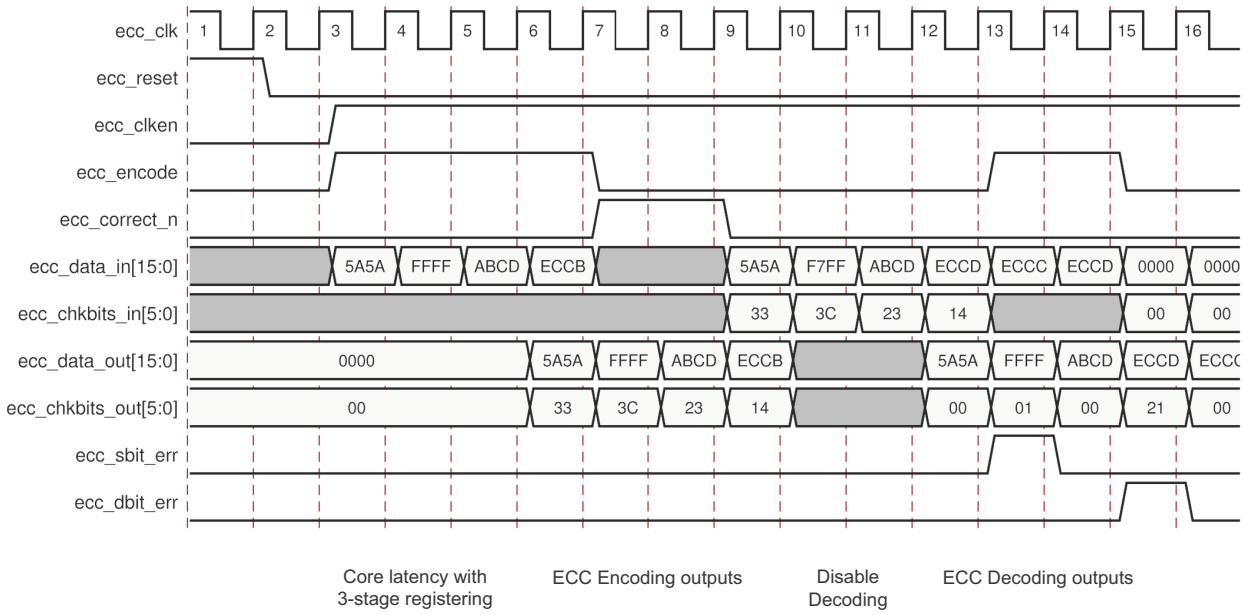

Figure 2-4: **ECC Encoder/Decoder Timing Diagram**

Resource Utilization

Table 2-3 and Table 2-4 show the resource utilization numbers for the ECC core for the Kintex™-7 family and -1 speed grade of FPGAs. Benchmark values have been generated using the Xilinx Vivado Design Suite for version 2012.3.

Table 2-3: **Resource Utilization for Hamming Algorithm**

Features					Resources		
Data Width	**Mode**	**Input Registering**	**Output Registering**	**Internal Pipeline**	**Slices**	**LUTs**	**FFs**
32- bit	Encoder	0	0	0	9	28	0
	Decoder	0	0	0	24	83	0
	Encoder/Decoder	0	0	0	30	101	0
	Encoder	1	0	0	14	28	32
	Decoder	0	1	1	28	87	82
	Encoder/Decoder	1	1	1	37	100	131

Table 2-3: **Resource Utilization for Hamming Algorithm *(Cont'd)***

Features					Resources		
Data Width	**Mode**	**Input Registering**	**Output Registering**	**Internal Pipeline**	**Slices**	**LUTs**	**FFs**
64-bit	Encoder	0	0	0	18	53	0
	Decoder	0	0	0	43	155	0
	Encoder/Decoder	0	0	0	49	169	0
	Encoder	1	0	0	34	53	64
	Decoder	0	1	1	54	164	148
	Encoder/Decoder	1	1	1	83	180	231

Table 2-4: **Resource Utilization for Hsiao Algorithm**

Features					Resources		
Data Width	**Mode**	**Input Registering**	**Output Registering**	**Internal Pipeline**	**Slices**	**LUTs**	**FFs**
64- bit	Encoder	0	0	0	14	47	0
	Decoder	0	0	0	47	164	0
	Encoder/Decoder	0	0	0	53	184	0
	Encoder	1	0	0	33	47	64
	Decoder	0	1	1	65	171	139
	Encoder/Decoder	1	1	1	83	172	223
128-bit	Encoder	0	0	0	29	100	0
	Decoder	0	0	0	88	299	0
	Encoder/Decoder	0	0	0	93	313	0
	Encoder	1	0	0	71	102	128
	Decoder	0	1	1	119	292	268
	Encoder/Decoder	1	1	1	226	293	416

Port Descriptions

Table 2-5 details the ECC core global signals.

Table 2-5: **ECC Core Global Signals**

Name	Direction	Description
ecc_clk	Input	**ECC Clock:** Applicable when one or more registering stages are enabled for the core. ECC core operations are synchronous to ecc_clk signal
ecc_clken	Input	**ECC Clock Enable**: Applicable when one or more registering stages are enabled for the core. When ecc_clken is used, ECC core operations are synchronous to ecc_clk clock and ecc_clken.
ecc_reset	Input	**ECC Reset:** Applicable when one or more registering stages are enabled for the core. This signal is synchronous and active-High.

Table 2-6 details the ECC core signals.

Table 2-6: **ECC Core Signals**

Name	Direction	Description
ecc_data_in[C_DATA_WIDTH -1:0]	Input	Data Input: For generating check bits or protection bits. The valid range for input data width is from 4 to 128 bits
ecc_data_out[C_DATA_WIDTH -1-1:0]	Output	Data Output: The valid range for output data width is from 4 to 128 bits. • **Encoder Mode**: Data Output with the associated check bits after encoding operation. • **Decoder Mode**: Data Output after decoding operations, corrected for any single bit errors • **Encoder/Decoder Mode**: When ecc_encode is asserted, provides Data Output with the associated check bits. When ecc_encode is de-asserted, provides Data Output, corrected for any single bit errors
ecc_chkbits_in[C_CHK_BIT_WIDTH -1:0]	Input	Input Check Bits: Applicable for decoder and encoder/decoder modes of operation. The valid range for check bit width is from 4 to 9 bits. See Table 4-1 for minimum number of check bits required for the configured data width. • **Decoder Mode**: Input check bits for error analysis over the associated data • **Encoder/Decoder Mode**: Ignored when ecc_encode is asserted. When ecc_encode is de-asserted, input check bits for error analysis over the associated data

Table 2-6: **ECC Core Signals *(Cont'd)***

Name	Direction	Description
ecc_chkbits_out[C_CHK_BIT_WIDTH-1:0]	Output	Output Check Bits/Syndrome (Encoder and Encoder/Decoder modes only): The valid range for check bit width is from 4 to 9 bits. See Table 4-1 for minimum number of check bits required for the configured data width. • **Encoder Mode**: Provides calculated check bits. • **Encoder/Decoder Mode**: When ecc_encode is asserted, provides calculated check bits. When ecc_encode is de-asserted, provides calculated syndrome.
ecc_correct_n	Input	Disable Error Correction: Applicable for decoder and encoder/decoder mode of operation. When asserted, suppresses single bit error correction in the data. • **Decoder Mode**: When asserted, input data is forwarded at the output, and both ecc_sbit_err and ecc_dbit_err status outputs are kept deasserted. • **Encoder/Decoder Mode**: Ignored when ecc_encode is asserted. When ecc_encode is de-asserted and ecc_correct_n is asserted, input data is forwarded at the output, and both ecc_sbit_err and ecc_dbit_err status outputs are kept deasserted
ecc_sbit_err	Output	Single-Bit Error: Applicable for decoder and encoder/decoder modes of operation. When asserted, flags the presence of a single-bit error in data which has been auto-corrected during ECC decoder operations.
ecc_dbit_err	Output	Double-Bit Error: Applicable for decoder and encoder/decoder modes of operation. When asserted, flags the presence of a double-bit error in data. Double-bit errors cannot be auto-corrected during ECC decoder operations.
ecc_encode	Input	Encoder Enable: Applicable for only encoder/decoder mode of operation. When asserted, the core performs encoding operations. When ecc_encode is de-asserted, the core performs decoding and/or error correction operations.

Designing with the Core

This chapter includes guidelines and additional information to facilitate designing with the core.

General Design Guidelines

The customizable ECC core provides multiple registering options to the user. Users can determine the frequency at which the core needs to be operated. Based on the required frequency, select the appropriate pipeline or input/output registering option. Each registering stage will impact the latency of the core by one clock cycle.

The clock enable functionality can be used when one or more registering stages are enabled for the core. The clock enable function allows the core to perform operations only when both clock and clock enable are asserted. Based on the synchronous elements gated by a common clock enable in the design, the ECC core can also be constrained with the clock enable period instead of applied clock period.

Clocking

The ECC core has a single clock (`ecc_clk`) input and is used only when one or more registering stages are enabled for the design.

Resets

The ECC core supports an active-High synchronous reset (`ecc_reset`) input. The reset input is applicable only when one or more registering stages are enabled for the design.

Customizing and Generating the Core

This chapter includes information about using Xilinx tools to customize and generate the core in the Vivado™ Design Suite environment.

GUI

Figure 4-1 shows the customization GUI for the ECC core.

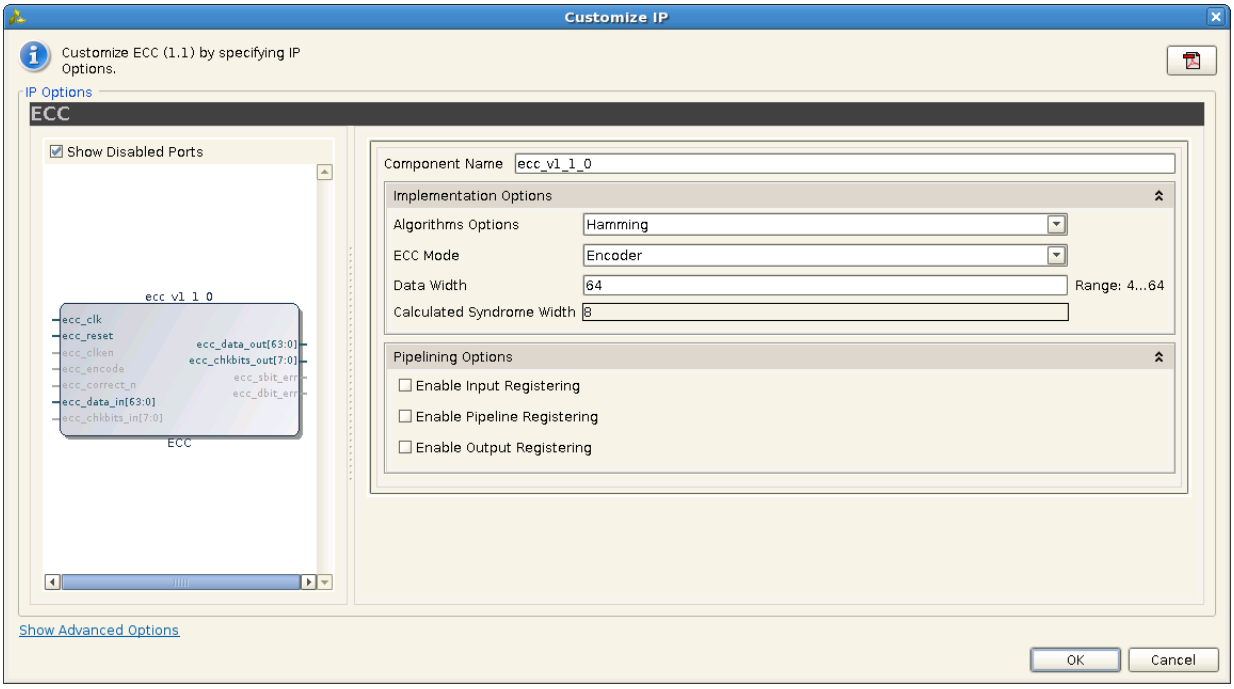

Figure 4-1: **ECC Customization GUI**

- Algorithm Option: Selects Hamming or Hsiao algorithms for ECC operations. The algorithm selected must be the same for encoder and decoder cores for ECC encoding and subsequent decoding operations.
- ECC Mode: Selects Encoder, Decoder or Encoder/Decoder operations of the ECC core.

- Data Width: Configures the width of data in bits for ECC operations. The valid range for data width is between 4 and 128 bits. Table 4-1 provides the minimum number of check bits required for the configured data width in bits.

Table 4-1: **Minimum Check Bits Utilization**

Data Width (Bits)	Minimum Check Bits
4	4
5-11	5
12-26	6
27-57	7
58-120	8
121-128	9

- Enable Input Registering: When selected, the ECC core registers all of its inputs.
- Enable Pipeline Registering: When selected, the ECC core inserts an internal pipeline register stage to the core.
- Enable Output Registering: When selected, the ECC core registers all of its outputs.

Output Generation

The output files generated from the Xilinx Vivado Design Suite are placed in the <project_directory> top-level directory. Depending on the settings, the file output list may include some or all of the following files:

<project_directory>/<project_name.data>
Contains constraints and file set details.

<project directory>/<project_name>.src/sources_1/ip/<component name>
Contains constraints and file set details.

<component name>/synth
Core release notes readme file

The ECC IP core directories and their associated files are defined in the following sections.

<project directory>/<project_name>.src/sources_1/ip/<component name>

This directory contains templates for instantiation of the core, example design, synth, XML and the XCI files.

Table 4-2: **Component Name Directory**

Name	Description
<component name>.[veo|vho]	VHDL or Verilog instantiation template.
<component name>.xci	Log file from Vivado Design Suite describing which options were used to generate the ECC core. An XCI file can also be used as an input to the Vivado Design Suite.

<component name>/synth

The synth directory contains the ECC synthesis file.

Table 4-3: **Synth Directory**

Name	Description
<component name>.[v|vhd]	Top level component wrapper file from the Vivado Design Suite used to synthesize the ECC core.

XCI Parameters

Table 4-4 shows parameters that can be used to run the TCL command mode.

Table 4-4: **XCI Parameters**

Generic Name	Type	Range	Default	Description
C_FAMILY	String	Virtex7, Kintex7, Artix7	Kintex7	Carries the family information
C_COMPONENT_NAME	String	a to z, 0 to 9, and "_".	ecc_1_1	Base name of the output files generated for this core. The name must begin with a letter and be composed of the following characters: a to z, 0 to 9, and "_".
C_ECC_TYPE	String	Hamming, HSIAO	Hamming	Determines ECC Algorithm. • 0: Hamming Algorithm • 1: Hsiao Algorithm
C_ECC_MODE	String	Encoder, Decoder, Encoder/ Decoder	Encoder	Determines ECC Mode of operation. • Encoder • Decoder • Encoder/Decoder
C_DATA_WIDTH	Integer	4-128	64	Data width in bits. The valid range for data width is from 4 to 128 bits
C_CHK_BIT_WIDTH	Integer	4-9	8	Check bit width in bits. The valid range for check bit width is from 4 to 9 bits. See Table 4-1 for minimum number of check bits required for the configured data width.

Table 4-4: **XCI Parameters *(Cont'd)***

Generic Name	Type	Range	Default	Description
C_REG_INPUT	Boolean	True, False	False	When set to true, inserts input registering stage.
C_REG_OUTPUT	Boolean	True, False	False	When set to true, inserts internal pipeline registering stage.
C_PIPELINE	Boolean	True, False	False	When set to true, inserts output registering stage.

Constraining the Core

This chapter contains information about constraining the core in the Vivado™ Design Suite environment.

Required Constraints

The ECC core constraints can be applied from the top-level constraints file. Clock constraint can be applied when one or more registering stages are selected for the core. Max delay constraint can be applied in case none of the registering stages are selected for the core.

Device, Package, and Speed Grade Selections

See IP Facts for details about support devices.

Clock Frequencies

There are no clock frequency constraints for this core.

Clock Management

There are no additional clock management constraints for this core.

Clock Placement

There are no additional clock placement constraints for this core.

Banking

There are no banking constraints for this core.

Transceiver Placement

There are no transceiver constraints for this core.

I/O Standard and Placement

There are no I/O constraints for this core.

Appendix A

Verification, Compliance, and Interoperability

This appendix includes information about how the IP was tested for compliance with the protocol to which it was designed.

Simulation

The ECC core has been tested with Xilinx® Vivado™ Design Suite for version 2012.3 and Mentor Graphics ModelSim simulator.

Hardware Testing

The ECC core has been validated at 200 MHz on KC705 board using Kintex-7 FPGA -2 speed grade device (325T). The core was configured for encoder, decoder, encoder/decoder modes across 4-128 data widths.

Appendix B

Additional Resources

This appendix contains additional resources for the ECC core.

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see the Xilinx Support website at:

www.xilinx.com/support.

For a glossary of technical terms used in Xilinx documentation, see:

www.xilinx.com/company/terms.htm.

References

These documents provide supplemental material useful with this product guide:

1. R. W. Hamming. 1950. "Error Detecting and Error Correcting Codes," *Bell System Technical Journal*.
2. M. Y. Hsiao. 1970. "A Class of Optimal Minimum Odd-weight-column SEC-DED Codes," *IBM Journal of Research and Development*.
3. Vivado™ Design Suite user documentation (www.xilinx.com/cgi-bin/docs/rdoc?v=2012.3;t=vivado+docs)

Technical Support

Xilinx provides technical support at www.xilinx.com/support for this LogiCORE™ IP product when used as described in the product documentation. Xilinx cannot guarantee timing, functionality, or support of product if implemented in devices that are not defined in the

documentation, if customized beyond that allowed in the product documentation, or if changes are made to any section of the design labeled DO NOT MODIFY.

See the IP Release Notes Guide (XTP025) for more information on this core. For each core, there is a master Answer Record that contains the Release Notes and Known Issues list for the core being used. The following information is listed for each version of the core:

- New Features
- Resolved Issues
- Known Issues

Revision History

The following table shows the revision history for this document.

Date	Version	Revision
10/16/2012	1.0	Initial Xilinx release.

Notice of Disclaimer