

ALTMEMPHY Megafunction

User Guide



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About this User Guide

Revision History The table below displays the revision history for the chapters in this User Guide.

Date/Version	Changes Made	Summary of Changes
June 2007, v3.0	Updated to include Arria™ GX and changes included in the Quartus® II software version 7.1.	—
March 2007, v2.0	Updated to included Cyclone III information.	—
February 2007, v1.0	Initial release.	—

How to Contact Altera

For the most up-to-date information about Altera® products, refer to the following table.








Contact (1)	Contact Method	Address
Technical support	Website	www.altera.com/support
Technical training	Website	www.altera.com/training
	Email	custrain@altera.com
Product literature	Website	www.altera.com/literature
Altera literature services	Email	literature@altera.com
Non-technical support (General) (Software Licensing)	Email	nacomp@altera.com
	Email	authorization@altera.com

Note to table:

(1) You can also contact your local Altera sales office or sales representative.

Typographic Conventions

This document uses the typographic conventions shown below.

Visual Cue	Meaning
Bold Type with Initial Capital Letters	Command names, dialog box titles, checkbox options, and dialog box options are shown in bold, initial capital letters. Example: Save As dialog box.
bold type	External timing parameters, directory names, project names, disk drive names, filenames, filename extensions, and software utility names are shown in bold type. Examples: f_{MAX} , lqdesigns directory, d: drive, chiptrip.gdf file.
<i>Italic Type with Initial Capital Letters</i>	Document titles are shown in italic type with initial capital letters. Example: <i>AN 75: High-Speed Board Design</i> .
<i>Italic type</i>	Internal timing parameters and variables are shown in italic type. Examples: <i>t_{PIA}</i> , <i>n + 1</i> . Variable names are enclosed in angle brackets (< >) and shown in italic type. Example: <file name>, <project name>.pof file.
Initial Capital Letters	Keyboard keys and menu names are shown with initial capital letters. Examples: Delete key, the Options menu.
“Subheading Title”	References to sections within a document and titles of on-line help topics are shown in quotation marks. Example: “Typographic Conventions.”
Courier type	Signal and port names are shown in lowercase Courier type. Examples: data1, tdi, input. Active-low signals are denoted by suffix n, e.g., resetn. Anything that must be typed exactly as it displays is shown in Courier type. For example: c:\qdesigns\tutorial\chiptrip.gdf. Also, sections of an actual file, such as a Report File, references to parts of files (e.g., the AHDL keyword SUBDESIGN), as well as logic function names (e.g., TRI) are shown in Courier.
1., 2., 3., and a., b., c., etc.	Numbered steps are used in a list of items when the sequence of the items is important, such as the steps listed in a procedure.
	Bullets are used in a list of items when the sequence of the items is not important.
	The checkmark indicates a procedure that consists of one step only.
	The hand points to information that requires special attention.
	A caution calls attention to a condition or possible situation that can damage or destroy the product or the user's work.
	A warning calls attention to a condition or possible situation that can cause injury to the user.
	The angled arrow indicates you should press the Enter key.
	The feet direct you to more information on a particular topic.

Device Family Support

Megafunctions provide either full or preliminary support for target Altera® device families, as described below:

- *Full support* means the megafunction meets all functional and timing requirements for the device family and may be used in production designs.
- *Preliminary support* means the megafunction meets all functional requirements, but may still be undergoing timing analysis for the device family.

Tables 1–1 and 1–2 show the level of support offered by the ALTMEMPHY megafunction for each Altera device family.

Table 1–1. Half-Rate and Full-Rate Support

Device Family	Half Rate	Full Rate
Stratix® III	✓	No
Cyclone® III	✓	✓
Stratix II/Stratix II GX	✓	✓
HardCopy® II	✓	✓
Arria™ GX	✓	✓

Table 1–2. Memory Support (Part 1 of 2)

Device Family	Memory Type	Support
Stratix III	DDR/DDR2/DDR3/QDRII/QDRII+	Preliminary
Cyclone III	DDR/DDR2	Preliminary
Cyclone III	DDR3/QDRII/QDRII+	No Support
Stratix II/Stratix II GX	DDR/DDR2	Full
Stratix II/Stratix II GX	DDR3/QDRII/QDRII+	No Support
HardCopy II	DDR/DDR2	Preliminary

Table 1–2. Memory Support (Part 2 of 2)

Device Family	Memory Type	Support
Arria GX	DDR/DDR2	Full
Arria GX	DDR3/QDRII/QDRII+	No Support

Glossary

To understand the functionality of the ALTMEMPHY megafunction, refer to the Glossary of Terms shown in [Table 1–3](#).

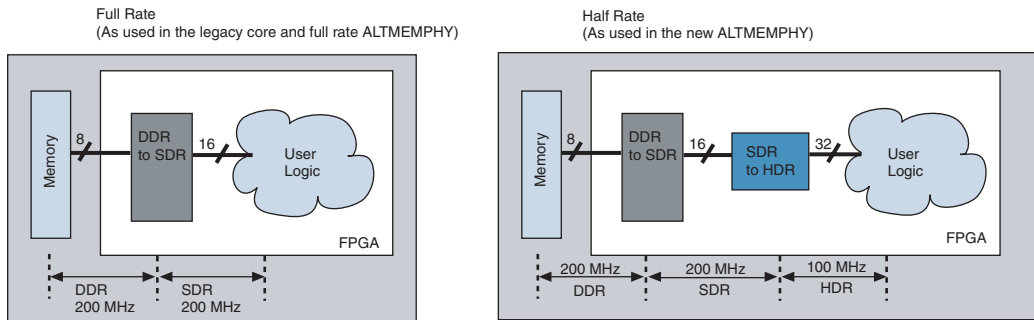
Table 1–3. Glossary of Terms (Part 1 of 2)

Term	Description
Sequencer	The logic block that performs calibration and tracking operations.
Calibration	The process of setting up the initial relationship between a clock; for example, the resynchronization clock and a data valid window (DVW) to provide the greatest timing margin. This calibration is done only once at system reset. This is also referred to as “Initial Calibration.”
Tracking	This is performed as a background process that tracks voltage and temperature (VT) variations to maintain the relationship between the resynchronization clock and the data valid window that was achieved at calibration.
Full-rate clock mode	Clock frequency of the controller and user-interface logic is the same as the memory interface clock (see Figure 1–1).
Half-rate clock mode	Clock frequency of the controller and user-interface logic is half that of the memory interface clock (see Figure 1–1).
Full-rate clock	Clock with a frequency equal to that of the memory interface clock.
Half-rate clock	Clock with a frequency equal to half that of the memory interface clock.
Half-rate controller	A memory controller implemented using the half-rate clock.
Full-rate controller	A memory controller implemented using the full-rate clock.
DDR (Double-data rate)	Data that changes on both edges of a clock or strobe operating at the full-rate clock frequency.

<i>Table 1–3. Glossary of Terms (Part 2 of 2)</i>	
Term	Description
SDR (Single-data rate)	Data that changes on one edge of the full-rate clock (twice the width of DDR data).
HDR (Half-data rate)	Data that changes on one edge of the half-rate clock (twice the width of SDR data and four times the width of DDR data).
Legacy core	The integrated PHY and controller core with no support for calibration and tracking (for example, DDR and DDR2 SDRAM Controller Compiler function).

Figure 1–1 shows the differences in the datapath width and the frequency at which the data is handled between full-rate and half-rate controllers.

Figure 1–1. Full-Rate and Half-Rate Controller Description



Introduction

Altera’s ALTMEMPHY megafunction allows the rapid creation of a physical layer interface (PHY) in Stratix II/Stratix II GX, Stratix III, Cyclone III, HardCopy II, and Arria GX devices. The PHY safely transfers data between memory and user logic. The easy-to-use ALTMEMPHY megafunction GUI enables the rapid configuration of the highly configurable PHY. The ALTMEMPHY megafunction can be used with either a user-designed controller or with the Altera DDR and DDR2 SDRAM high-performance controllers. The ALTMEMPHY megafunction can be configured either to support a full-rate or a half-rate controller.

The major advantage of the new ALTMEMPHY megafunction is that it supports an initial calibration sequence to remove process variations in the FPGA and memory device. During operation, the voltage and

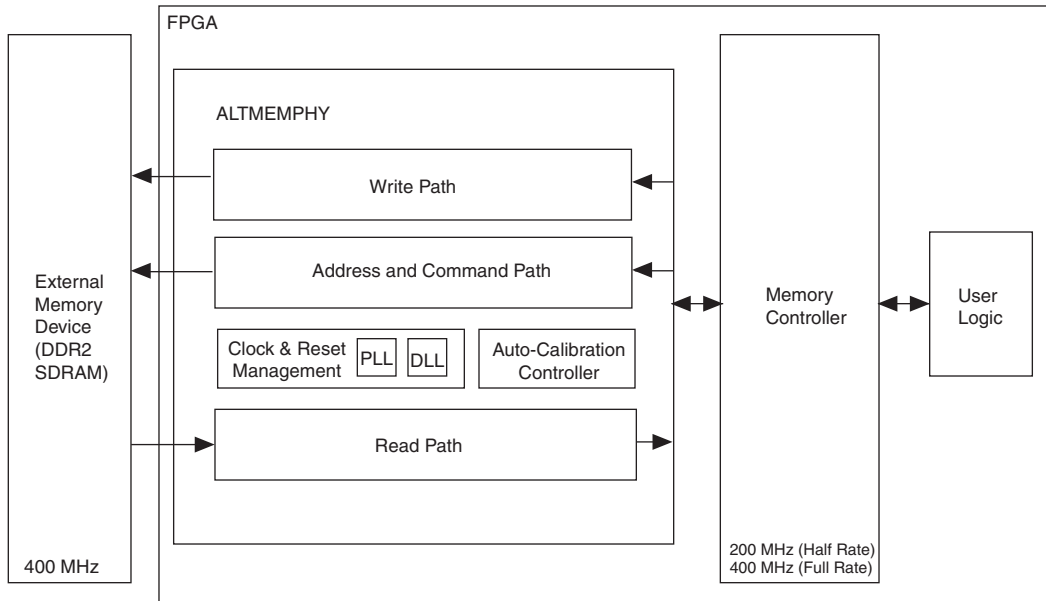
temperature (VT) tracking mechanism eliminates the effects on timing margin of VT variation. The calibration process centers the resynchronization clock phase into the middle of the data valid window to maximize the setup and hold margin.



Go to <http://www.altera.com/literature/tb/tb-091.pdf> for selection criteria such as whether to use the legacy DDR/DDR2 SDRAM controller or the DDR/DDR2 SDRAM High-Performance Controller with the ALTMEMPHY megafunction.

Figure 1–2 shows the major blocks of the ALTMEMPHY megafunction and how it interfaces with the external memory device and the controller.

Figure 1–2. Major Blocks of the ALTMEMPHY Megafunction Interfacing with Controller and External Memory
Note (1)



Note to Figure 1–2:

- (1) DDR2 at 400 MHz is shown here only as an example. You should ensure that your FPGA and external memory combination can achieve your target speed.

The ALTMEMPHY megafunction is used as an interface between the memory controller and the memory devices to perform read and write operations to the memory. The megafunction is available as a stand-alone product or as an integrated product with the high-performance memory controllers. As a stand-alone product, you can use ALTMEMPHY with either custom or third-party controllers. The ALTMEMPHY megafunction is composed of the following functional units:

- Read datapath
- Write datapath
- Address and command datapath
- Clock and reset management
- Auto-calibration controller

A detailed explanation of the functional units is presented in [“Specifications” on page 3-1](#).

Support Matrix

The ALTMEMPHY megafunction support matrices for Stratix III, Stratix II, Stratix II GX, Arria GX, and Cyclone III are shown in [Tables 1-4 through 1-7](#).



The performance numbers correspond to the highest speed grade of the device family.

Table 1-4. ALTMEMPHY Megafunction Support Matrix for Stratix III			
Memory Type	Stratix III	Maximum Supported Frequency (Half Rate)	Maximum Supported Frequency (Full Rate)
DDR SDRAM	Preliminary	200 MHz	No Support
DDR2 SDRAM	Preliminary	400 MHz	No Support
DDR3 SDRAM	Preliminary	400 MHz	No Support
QDRII/QDRII+	Preliminary	350 MHz	No Support

Table 1-5. ALTMEMPHY Megafunction Support Matrix for Stratix II and Stratix II GX			
Memory Type	Stratix II Stratix II GX	Maximum Supported Frequency (Half Rate)	Maximum Supported Frequency (Full Rate)
DDR SDRAM	Full	200 MHz	200 MHz
DDR2 SDRAM	Full	333 MHz	233 MHz

Table 1–6. ALTMEMPHY Megafunction Support Matrix for Arria GX			
Memory Type	Arria GX	Maximum Supported Frequency (Half Rate)	Maximum Supported Frequency (Full Rate)
DDR SDRAM	Preliminary	200 MHz	200 MHz
DDR2 SDRAM	Preliminary	233 MHz	167MHz

Table 1–7. ALTMEMPHY Megafunction Support Matrix for Cyclone III			
Memory Type	Cyclone III	Maximum Supported Frequency (Half Rate)	Maximum Supported Frequency (Full Rate)
DDR SDRAM	Preliminary	200 MHz	125 MHz
DDR2 SDRAM	Preliminary	200 MHz	125 MHz

Features

When compared to the Static PHY, the ALTMEMPHY megafunction offers the following:

- Simple setup
- Automated calibration eliminates complicated data capture timing calculations
- VT tracking guarantees maximum stable performance
- Self-contained datapath makes connection to Altera controller or third-party controller independent of the critical timing paths
- Can be configured to integrate with either a full-rate or a half-rate controller

Resource Utilization and Performance

Tables 1–8 through 1–14 show the typical size (half rate and full rate) of the ALTMEMPHY megafunction in Stratix II, Stratix III, Cyclone III, and Arria GX devices.

Table 1–8. ALTMEMPHY Megafunction Resource Usage in Stratix II Devices (Half Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M512K Blocks	M4K Blocks
64	256	1052	1869	4	12
72	288	1123	2030	3	13

Table 1–9. ALTMEMPHY Megafunction Resource Usage in Stratix II Devices (Full Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M512K Blocks	M4K Blocks
64	128	794	1075	3	7
72	144	864	1144	3	7

Table 1–10. ALTMEMPHY Megafunction Resource Usage in Stratix III Devices (Half Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	Memory ALUTs
64	256	1423	1896	5
72	288	1540	2047	6

Table 1–11. ALTMEMPHY Megafunction Resource Usage in Cyclone III Devices (Half Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M9K Blocks
64	256	2647	1905	13
72	288	2762	1301	13

Table 1–12. ALTMEMPHY Megafunction Resource Usage in Cyclone III Devices (Full Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M9K Blocks
64	128	1664	1123	7
72	144	1782	1209	7

Table 1–13. ALTMEMPHY Megafunction Resource Usage in Arria GX Devices (Half Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M512K Blocks	M4K Blocks
64	256	1122	1883	4	12
72	288	1193	2044	3	13

Table 1–14. ALTMEMPHY Megafunction Resource Usage in Arria GX Devices (Full Rate)

Memory Width (Bits)	Local Width (Bits)	Combinational ALUTs	Dedicated Logic Registers	M512K Blocks	M4K Blocks
64	128	855	1088	4	12
72	144	901	1164	3	13

System Requirements

The instructions in this section require the following hardware and software:

- For OS Support information, refer to:

http://www.altera.com/support/software/os_support/oss-index.html

- The Quartus® II software version 7.1 or higher

MegaWizard Plug-In Manager Customization

Use the MegaWizard® Plug-In Manager to specify the ALTMEMPHY megafunction in your design. Start the MegaWizard Plug-In Manager in one of the following ways:

- On the **Tools** menu, click **MegaWizard Plug-In Manager**.
- When working in the Block Editor, click **MegaWizard Plug-In Manager** in the **Symbol** dialog box.
- Start the stand-alone version of the MegaWizard Plug-In Manager by typing the following command at the command prompt: `qmegawiz`.



The ALTMEMPHY megafunction is also instantiated when the high-performance controller is generated using the MegaWizard Plug-In Manager. There is no need to launch the ALTMEMPHY MegaWizard Plug-In Manager separately. Refer to “[Compiling in the Quartus II Software](#)” on page 2–16 for more details.



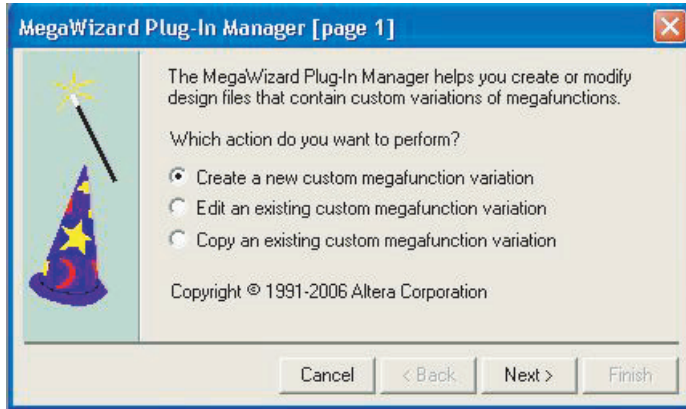
Refer to Quartus II Help for more information on how to use the MegaWizard Plug-In Manager.

MegaWizard Page Descriptions

This section provides descriptions of the options available on the ALTMEMPHY MegaWizard Plug-In Manager pages.

On page 1 of the MegaWizard Plug-In Manager, select **Create a new custom megafunction variation** from the three available options shown in [Figure 2-1](#) and click **Next**.

Figure 2-1. MegaWizard Plug-In Manager [page 1]

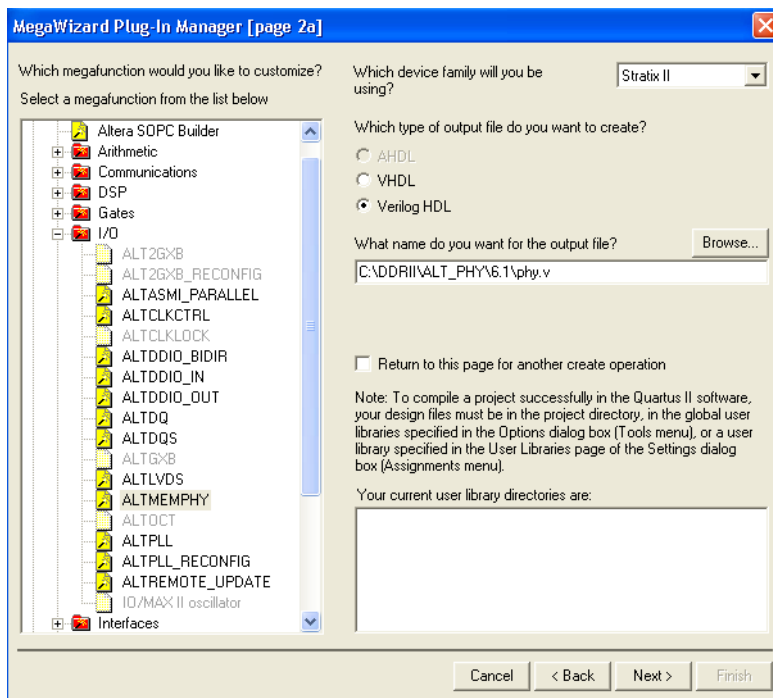


On page 2a of the MegaWizard Plug-In Manager, select **ALTMEMPHY** by expanding the **I/O** section in the **Megafunction** list. Select the appropriate device family, output file type, and name of your output file.

[Figure 2-2](#) shows an example of an **ALTMEMPHY** megafunction named *phy.v*.



The *<variation name>* must be a different name from the project name and the top-level design entity name.

Figure 2–2. MegaWizard Plug-In Manager [page 2a]

Click **Next** to launch the **ALTMEMPHY Parameter Settings** page (Figure 2–3).

Figure 2–3 shows the **ALTMEMPHY Parameter Settings** page. By clicking on the appropriate tab, this page allows you to parameterize:

- Memory settings
- PHY settings

Figure 2–3. ALTMEMPHY Parameter Settings Page

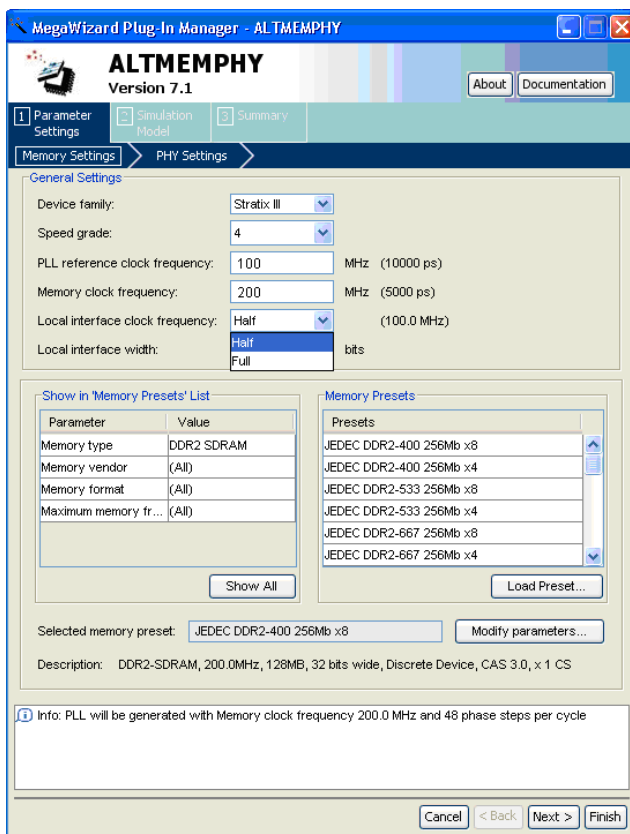


Table 2–1 describes the General Settings available on the **Memory Settings** page of the ALTMEMPHY wizard.

Parameter Name	Description
Device family	Name of the device family (for example, Stratix® II).
Speed grade	Speed grade of the device (for example, 3, 4, 5).
PLL reference clock frequency	Clock frequency of the external input clock to the PLL.

<i>Table 2–1. General Settings (Part 2 of 2)</i>	
Parameter Name	Description
Memory clock frequency	Memory interface clock frequency.
Local interface clock frequency	Set the frequency equal to either the memory interface frequency (Full) or half of the memory interface frequency (Half).

Table 2–2 describes the options available to filter the Memory Presets that are displayed.

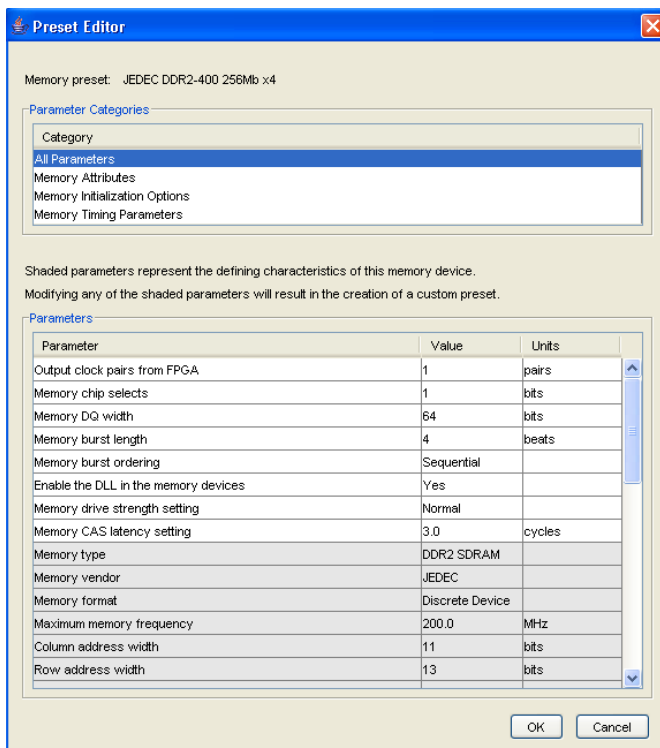
<i>Table 2–2. Memory Presets List</i>	
Parameter Name	Description
Memory type	Allows you to filter the type of memory to display (for example, DDR2 SDRAM).
Memory vendor	Allows you to filter the memory types by vendor. JEDEC is also one of the options, allowing you to choose the JEDEC specifications.
Memory format	Allows you to filter the type of memory by format (for example, discrete devices or dual in-line memory module [DIMM] packages).
Maximum frequency	Allows you to filter the type of memory by maximum operating frequency.

Click the **Modify Parameters** button to parameterize (Figure 2–4):

- All parameters
- Memory attributes
- Memory initialization options
- Memory timing parameters

Tables 2–3 to 2–5 describe the DDR/DDR2 parameters available for each of the above three options.

Figure 2–4. ALTMEMPHY Memory Parameters Note (1)



Note to Figure 2–4:

- (1) The parameters with a white background can be changed. The parameters with a gray background are characteristics of the memory and changing them will create a new custom memory preset.

Table 2–3. Memory Initialization Options (Part 1 of 2)

Parameter Name	Range	Units	Description
Memory burst length	4	beats	The megafunction supports only burst sizes of one on the local interface, which equates to four on the memory interface. For the half-rate controller, the megafunction supports burst sizes of both 1 and 2 on the local side.
Memory burst ordering	Sequential or Interleaved	—	This option controls the order in which data is transferred between memory and the FPGA during a read transaction.

Table 2–3. Memory Initialization Options (Part 2 of 2)

Parameter Name	Range	Units	Description
Enable the DLL in the memory devices	On or Off	—	When turned on, the DLL within the memory device is enabled. The default option is yes.
Memory drive strength setting	Normal or Reduced	—	Controls the drive strength of the memory device's output buffers. Reduced drive strength is not supported on all memory devices. The default option is normal.
Memory CAS latency setting	2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0	Cycles	The delay in clock cycles from the read command to the first output data from the memory.
Memory latency setting	1.5 for QDRII and 2.0, 2.5 for QDRII+	Cycles	Defines the memory read latency.

Table 2–4. Memory Attributes Settings (Part 1 of 2)

Parameter Name	Range (1)	Units	Description
Memory vendor	—	—	Name of the memory vendor.
Maximum frequency supported by memory	See the memory device datasheet	MHz	Maximum frequency supported by the memory.
Column address width	8–13	bits	The number of column address bits for your memory.
Row address width	10–14	bits	The number of row address bits for your memory.
Bank address width	2 or 3	bits	The number of bank address bits for your memory.
Output clock pairs from FPGA	1–6	integer	The number of differential clock pairs driven from the FPGA to the memory. More clock pairs reduce the loading of each output.
Chip selects per DIMM	1–8	—	The number of chip selects on each DIMM in your memory system.
DQ bits per DQS bit	4 or 8	bits	The number of data (DQ) bits for each data strobe (DQS) pin.
Precharge all address bit	8 or 10	—	The bit of the address bus to use as the precharge “all” address bit.
Memory chip selects	1, 2, 4, or 8	—	The number of chip selects in your memory interface. This is the depth of your memory in terms of number of chips.

Table 2–4. Memory Attributes Settings (Part 2 of 2)

Parameter Name	Range (1)	Units	Description
Memory DQ width	≥ 4	bits	Number of DQ pins on the memory interface.

Note to **Table 2–4**:

(1) The range values depend on the memory used.

Table 2–5. Memory Timing Parameter Settings Note (1) (Part 1 of 2)

Parameter Name	Range	Units	Description
(t_{INT})	0.001–1000	μs	Minimum memory initialization time. After reset, the controller does not issue any commands to the memory during this period.
(t_{MRD})	2–39	ns	Minimum load mode register command period. The controller waits for this period of time after issuing a load mode register command before issuing any other commands.
(t_{RAS})	8–200	ns	Minimum active to precharge time. The controller waits for this period of time after issuing an active command before issuing a precharge command to the same bank.
(t_{RCD})	4–65	ns	Minimum active to read-write time. The controller does not issue read or write commands to a bank during this period of time after issuing an active command.
(t_{RP})	4–65	ns	Minimum precharge command period. The controller does not access the bank for this period of time after issuing a precharge command.
(t_{REFI})	1–65534	μs	Maximum interval between refresh commands. The controller performs regular refresh at this interval unless user-controlled refresh is turned on.
(t_{RFC})	14–1651	ns	Minimum auto-refresh command period. The length of time the controller waits before doing anything else after issuing an auto-refresh command.
(t_{WR})	4–65	ns	Minimum write recovery time. The controller waits for this period of time after the end of a write transaction before issuing a precharge command.
(t_{WTR})	2–39	t_{CK}	Minimum write-to-read command delay. The controller waits for this period of time after the end of a write command before issuing a subsequent read command to the same bank. This timing parameter is specified in clock cycles and the value is rounded off to the next integer.
(t_{AC})	300–750	ps	DQ output access time.
(t_{DHA})	10–600	ps	DQ and DM input hold time relative to DQS.
(t_{DQSQ})	100–500	ps	The maximum DQS to DQ skew; DQS to last DQ valid, per group, per access.

Table 2-5. Memory Timing Parameter Settings Note (1) (Part 2 of 2)

Parameter Name	Range	Units	Description
(t_{DQSS})	0–0.3	t_{CK}	Positive DQS latching edge to associated clock edge (t_{CK}).
(t_{DSA})	10–600	ps	DQ and DM input setup time relative to DQS (ps).
(t_{DSH})	0.1–0.5	t_{CK}	DQS falling edge to CK rising - hold time (t_{CK}).
(t_{DSS})	0.1–0.5	t_{CK}	DQS falling edge to CK rising - setup time (t_{CK}).
(t_{IHA})	100–1000	ps	Address and control input hold time (ps).
(t_{ISA})	100–1000	ps	Address and control input setup time (ps).
(t_{QHS})	100–700	ps	The maximum data hold skew factor.

Note to **Table 2-5**:

(1) See the memory device datasheet for the parameter range.

Tables 2-6 to 2-8 describe the QDRII/QDRII+ SRAM parameters available for each of the following three options.

- Memory initialization options
- Memory attribute settings
- Memory timing parameter settings

Table 2-6. Memory Initialization Options

Parameter Name	Range	Units	Description
Memory burst length	4	beats	The megafunction supports only burst sizes of one on the local interface, which equates to four on the memory interface.
Memory latency setting	1.5	Cycles	1.5 for QDRII; 2.0 and 2.5 for QDRII+.

Table 2-7. Memory Attribute Settings (Part 1 of 2)

Parameter Name	Range (1)	Units	Description
Memory vendor	—	—	Name of the memory vendor.
Maximum memory frequency	See the memory device datasheet	MHz	Maximum frequency supported by the memory.
Output clock pairs from FPGA	1-16	integer	The number of differential clock pairs driven from the FPGA to the memory. More clock pairs reduce the loading of each output.

Parameter Name	Range (1)	Units	Description
Memory depth expansion	1-2	chips	Number of chip selects of memory supported. This option is used for memory depth expansion.
Drive BWS_N/NWS_N from FPGA	No, Yes	—	Set to YES if logic is required to drive the Write Select inputs of the memory devices.
DQ bits per chip	8, 9, 18, 36	bits	Width of D/Q databus on each QDRII chip.
Memory DQ data bits	8-288	bits	Width of external memory read and write databus.
Address width	15-25	bits	Number of address bits.
I/O Standard	1.8 V for QDRII 1.8 V or 1.5 V HSTL for QSRII+	—	I/O standard to be applied to the memory interface pins.

Note to **Table 2–7**:

(1) The range values depend on the memory used.

Parameter Name	Range	Units	Description
(t _{SA})	200-500	ps	Address setup time to K clock rise.
(t _{SC})	200-500	ps	Control setup time to K clock rise.
(t _{HA})	200-500	ps	Address hold time to K clock rise.
(t _{HC})	200-500	ps	Control hold time after K clock rise.
(t _{SD})	200-500	ps	D setup time to K clock rise.
(t _{HD})	200-500	ps	D hold time to K clock rise.
(t _{COHQV})	200-500	ps	Echo clock high to data valid.
(t _{COHOX})	200-500	ps	Echo clock high to data invalid.

PHY Settings

Click the **PHY Settings** tab (Figure 2–5) to set the options described in Table 2–9.

Figure 2–5. ALTMEMPHY PHY Parameter Settings Page

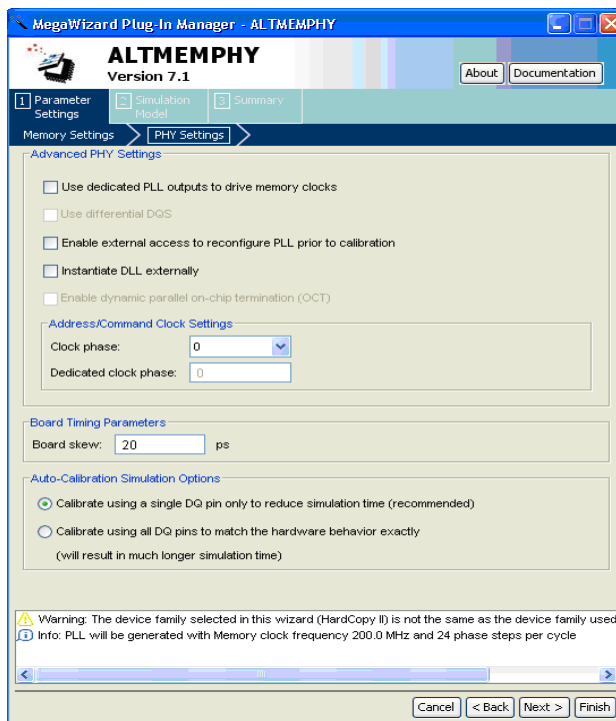


Table 2–9. ALTMEMPHY PHY Settings (Part 1 of 2)

Parameter Name	Description
Use dedicated PLL outputs to drive memory clocks	Turn on to use dedicated PLL outputs to generate the clocks, which is recommended for HardCopy II devices. When turned off, the ALTTDDIO megafunction outputs generate the clock outputs.
Use differential DQS	Enable this feature for better signal integrity. This is applicable to Stratix III devices only.

Table 2–9. ALTMEMPHY PHY Settings (Part 2 of 2)	
Parameter Name	Description
Enable external access to reconfigure PLL prior to calibration	By enabling this option, the inputs to the ALTPLL_RECONFIG is brought to the top level. This option is applicable for HardCopy II devices only. (1)
Instantiate DLL externally	This option allows the DLL to be shared between multiple PHY instances. Enabling this option allows the DLL to be connected externally to the ALTMEMPHY megafunction. (2)
Enable dynamic parallel on-chip termination	This option provides I/O impedance matching and termination capabilities. This is applicable for Stratix III devices and is used for bidirectional signals such as DQ and DQS.
Clock phase	Adjusting the address and command phase can improve the address and command setup and hold margins at the memory device to compensate for the propagation delays that vary with different loadings. Applicable to Stratix III and Cyclone III devices. (3)
Dedicated clock phase	Only applicable to Stratix III devices and should be left to default settings for the Quartus II software version 7.1.
Board skew	The worst case board delay skew between clock DQS and its respective DQ pins (in ps).
Calibrate using a single DQ pin only to reduce simulation time (recommended)	Calibration of the resynchronization clock is done using the data read through one DQ pin. This reduces simulation time. (4)
Calibrate using all DQ pins to match the hardware behavior exactly (will result in much longer simulation time)	Calibration of the resynchronization clock is done using the data read through DQ pins one after another. This results in increased simulation time. (4)

Notes to Table 2–9:

- (1) Refer to “ALTPLL_RECONFIG” on page 3–9 for more information regarding this option.
- (2) Available for the Stratix II device family only.
- (3) Available for the Stratix III and cyclone III device families only.
- (4) This option only affects RTL simulation and not the actual hardware or gate-level simulation.

Click **Next** or click the **Simulation Model** tab (Figure 2–6) to set your Simulation Model settings.

Simulation Model

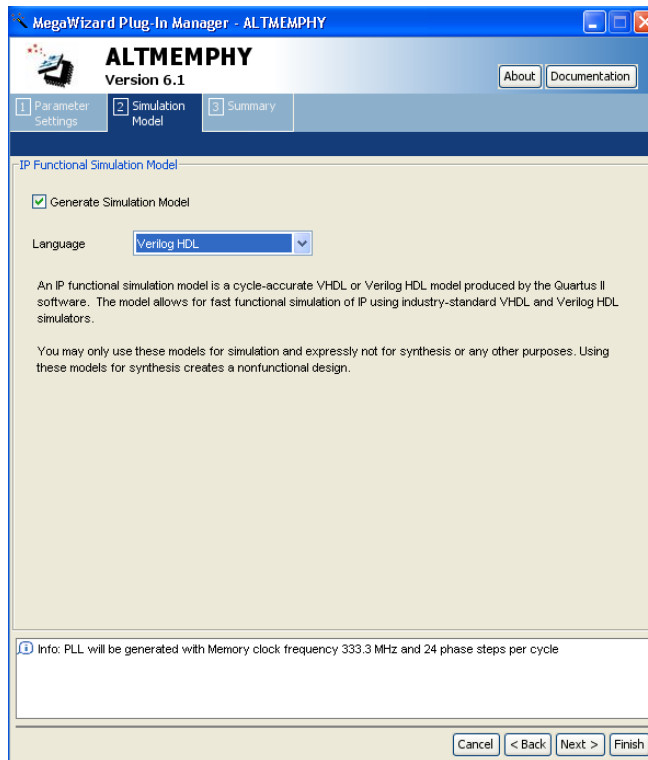
An IP functional simulation model is a cycle-accurate VHDL or Verilog HDL model produced by the Quartus II software (Figure 2–6). The model allows for fast-functional simulation of IP using industry-standard VHDL and Verilog HDL simulators.



You should generate your simulation model in the same language that you are using to generate your megafunction variation. The simulation model that is generated is `<project_dir>\<variation>_alt_mem_phy_sequencer_wrapper.vo/vho`, and is used during the RTL Nativelink simulation. Refer to “[Simulating ALTMEMPHY](#)” on page 2–22 for more information.

Use these simulation model output files for simulation only. Using these files for synthesis creates a nonfunctional design.

Figure 2–6. ALTMEMPHY Simulation Model Generation Page



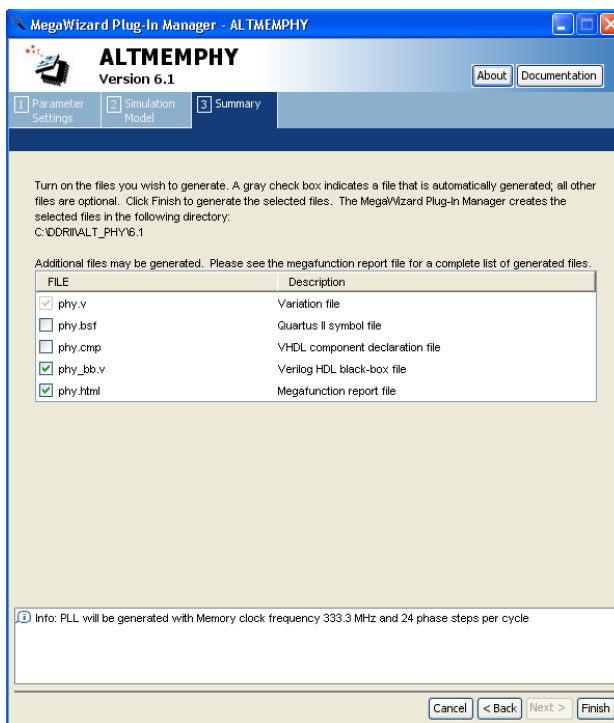
Click **Next** to go to the **Summary** page or click the **Summary** tab (Figure 2–7).

Summary Page

On the **Summary** page (Figure 2–7) of the MegaWizard Plug-In Manager, specify the files you wish to have generated for your custom megafunction. The gray check marks indicate files that are always generated; the other files are optional and are generated only if selected (indicated by a black check mark). Choose from:

- HDL wrapper file, (<variation_name>.v / <variation_name>.vhd)
- Block Symbol file (.bsf)
- VHDL Component declaration file (<variation_name>.cmp)
- Verilog Black Box declaration file (<variation_name>_bb.v).
- Megafunction report file (<variation_name>.html).

Figure 2–7. ALTMEMPHY Summary Page



Inferring Megafunctions from HDL Code

The ALTMEMPHY megafunction cannot be inferred from the HDL code.

Instantiating Megafunctions in HDL Code

When you use the MegaWizard Plug-In Manager to set up and parameterize a megafunction, it creates either a VHDL or Verilog HDL wrapper file that instantiates the megafunction (a black box methodology). Refer to the following for details about how to instantiate a megafunction in your design:

- *Recommended HDL Coding Styles* chapter in volume 1 of the *Quartus II Handbook*.
- *Quartus II Integrated Synthesis* chapter in volume 1 of the *Quartus II Handbook*.

- *Synplicity Synplify and Synplify Pro Support* chapter in volume 1 of the *Quartus II Handbook*.
- *Mentor Graphics Precision RTL Synthesis Support* chapter in volume 1 of the *Quartus II Handbook*.

Compiling in the Quartus II Software

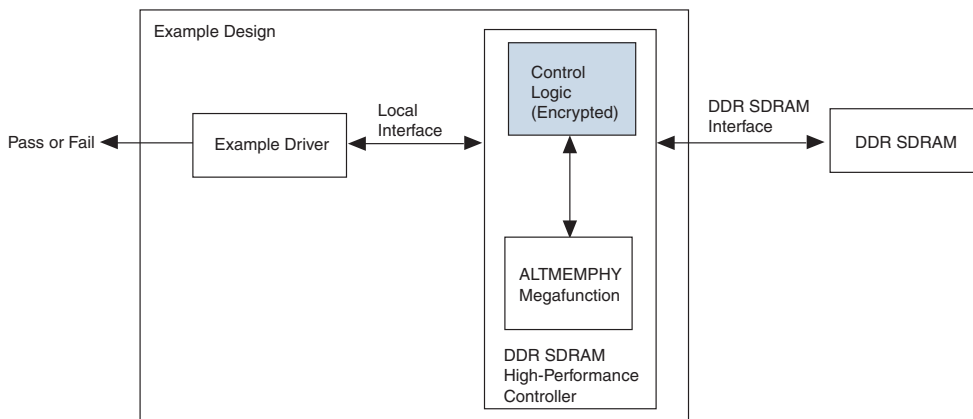
ALTMEMPHY can be compiled as a stand-alone top-level design. The advantage of doing this is that you do not have to create a complete design to check that ALTMEMPHY meets your required target frequency. However, this is only a guide and for a more accurate result, you should use a realistic design. A typical scenario of compiling ALTMEMPHY is either when it is integrated with your own controller or when it is integrated with Altera's DDR/DDR2 SDRAM High-Performance Controller (Figure 2–8).

When using Altera's DDR and DDR2 SDRAM High-Performance Controller, the controller MegaWizard Plug-In Manager generates both ALTMEMPHY and the High-Performance Memory Controller; there is no need to launch the ALTMEMPHY MegaWizard Plug-In Manager separately. The controller MegaWizard Plug-In Manager also generates an example design consisting of:

- ALTMEMPHY
- High-performance memory controller
- Example driver

Each example design can be synthesized and simulated.

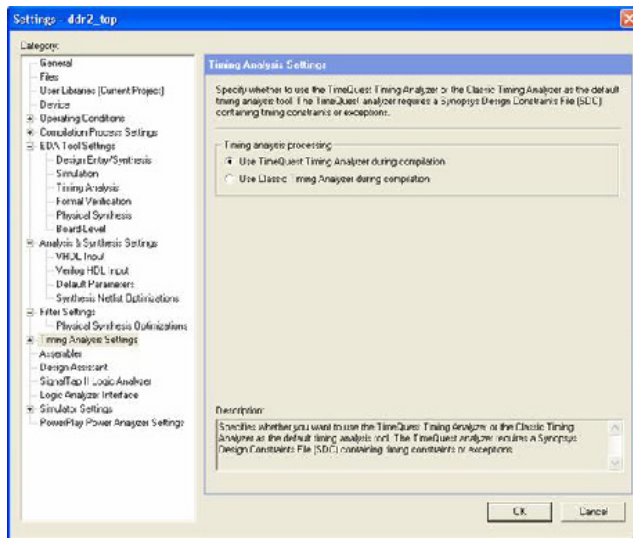
Figure 2–8. DDR SDRAM Controller System-Level Diagram



Perform the following steps before you compile the design:

1. Enable the TimeQuest timing analyzer (Figure 2-9) by selecting the following:
 - a. On the Assignments menu, click **Settings**, expand **Timing Analysis Settings**, and select **Use TimeQuest Timing Analyzer during compilation** and click OK.
 - b. Add the Synopsys design constraints file, *<variation name>_phy_dds_timing.sdc*, to your project. On the Project menu, click **Add/Remove Files in Project** and browse the file.

Figure 2-9. Enabling the TimeQuest Timing Analyzer



2. Add pin I/O standard assignments in one of the following ways:



The I/O standard pin assignment script is not run automatically. As a result, all pins may likely have the wrong I/O standard assigned causing the Quartus II fitter to fail. Therefore, you must run the I/O standard assignment script manually before running the Quartus II fitter.



- a. For Stratix III devices, you must run *<variation name>_pin_assignments.tcl*.

- b. For all other devices, run `<variation name>_pin_assignments.tcl`.



Before running the Tcl scripts, modify the pin names to reflect the pin names in the top-level design.

or follow these steps:

- Edit your top-level design to add a prefix to all DDR or DDR2 signal names. For example, change `mem_ddr` to `core1_mem_addr`.
 - On the Assignments menu, click **Pins**. Right-click in the window and click **Create/Import Megafunction**. Select **Import an existing custom megafunction** and navigate to `<variation name>.ppf`.
 - Type the prefix that you added to your top-level DDR or DDR2 signal names into the **Instance name** box and click **OK**.
3. Set the top-level entity to the example project.
 - a. On the File menu, click **Open**.
 - b. Browse to `<variation name>_example_top.v/vhd` created by the DDR/DDR2 High Performance Controller megafunction or your top-level design file and click **Open**.
 - c. On the Project menu, click **Set as top-level entity**.
 4. On the Processing menu, point to **Start** and click **Start Analysis and Synthesis**.
 5. Assign the DQ and DQS pin groups.
 - a. For Stratix III devices only, add the DQ group assignments to relate the DQ and DQS pin groups together for the Quartus II fitter to place them correctly, by running `<variation name>_assign_dq_groups.tcl`.
-  Before running the Tcl scripts, modify the pin names to reflect the pin names in the top level design.
-  For all other families, the following steps are optional.
- b. Manually specify all DQ and **DQS** pins to align your project with your PCB requirements.

or

- c. Manually specify all other project pin locations to align your project with your PCB requirements.



When you are assigning pins, ensure the I/O standard is set to one compatible with your memory device and compatible with the other pins sharing the I/O bank. For example, for the clock source, the reset, and the address and command signals. Also, select which bank or side of the device you want the Quartus II software to place them in.

6. Set the output pin loading for all memory interface pins.
7. Select your required I/O driver strength (derived from simulation) to ensure that you correctly drive each signal and do not suffer from overshoot or undershoot.
8. On the Process menu, click **Start Compilation** to compile the design.
9. *Optional:* Run a report timing to get a detailed DDR SDRAM interface timing report. Run `<variation name>_report_timing.tcl`:
 - a. On the Tools menu, click **Tcl scripts**.

or

- b. On the Tools menu, click **TimeQuest Timing Analyzer**. Go to the left pane and double-click **Read SDC File**, then on the Script menu, select `<variation name>_report_timing.tcl`.



To attach the SignalTap II logic analyzer to your design, refer to *AN 380: Test DDR or DDR2 SDRAM Interfaces on Hardware Using the Example Driver*.

Analyzing Timing

Timing analysis of the ALTMEMPHY megafunction is critical if your hardware is to operate as intended. Timing analysis scripts that are generated along with ALTMEMPHY enable you to perform detailed timing analysis of both core and I/O timing paths, as shown in [Table 2–10](#). Timing analysis of ALTMEMPHY is supported by the TimeQuest static timing analyzer only, for the following reasons:

- The timing constraints scripts generated along with the ALTMEMPHY megafunction supports only the TimeQuest static timing analyzer.

- The Classic Timing Analyzer (TAN) does not offer analysis of source-synchronous outputs; for example, write data, and address and command outputs.



For more information about Timing Analysis, refer to *AN 438: Constraining and Analyzing Timing for External Memory Interfaces*.

Timing Constraints

The MegaWizard Plug-In Manager-generated SDC script file `<variation_name>_ddr_timing.sdc`, found in the project directory, sets the following constraints on the ALTMEMPHY megafunction:

- Creates all the necessary clocks with proper clock periods
- Sets all the board and memory parameter settings
- Sets the output delay on the DQS pins for write analysis
- Sets the input delay on the DQS pins for read analysis
- Sets clock uncertainty for DQS pins versus CK pins timing analysis
- Sets the output delay on the address and command pins
- Sets necessary multicycle path assignments

Timing Analysis Using the TimeQuest Timing Analyzer

This section describes the steps required to perform timing analysis of the ALTMEMPHY megafunction.

1. Generate the ALTMEMPHY megafunction with the desired parameter settings as explained in *“MegaWizard Plug-In Manager Customization”* on page 2-1.
2. Perform the preliminary steps as described in *“Compiling in the Quartus II Software”* on page 2-16.
3. Compile the design.
4. Perform timing analysis. To see the timing report, you can either:
 - Execute the Tcl script with the Quartus II software (by choosing **Tools -> Tcl scripts -> <variation_name>_report_timing.tcl**) or
 - Run the timing analysis inside the TimeQuest timing analyzer by choosing **Tools -> TimeQuest Timing Analyzer**

Inside the TimeQuest tool, double-click on **Update Timing Netlist** to load your design and analyze it. You can now report timing paths by the TimeQuest methods as described in *“Timing Analysis Using the TimeQuest Timing Analyzer”* on page 2-20, or run the Tcl script

`<project_dir>/<variation_name>_report_timing.tcl` by choosing **Tools -> Tcl scripts**, which creates a set of pre-defined reports for the critical paths (refer to [Table 2-10](#)).



Timing analysis of ALTMEMPHY confirms that the ALTMEMPHY megafunction can operate at the desired frequency. The `<project_dir>/<variation_name>_ddr_timing.sdc` script can be used when the top-level design is either ALTMEMPHY alone or when ALTMEMPHY is used along with the controller and user logic.

Timing Paths

[Table 2-10](#) lists the timing paths that are analyzed by the timing `<variation_name>_phy_report_timing.tcl` script.

Table 2-10. ALTMEMPHY Timing Paths (Part 1 of 2)		
Timing Path	Clock	Description
Write datapath	dqs (<code><variation>_phy_ddr_dqsout_mem_dqs</code>)	Setup and hold requirement for the DQ pins with respect to DQS strobe at the memory.
Address and command	mem_clk (<code><variation>_phy_ddr_ck_mem_clk</code>)	Setup and hold requirement for the chip select (<code>cs_n</code>) pin with respect to the <code>mem_clk</code> at the memory.
Half-rate address and command	mem_clk (<code><variation>_phy_ddr_ck_mem_clk</code>)	Setup and hold requirement for the address and command (except <code>cs_n</code>) pins with respect to <code>mem_clk</code> clock at the memory.
Read capture	dqs (<code><variation>_phy_ddr_dqsin_mem_dqs[]</code>)	Setup and hold requirement for the DQ pins with respect to DQS strobe at the FPGA capture registers.
Resynchronization	Resynchronization clock (<code><variation>_phy_ddr_resync</code>)	Setup and hold requirement for the DQ data with respect to resynchronization clock at the resynchronization registers.
Core	Internal clocks	Internal timing of the controller and ALTMEMPHY.

Table 2–10. ALTMEMPHY Timing Paths (Part 2 of 2)

Timing Path	Clock	Description
Postamble	Postamble clock (<variation>_phy_ ddr_delayed_dqs)	Setup and hold requirements for the postamble-enable registers with respect to the postamble clock.
Mimic path	Measure clock (<variation>_phy_ ddr_mimic)	Placement and routing of the mimic path register with respect to the mem_ck output pins, such that it matches the resynchronization path.



For more information about timing paths analyzed, refer to *AN 438: Constraining and Analyzing Timing for External Memory Interfaces*.

Simulating ALTMEMPHY

The ALTMEMPHY megafunction cannot be simulated on its own. To simulate the ALTMEMPHY megafunction, you will need the following:

- Memory controller
- Example driver (to initiate read and write transactions)
- Testbench and a suitable memory model

If you generate the high-performance controller using the MegaWizard Plug-In Manager, it will also generate a testbench that can be simulated using Altera-supported third-party simulators.

Simulation of the ALTMEMPHY megafunction is supported through Nativelink, whether in the context of Altera’s example design or your own design.



Refer to the *High-Performance Controller User Guide* to learn more about simulating the example design that instantiates the ALTMEMPHY megafunction.

Integrating User Logic with ALTMEMPHY and High-Performance Controller

The ALTMEMPHY megafunction is the only PHY supported by Altera’s high-performance DDR/SDRAM memory controllers. Perform the following steps to integrate your logic with the Altera high-performance controller and the ALTMEMPHY megafunction.

1. Generate the high-performance controller either by selecting **DDR** or **DDR2 SDRAM High-Performance Controller** using the MegaWizard Plug-In Manager, as shown in [Figure 2-10](#). The MegaWizard Plug-In Manager generates files for both the controller and the ALTMEMPHY megafunction.

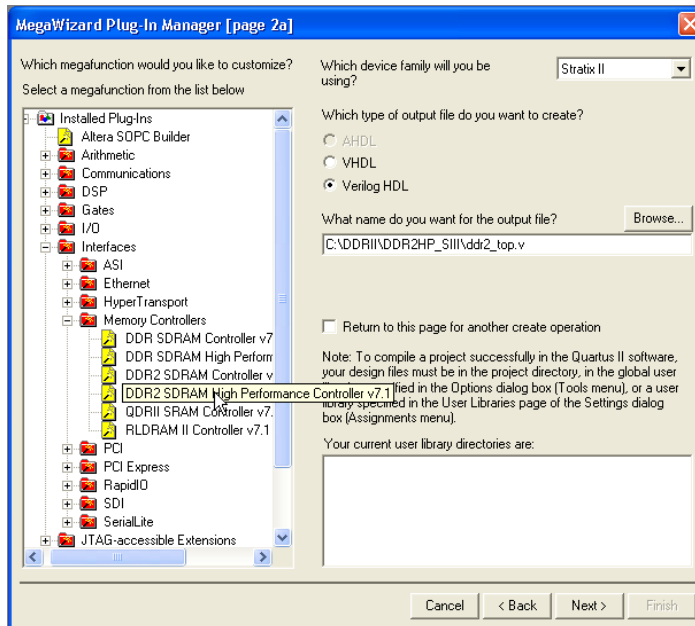


Refer to the *High-Performance Controller User Guide* for more information about the files generated.



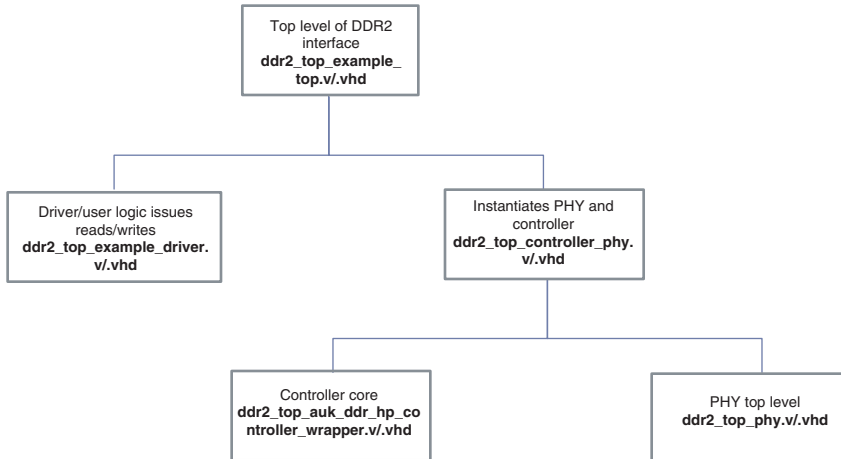
For more information, refer to “[Integrating ALTMEMPHY with Your Own Controller](#)” on page 3-36.

Figure 2-10. Generating the SDRAM High-Performance Controller



The hierarchy of the top-level design generated by the MegaWizard Plug-In Manager is shown in [Figure 2–11](#).

Figure 2–11. Hierarchy of the Top-Level Design



As shown in [Figure 2–11](#), the top-level design instantiates the instance `ddr2_top_controller_phy`, which in turn instantiates and integrates ALTMEMPHY and the controller.

2. Integrate your driver logic with the controller and ALTMEMPHY.



The top-level design generated by the MegaWizard Plug-In Manager has an example driver. Remove that driver and integrate your driver logic.

3. Complete synthesis and simulation.



For more information about Steps 2 and 3, refer to the *High-Performance Controller User Guide*.

Stratix II Support for DDR/DDR2 SDRAM

This chapter describes the operation of different blocks of the ALTMEMPHY megafunction based on the supported FPGA families.

The following sections describe the ALTMEMPHY megafunction support for Stratix® II DDR/DDR2 SDRAM.

Half-Rate Support

The following section discusses half-rate support.

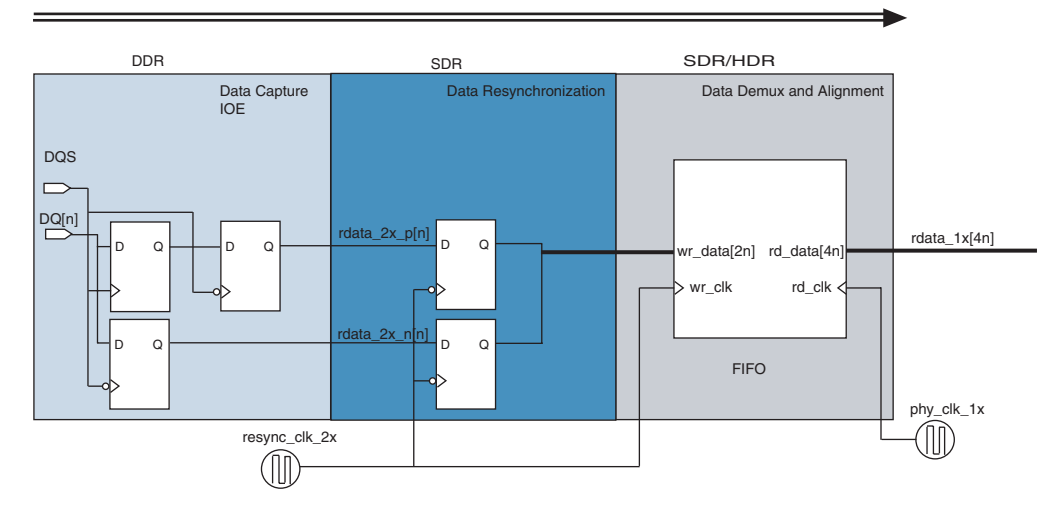
Read Datapath

The read datapath logic is responsible for capturing data sent by the memory device and subsequently aligning the data back to the system clock domain. The functions performed by the read datapath are:

1. Data capture and resynchronization
2. Data demultiplexing
3. Data alignment

Figure 3–1 shows the order of the functions performed by the read datapath, along with the frequency at which the read data is handled.

Figure 3–1. Read Datapath



Data Capture and Resynchronization

Data capture and resynchronization is the process of capturing the read data (DQ) with the DQS strobe and re-synchronizing the captured data to an internal free-running full-rate clock supplied by the enhanced phase-locked loop (PLL).

The resynchronization clock is an intermediate clock whose phase shift is determined during the calibration stage.

Timing constraints are used to ensure that the data resynchronization registers are placed close to the DQ pins to achieve maximum performance. Timing constraints are also used to further limit skew across the DQ pins. The captured data (`rdata_2x_p` and `rdata_2x_n`) is synchronized to the resynchronization clock (`resync_clk_2x`), as shown in the [Figure 3–1](#).

Data Demultiplexing

Data demultiplexing is the process of converting single-data rate (SDR) data into half-data rate (HDR) data. Data demultiplexing is required to bring the frequency of the resynchronized data down to the frequency of the system clock, so that data from the external memory device can ultimately be brought into the FPGA DDR/DDR2 SDRAM controller clock domain. Before data capture, the data is DDR and n -bit wide. After

data capture, the data is SDR and $2n$ -bit wide. After data demuxing, the data is HDR of width $4n$ -bits wide. The system clock frequency is half the frequency of the memory clock.

Demultiplexing is achieved using a dual-port memory with a $2n$ -bit wide write-port operating on the resynchronization clock (SDR) and a $4n$ -bit wide read-port operating on the PHY clock (HDR). The basic principle of operation is that data is written to the memory at the SDR rate and read from the memory at the HDR rate while incrementing the read- and write-address pointers. As the SDR and HDR clocks are generated, the read and write pointers are continuously incremented by the same PLL, and the $4n$ -bit wide read data follows the $2n$ -bit wide write data with a constant latency.

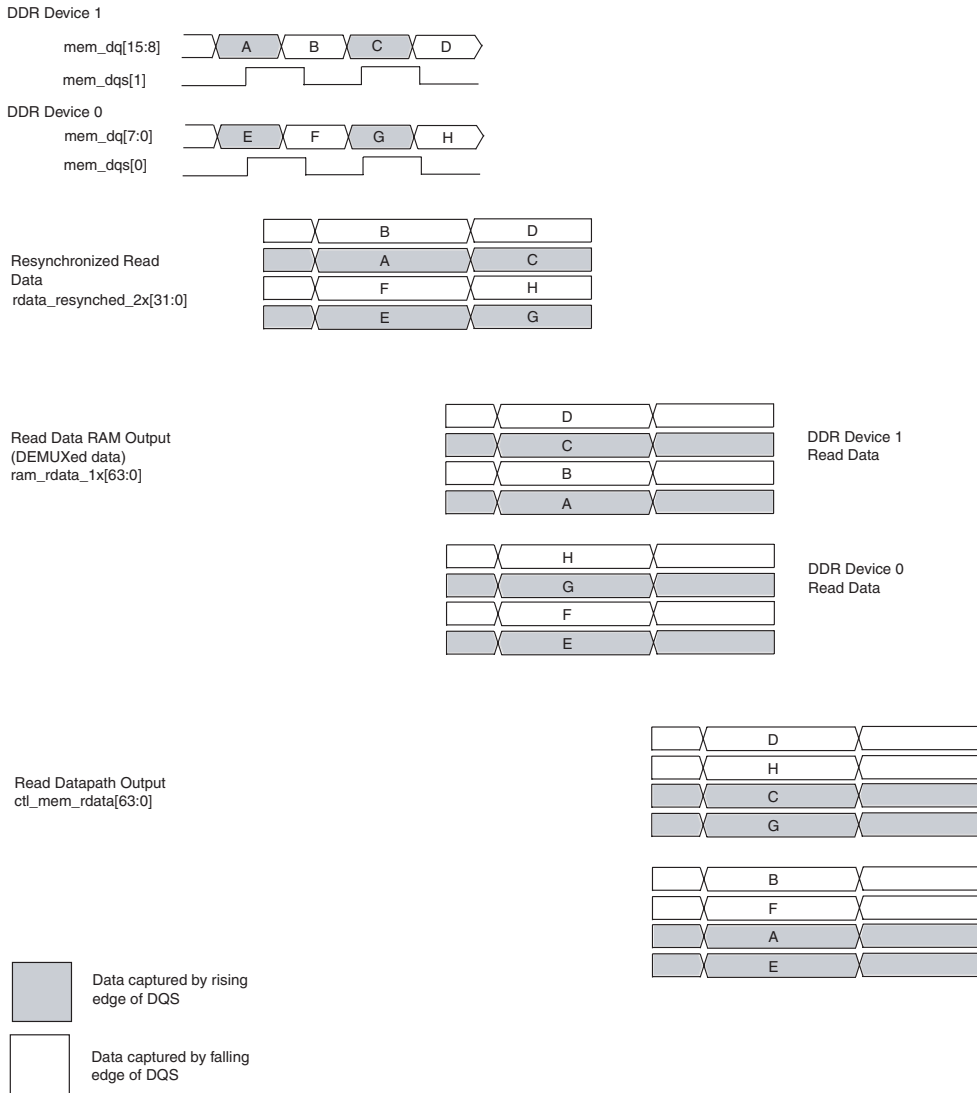
Read Data Alignment

Data alignment is the process controlled by the sequencer to ensure the correct captured read data is present in the same half-rate clock cycle at the output of the read data dual-port RAM. This is implemented using either M4K or M512 memory blocks. The concatenation of the read data into valid HDR data is shown at the bottom of [Figure 3-2](#).

Data Mapping Steps

In this example ([Figure 3-2](#)), the memory interface consists of two 8-bit wide memory devices, resulting in a memory interface 16-bits wide.

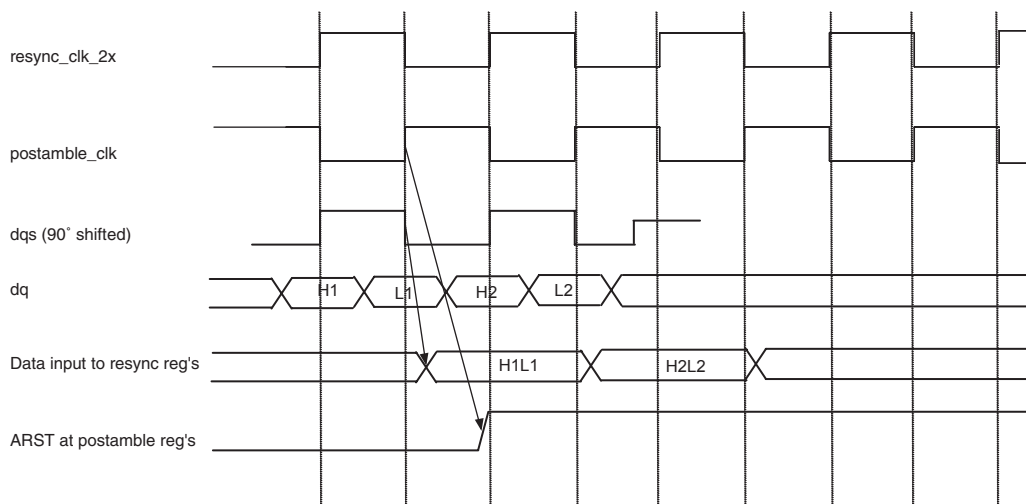
Figure 3–2. Read Data Ordering



1. Data B and F each of width 8 bits is captured during the first falling edge of DQS and data A and E each of width 8 bits is captured during the first rising edge of DQS. Referring to [Figure 3–2](#), you can treat data D and H as `rdata_2x_n` (16 bit) and data C and G as `rdata_2x_p` (16 bit).
2. Now the resynchronization registers resynchronizes `rdata_2x_n` (16 bit) and `rdata_2x_p` (16 bit) to the resynchronization clock (`rsync_clk_2x`) as `rdata_resynched_2x` ([Figure 3–2](#)) of width 32 bits. During the first cycle you get BAFE, and during the second cycle you get DCHG. Also note that the data changes with each clock cycle of the resynchronization clock.
3. Because the FIFO is 32-bits wide on the write side and 64-bits wide on the read side, the two sets (DCHG and BAFE) of 32-bit data forms one 64-bit wide data on the read side. The data (`ram_rdata_1x`) from the FIFO is arranged as DCBAHGFE and is one 64-bit wide data.
4. Now the 64-bit wide data (`ram_rdata_1x`) is presented at the local interface in the form of DHCGBFAE. The user-data interface to the read ports of the ALTMEMPHY megafunction can be thought of as being split into four words, each representing an edge of DQS. [Figure 3–2](#) shows that the LSB is the first in time seen on a DQ pin.

Postamble Protection

The ALTMEMPHY megafunction provides the DQS postamble logic. The postamble clock is derived from the resynchronization clock and is the negative edge of the resynchronization clock. The ALTMEMPHY megafunction calibrates the resynchronization clock such that it is in the center of the data-valid window. This means that the clock used to control the postamble logic, the postamble clock, is the negative edge of the resynchronization clock. No additional clocks are required. [Figure 3–3](#) shows the relationship between the postamble clock and the resynchronization clock.

Figure 3–3. Relationship Between Postamble Clock and Resynchronization Clock *Note (1)***Note to Figure 3–3:**

(1) `resync_clk_2x` is delayed further to allow for the I/O element (IOE) to core transition time.



For more information about the postamble circuitry, refer to the *External Memory Interfaces* chapter in the *Stratix II Device Handbook*.

Clock and Reset Management

The clocking and reset block is responsible for clock generation, reset management, and phase shifting of clocks, as well as control of clock network types used to route the clocks.

The ability of the ALTMEMPHY megafunction to work out the optimum resynchronization clock phase during calibration, and to track the system voltage and temperature (VT) variations, relies upon phase shifting the clocks relative to each other.

Clock management circuitry is implemented by using the following device resources:

- PLL
- PLL reconfiguration
- DLL

PLL

The ALTMEMPHY MegaWizard® Plug-In Manager automatically generates an ALTPLL megafunction instance. The ALTPLL megafunction is responsible for generating the different clock frequencies and relevant phases used within the ALTMEMPHY megafunction.

The device families available have different PLL capabilities. The minimum PHY requirement is to have 16 phases of the highest frequency clock. The PLL uses **No Compensation** mode to minimize jitter.



For more information about the VCO frequency range and the available phase shifts, refer to the *PLLs in Stratix II and Stratix II GX Devices* chapter in the *Quartus II Handbook*.

Figure 3–4 shows the clocking of different blocks of the ALTMEMPHY megafunction using Stratix II PLL.

Figure 3–4. Clocking of the ALTMEMPHY Blocks Using ALTPLL Clocks in Stratix II

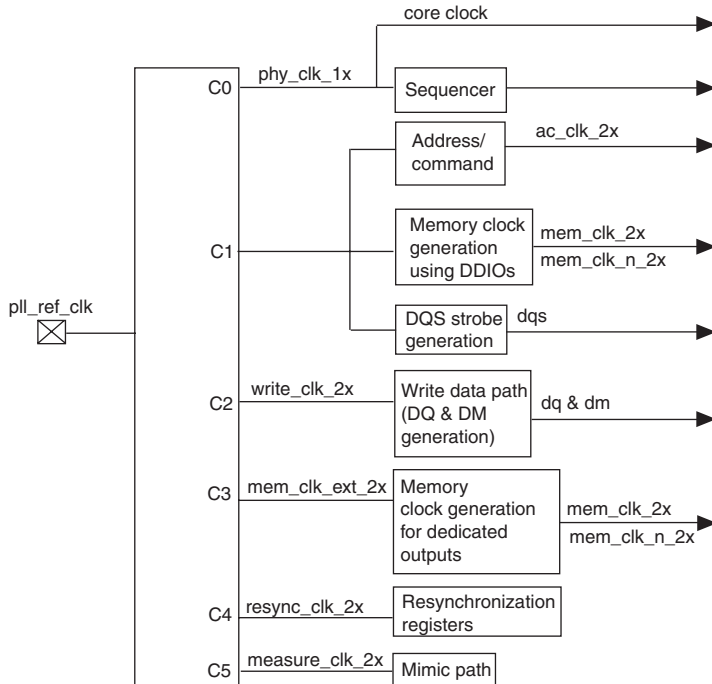


Table 3–1 shows the Stratix II PLL clock outputs.

Clock Name (1)	Postscale Counter	Phase (Degrees)	Half-Rate/ Full-Rate	Clock Network Type	Notes
phy_clk_1x	C0	0	Half-rate	Global	This is the only clock that is made available on the user interface of the ALTMEMPHY megafunction.
mem_clk_2x	C1	0	Full-rate	Global	This clock is used for clocking DQS and as a reference clock for the memory devices.
write_clk_2x	C2	-90	Full-rate	Global	This clock is used for clocking the data out of the double-data rate input/output (DDIO) pins in advance of the DQS strobe (or equivalent). As a result, its phase leads that of the mem_clk_2x by 90°.
mem_clk_ext_2x	C3	> 0	Full-rate	Dedicated	This clock is only used if the memory clock generation uses dedicated output pins.
resync_clk_2x	C4	Calibrated	Full-rate	Regional	This clock is used to clock the resynchronization registers after the capture registers. Its phase is adjusted to the center of the data valid window across all the DQS-clocked DDIO groups.
measure_clk_2x	C5	Calibrated	Full-rate	Regional	This clock is used for VT tracking. This free-running clock is used to measure relative phase shifts between the internal clock(s) and those being fed back through a mimic path. As a result, the ALTMEMPHY megafunction can track VT effects on the FPGA and compensate for the effects.
ac_clk_2x	-	0, 90, 180, 270	Full-rate	Global	The ac_clk_2x clock is derived from mem_clk_2x or write_clk_2x.

Note to Table 3–1:

- (1) The _1x clock represents a frequency that is half of the memory clock frequency; the _2x clock represents the memory clock frequency.

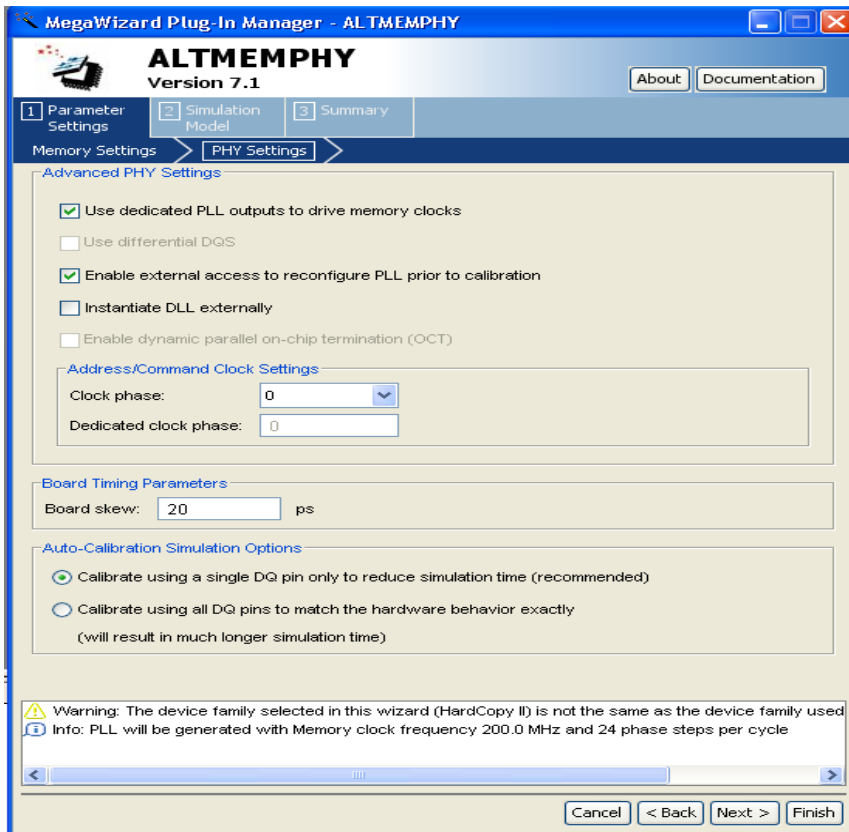
ALTPLL_RECONFIG

The ALTMEMPHY MegaWizard Plug-In Manager automatically generates an ALTPLL_RECONFIG instance to match the generated ALTPLL megafunction instance. The ALTPLL_RECONFIG is used to vary the resynchronization clock phase as well as the measure clock phase.

Hard Copy II Support

The Quartus® II version 7.1 software and onwards offers support for Hard Copy® II devices and also has the **Enable external access to configure PLL prior to calibration** option, as shown in [Figure 3–5](#).

Figure 3–5. Settings to Enable External Access to Reconfigure PLL



By enabling the **Enable external access to configure PLL prior to calibration** option, the ports of ALTPLL_RECONFIG are brought to the top level. You need to reconfigure the PLL before calibration to adjust, if necessary, the phase of the memory clock (`mem_clk_2x`) before the start of the calibration of the resynchronization clock on the read side. The calibration of the resynchronization clock on the read side depends on the phase of the memory clock on the write side.



Altera® recommends you enable this option for HardCopy II devices. When you use ALTDDIO for the memory clock, both the memory clock and the DQS signals are well aligned. When the dedicated clock outputs are used for the memory clock, the memory clock and the DQS signals are not aligned properly and will require a positive phase offset.

DLL

A DLL instance is included in the generated ALTMEMPHY variation for the Stratix series, HardCopy II, and Arria™ GX devices. When using the DQS to capture the DQ read data, the DLL center-aligns the DQS strobe to the DQ data.



For more information, refer to the *External Memory Interfaces* chapter in the *Stratix II Device Handbook* or the *Stratix II GX Device Handbook*.

Reset Management

The reset management block is responsible for the following:

- Provides appropriately timed resets to the ALTMEMPHY megafunction datapaths and functional modules
- Performs the reset sequencing required for different clock domains
- Provides reset management of PLL and PLL reconfiguration functions
- Manages any circuit-specific reset sequencing

Each reset is asynchronous assert and synchronous de-assert on the appropriate clock domain. The reset management design uses a standard two-register synchronizer to avoid metastability.

Write Datapath

The write datapath logic efficiently transfers data from the HDR memory controller to DDR SDRAM-based memories. The write datapath logic consists of:

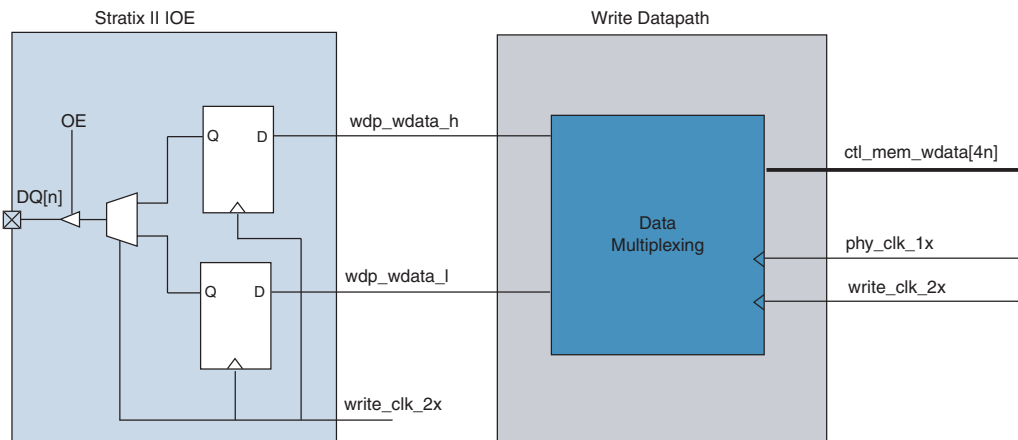
- DQ and DQ output-enable logic
- DQS and DQS output-enable logic
- Data mask (DM) logic

Overview

The memory controller interface outputs 4n-bit wide data (`ctl_mem_wdata[4n]`) at half-rate frequency. Figure 3-6 shows that the HDR write data (`ctl_mem_wdata[4n]`) is clocked by the half-rate clock `phy_clk_1x` and is converted into SDR which is represented by `wdp_wdata_h` and `wdp_wdata_l`.

The DQ IOEs convert 2-n SDR bits to n-DDR bits.

Figure 3-6. Stratix II Write Datapath



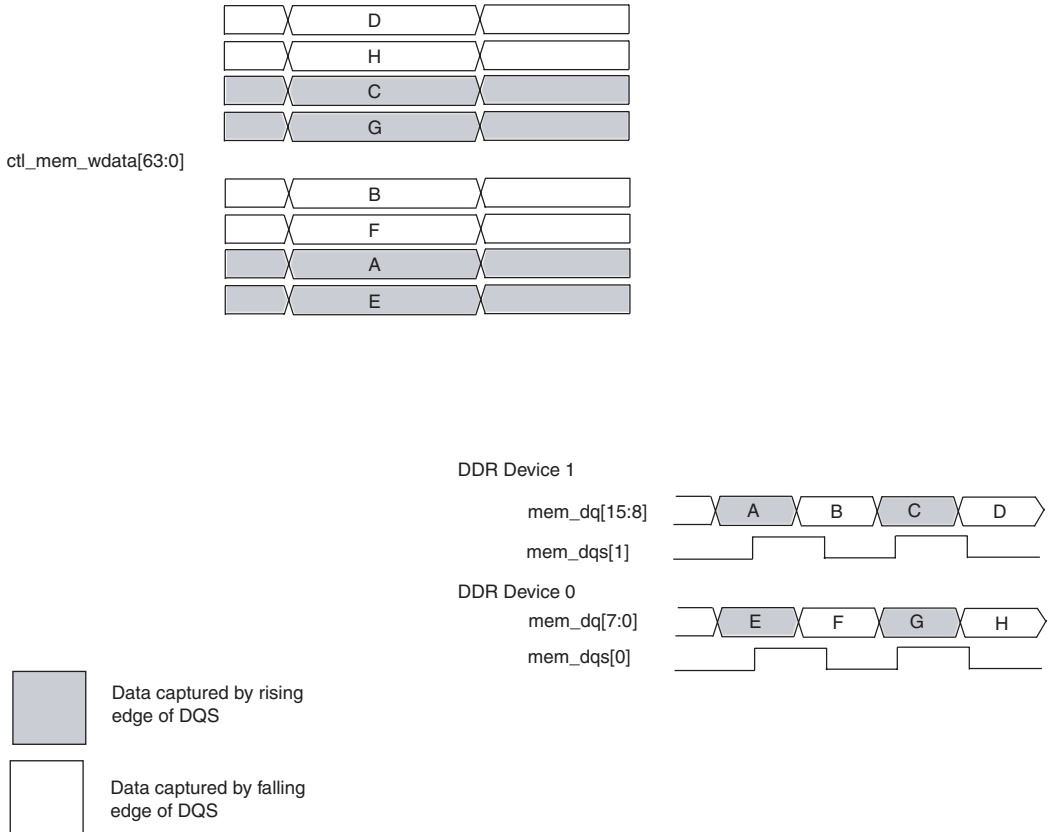
Data Mapping

The write data at the controller, which is 4n-bit wide, is converted to n bits at the memory interface. Figure 3-7 shows how the `ctl_mem_wdata` is mapped into the `mem_dq` by using a 64-bit `ctl_mem_wdata` as an example.



This is the reverse of the steps required for the read. For details, refer to “Read Data Alignment” on page 3–3.

Figure 3–7. Data Mapping Along the Write Datapath



Address and Command Datapath

The address and command datapath is responsible for taking the address and command outputs from the controller and converting them from half-rate clock to full-rate clock. Two types of addressing are possible:

- 1T—The duration of the address and command is a single memory-clock cycle (`mem_clk_2x`, Figure 3–8).
- 2T—The duration of the address and command is two memory-clock cycles. For the half-rate controller, the ALTMEMPHY megafunction supports only a burst size of four, which means the burst size on the

local interface is always set to 1. The size of the data is 4n-bits wide on the local side and is n-bits wide on the memory side. To transfer all the 4n-bits at the double-data rate, two memory-clock cycles are required. This means that the new address and command can be issued to the memory every two clock cycles.


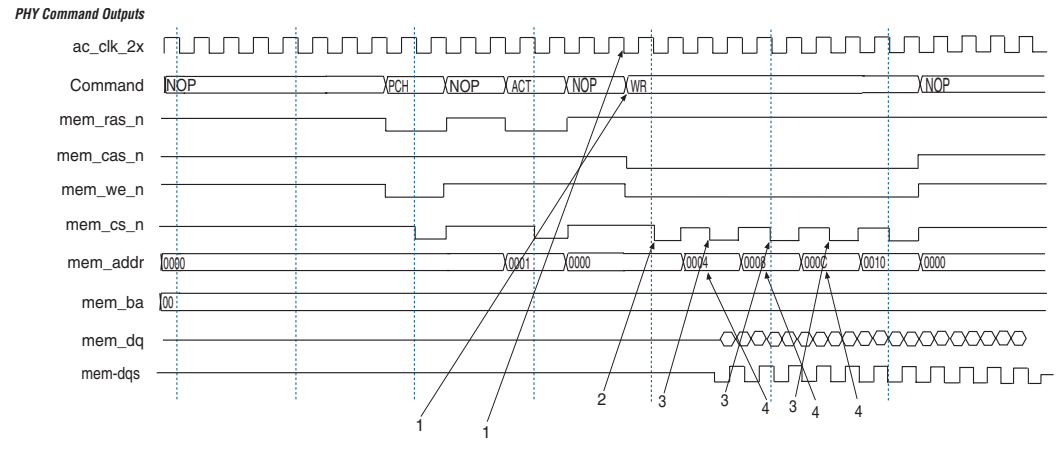
 Refer to Table 3-1 in “PLL” on page 3-7 to see the frequency relationship of mem_clk_2x with the rest of the clocks.

Figure 3-8 shows a 1T chip select signal (mem_cs_n), which is active low, and disables the command in the memory device. All commands are masked when the chip-select signal is inactive. The mem_cs_n signal is considered part of the command code.

Figure 3-8. Stratix II Address and Command Datapath



The command interface is made up of the signals mem_ras_n, mem_cas_n, mem_we_n, mem_cs_n, mem_cke, and mem_odt.

The waveform in Figure 3-8 shows a NOP command followed by five back-to-back write commands.

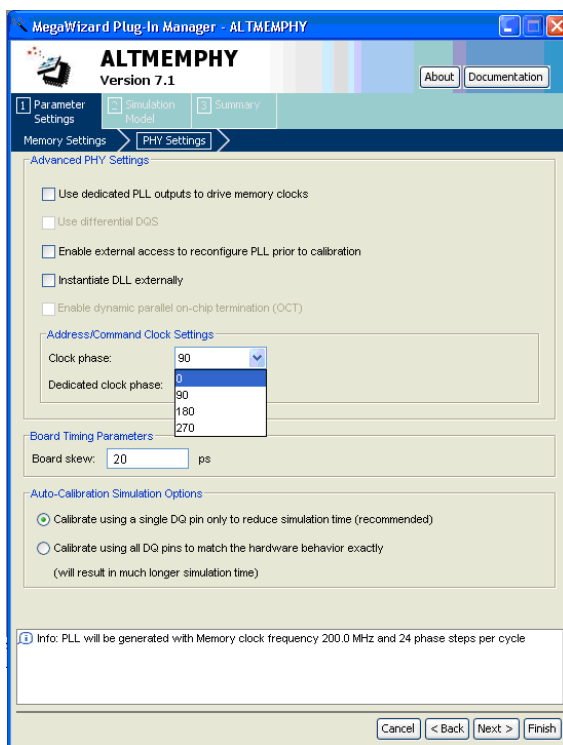
1. The commands are asserted either on the rising or falling edge of ac_clk_2x (this depends upon the setting of the address and command clock phase, as shown in Figures 3-10 to 3-14). The outputs remain on the bus for two clock cycles, allowing sufficient time for the signals to settle.

2. On the next falling edge of `ac_clk_2x`, the chip select signal, `mem_cs_n`, is asserted low and the memory sees the command which has already been on the bus for a cycle.
3. By asserting the chip-select signal in alternative cycles, back-to-back read or write commands can be issued.
4. The address is incremented every other `ac_clk_2x` cycle.



The address and command outputs to the memory are generated according to the settings of the address and command clock (`ac_clk_2x`) in the PHY settings page, as shown in [Figure 3-9](#). The phase of the address and command clock is chosen to meet the setup and hold-time requirements of the address and command signals with respect to the memory clock.

Figure 3-9. Choosing the Right Phase for the Address/Command Clock



Figures 3–10 through 3–13 show the assertion of the command signals with respect to different `ac_clk_2x` phase settings.

Figure 3–10. Address and Command Clock (0° Phase)

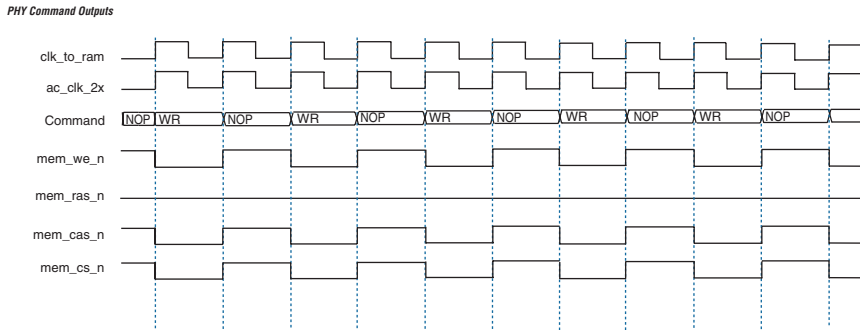


Figure 3–11. Address and Command Clock (90° Phase)

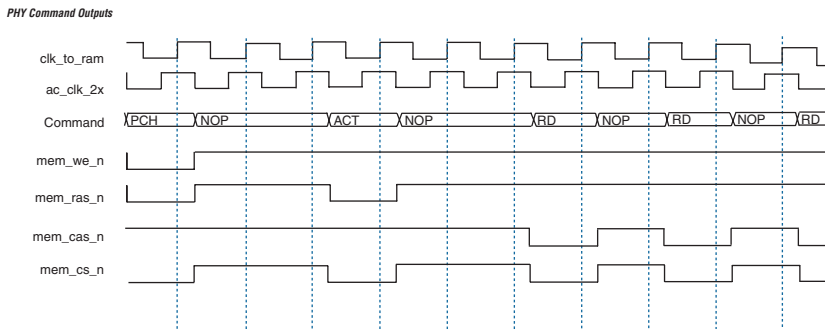
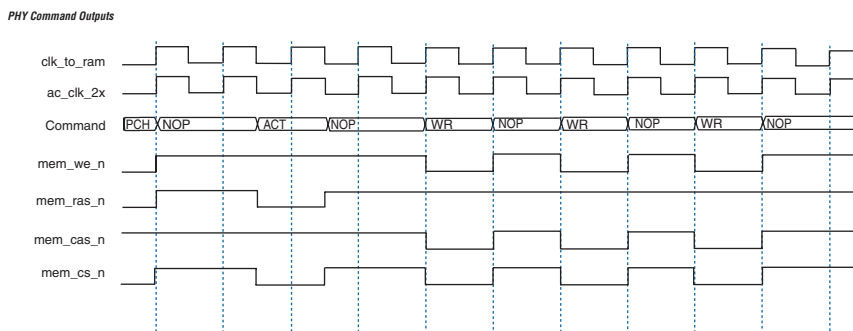
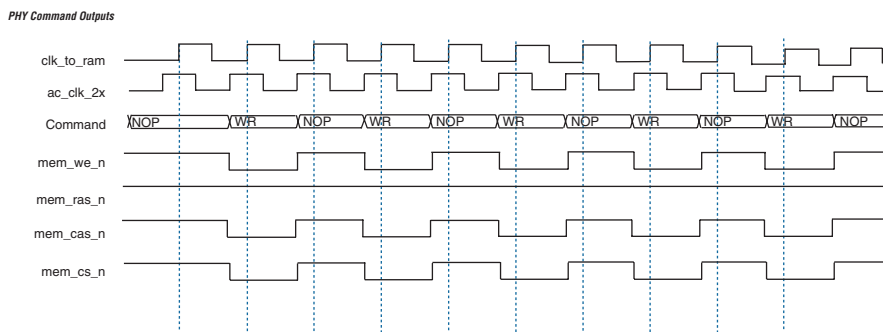


Figure 3–12. Address and Command Clock (180° Phase)**Figure 3–13. Address and Command Clock (270° Phase)**

Observe the phase of `ac_clk_2x` with respect to the memory clock (`clk_to_sdram`) to understand the assertion of command signals with respect to the different phase settings of `ac_clk_2x`. For example, in both the 180° and 270° phase for `ac_clk_2x`, the commands are asserted along with the positive edge of `ac_clk_2x`, but the relationship between `ac_clk_2x` and `clk_to_sdram` is different for 180° and 270°.



Refer to the *External Memory Interfaces* chapter in the *Stratix II Device Handbook* or the *Stratix II GX Device Handbook* for help in selecting I/O pins for the address and command signals.

Full-Rate Support

The following section discusses full-rate support.

Read Data Path

The full-rate datapath is similar to the half-rate datapath except that the function performed along the full-rate datapath is only data capture and resynchronization. The full-rate data path also consists of a RAM with the same width as the data input (just like that of the half-rate), but the width on the data output of the RAM is half that of the half-rate PHY. The function of the RAM is to transfer the read data from the resynchronization clock domain to system clock domain.

Postamble Protection

The postamble protection is the same as the half-rate support (refer to [“Half-Rate Support” on page 3-1](#) for more information).

Clock and Reset Management

Clock and reset management is similar to half-rate support except that the `phy_clk_1x` clock defined in [Table 3-3](#), is now a full-rate clock and is derived from `mem_clk_2x` (refer to [“Half-Rate Support” on page 3-1](#) for more information).



`phy_clk_1x` is now full-rate, despite the "1x" naming convention.

Write Data Path

The write datapath is similar to the half-rate PHY. The I/O element (IOE) block is identical to the half-rate PHY. The latency of the write datapath in the full-rate PHY is less than in the half-rate PHY because the full-rate PHY is free from the half-rate-to-full-rate conversion logic.



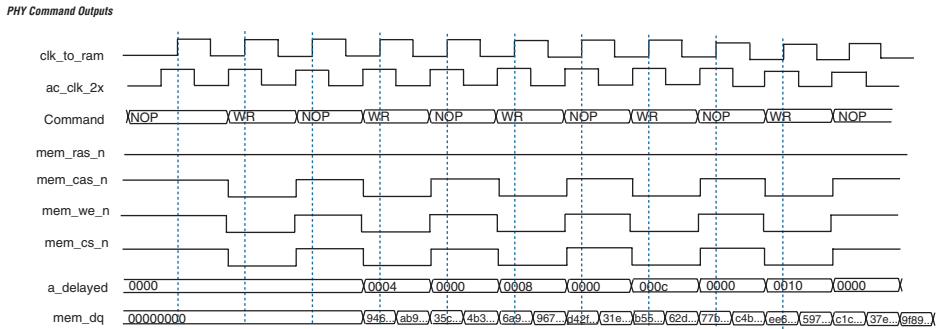
Refer to [“Latency Numbers” on page A-1](#) for more information on latency figures.

Address and Command DataPath

The address and command datapath is based on 1T addressing. For the full-rate PHY, the ALTMEMPHY supports only a burst size of four on the memory interface, which in turn equals a burst size of two on the local interface. Since the burst size is fixed at four for the memory interface, it takes two memory clock cycles to either read or write data that is

requested at the local interface, as shown in Figure 3–14. Since the address and command is 1T, the controller will be inserting a NOP command between every read and write command.

Figure 3–14. Stratix II Full-Rate Address and Command



Stratix III Support for DDR/DDR2/SDRAM and QDRII/QDRII+ SRAM

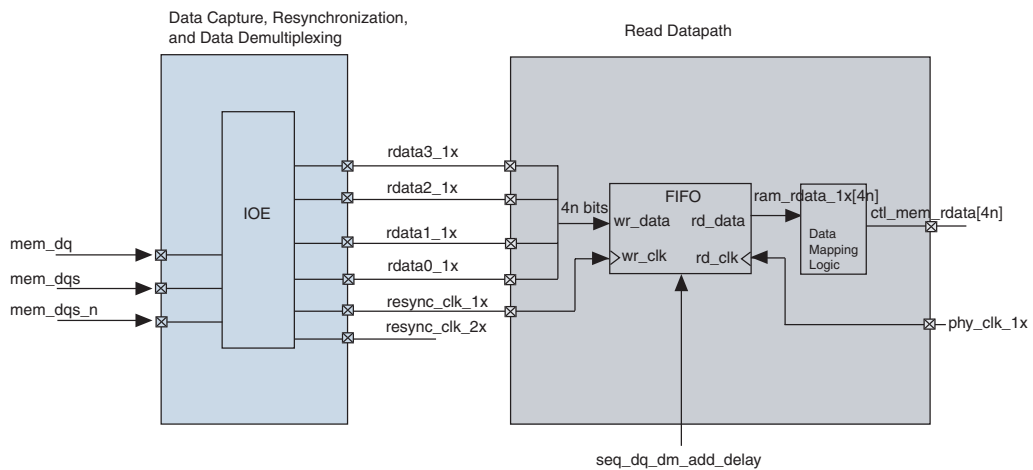
Half-Rate Support

The following section discusses half-rate support.

Read Datapath

The Stratix III read datapath (Figure 3–15) consists of two main blocks:

- Data Capture, Resynchronization, and Demultiplexing
- Read Datapath logic (Read Datapath)

Figure 3–15. Data Capture and Read Data Mapping in Stratix III

Data Capture, Resynchronization, and Demultiplexing

In Stratix III devices, the smart interface module in the IOE performs the following tasks:

- Captures the data
- Resynchronizes the captured data from the DQS domain to the resynchronization clock (`resync_clk_2x`) domain
- Converts the resynchronized data into half-data rate (HDR) data. This is performed by feeding the resynchronized data into the HDR conversion block within the IOE, which is clocked by the half-rate version of the resynchronization clock.



For more information about IOE registers, refer to the *External Memory Interfaces in Stratix III Devices* chapter of the *Stratix III Device Handbook*.

Data Resynchronization and Read Data Mapping

The read datapath block performs the following two tasks:

1. Transfers the captured read data (`rdata[n]_1x`) from the half-rate resynchronization clock (`resync_clk_1x`) domain to the half-rate system clock (`phy_clk_1x`) domain using dual port RAM. Resynchronized data from the FIFO is shown as `ram_data_1x`.
2. Reorders the resynchronized data (`ram_rdata_1x`) into `ctl_mem_rdata`.



The data bus for QDRII/QDRII+ SRAM is unidirectional when compared to DDR/DDR2 SDRAM. The read data bus is `mem_dq` and the write data bus is `mem_d` for QDRII and QDRII+ SRAM implementation.

Postamble Protection

Stratix III devices have a dedicated postamble register that can be controlled to gate the shifted DQS signal used to clock the DQ input registers at the end of a read operation. This ensures that any glitches on the DQS input signals at the end of the read postamble time do not cause erroneous data to be captured as a result of postamble glitches.



For more information about the postamble protection circuitry, refer to the *External Memory Interfaces for Stratix III Devices* chapter in the *Stratix III Device Handbook*.



For QDRII/QDRII+ SRAM, postamble protection circuitry is not needed as the data from the memory is captured on a free running read (`cq`) clock.

Clock and Reset Management

The clocking and reset block is responsible for clock generation, reset management, and phase shifting of clocks as well as control of clock network types used to route the clocks.

The ability of the ALTMEMPHY megafunction to work out the optimum phase during calibration and to track voltage and temperature variation relies on phase shifting the clocks relative to each other. Note that certain clocks need to be phase shifted during the ALTMEMPHY megafunction operation.

Clock management circuitry is implemented by using:

- PLL
- DLL

PLL

The ALTMEMPHY MegaWizard Plug-In Manager automatically generates an ALTPLL megafunction instance. The ALTPLL megafunction is responsible for generating the different clock frequencies and relevant phases used within the ALTMEMPHY megafunction.

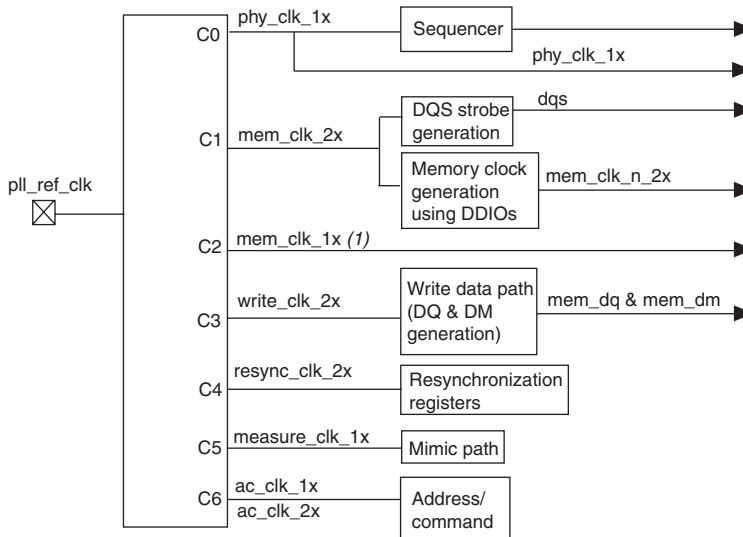
The device families available have different PLL capabilities. The minimum PHY requirement is to have 16 phases of the highest frequency clock. The PLL uses **No Compensation** mode to minimize jitter.



For more information about the VCO frequency range and the available phase shifts, refer to the *Clock Networks and PLLs in Stratix III Devices* chapter of the *Stratix III Device Handbook*.

Figure 3–16 shows the clocking of different blocks of the ALTMEMPHY megafunction using Stratix III PLL.

Figure 3–16. Stratix III PLL Outputs



Note to Figure 3–16:

(1) C2 output tap is needed only to generate dedicated memory clock outputs.

Table 3–2 shows the PLL outputs and their usage for Stratix III devices.

Table 3–2. Stratix III PLL Outputs (Part 1 of 2)					
Clock Name (1)	Postscale Counter	Phase (Degrees)	Half-Rate/ Full-Rate	Clock Network Type	Notes
phy_clk_1x	C0	0	Half-rate	Global	This is the only clock that is made available on the user interface of the ALTMEMPHY megafunction.
mem_clk_2x	C1	0	Full-rate	Regional	Used for clocking the DQS generation block. This clock is also used as a reference clock to DLL.
mem_clk_1x	C2	–	Full-rate	Global	Same as phy_clk_1x (if another half-rate clock is required due to timing/setup issues).
write_clk_2x	C3	-90	Full-rate	Regional	This clock is used for clocking the data out from the DDIO pins in advance of the DQS strobe. As a result, its phase leads that of the mem_clk by 90°.
resync_clk_2x	C4	0	Full-rate	Regional	This clock is used to read the data out of the DDIO pins. Its phase is adjusted to the center of the data valid window across all of the DQS-clocked DDIO groups.
measure_clk_1x	C5	0	Full-rate	Regional	This clock is used for VT tracking. This free-running clock is used to measure relative phase shifts between the internal clock(s) and those being fed back through a mimic path. As a result, you can track VT effects on the FPGA and compensate for the effects.

Table 3–2. Stratix III PLL Outputs (Part 2 of 2)

Clock Name (1)	Postscale Counter	Phase (Degrees)	Half-Rate/ Full-Rate	Clock Network Type	Notes
ac_clk_1x	C6	Determined using timing analysis	Half-rate	Regional	Address and command clock.

Note to Table 3–2:

- (1) The `_1x` notation represents a frequency that is half of the memory clock frequency; the `_2x` notation represents the memory clock frequency.



For Stratix III devices, the PLL reconfiguration is done using the phase-shift inputs on the PLL. The PLL reconfiguration megafunction is not required.

DLL

The DLL for Stratix III devices is instantiated in the same way as for Stratix II devices. Refer to the *External Memory Interfaces in Stratix III Devices* chapter of the *Stratix III Device Handbook* for more information.

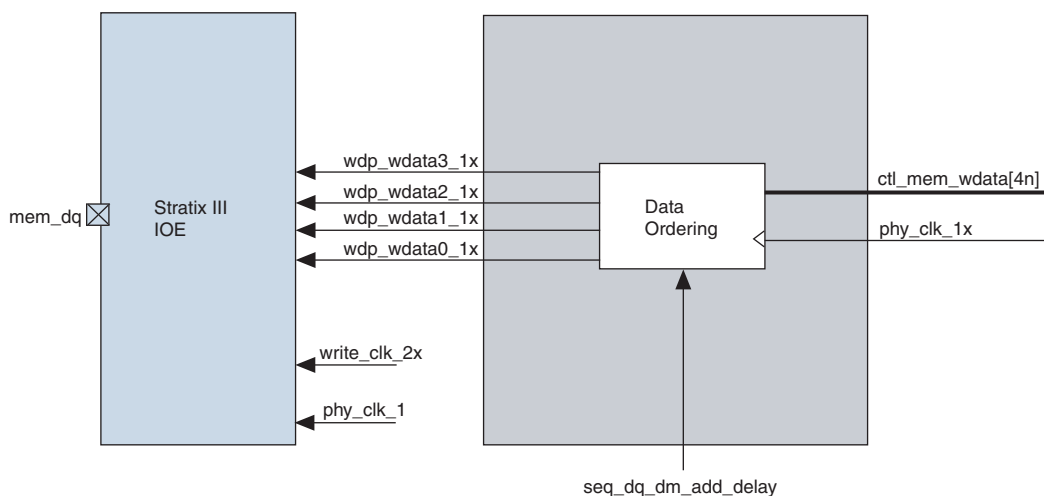
Reset Management

The reset management for Stratix III devices is instantiated in the same way as it is with Stratix II devices. Refer to “[Reset Management](#)” on [page 3–10](#).


Write Datapath

The memory controller interface outputs 4 n-bit wide data (`ctl_mem_wdata`) at `phy_clk_1x` frequency. The write data is clocked by the system clock `phy_clk_1x` at half-data rate (HDR) and reordered into HDR of width 4 n-bits represented in [Figure 3–17](#) by `wdp_wdata3_1x`, `wdp_wdata2_1x`, `wdp_wdata1_1x` and `wdp_wdata0_1x`.

As [Figure 3–17](#) shows, the reordered or the reordered-and-delayed HDR data is then converted to DDR data within the IOE element using both the half-rate and full-rate clocks.


Figure 3–17. Write Datapath in Stratix III Devices

The main difference between the Stratix II and Stratix III write datapaths is that all of the write datapath registers in the Stratix III device are clocked by the half-rate clock, `phy_clk_1x`.

 For more information about the Stratix III I/O structure, refer to the *External Memory Interface in Stratix III Devices* chapter of the *Stratix III Device Handbook*.

Data Mapping

The write data mapping for Stratix III devices is identical to the mapping defined for Stratix II devices. Refer to “[Data Mapping](#)” on page 3–11.

 The data bus for QDRII/QDRII+ SRAM is unidirectional when compared to DDR/DDR2 SDRAM. The read data bus is `mem_dq` and the write data bus is `mem_d` for QDRII and QDRII+ SRAM implementation.

Address and Command Datapath

The address and command datapath is similar to Stratix II devices, as described in “[Address and Command Datapath](#)” on page 3–12. The only difference is that in Stratix II designs, the address and command clock is configured to be `write_clk_2x` or `mem_clk_2x`. For Stratix III devices,

the address and command clock is one of the PLL dedicated clock outputs whose phase can be adjusted to meet the setup and hold requirements of the memory clock.

Full-Rate Support

There is no full-rate support in the Quartus II version 7.1 software.

Arria GX Support for DDR/DDR2 SDRAM

Operation of the Arria GX device is similar to the Stratix II device. Refer to [“Stratix II Support for DDR/DDR2 SDRAM”](#) on page 3-1 for more information.

Cyclone III Support for DDR/DDR2 SDRAM

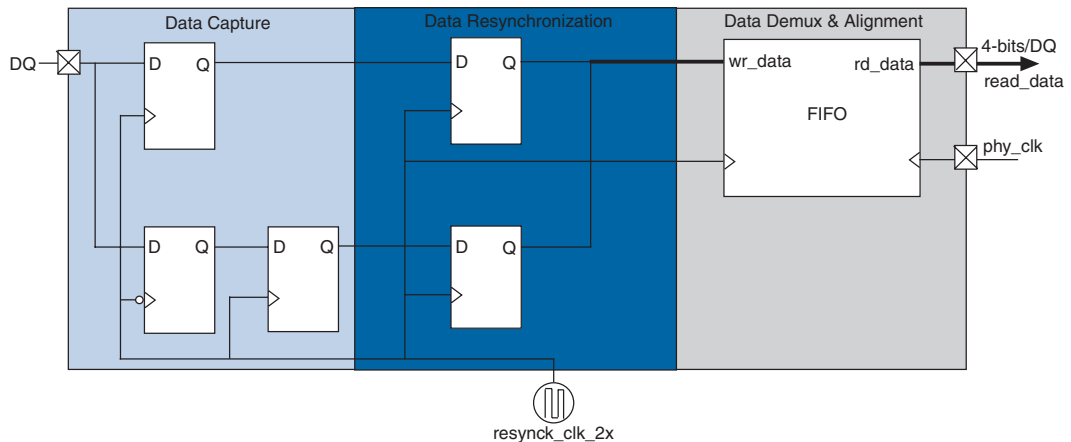
Half-Rate Support

The following section discusses half-rate support.

Read Datapath

[Figure 3-18](#) shows the Cyclone[®] III read datapath for a single DQ pin. The diagram shows a half-rate read path where four data bits are produced for each DQ pin. Unlike Stratix II and Stratix III devices, data capture is entirely done in the core logic since the IOE does not contain DDIO capture registers.

Figure 3-18. Cyclone III Read Datapath



Capture and Pipelining

The DDR and DDR2 SDRAM read data is captured using registers in the Cyclone III FPGA core. These capture registers are clocked using the capture clock (`resynch_clk_2x`, refer to [Figure 3-18](#)). The captured read data generates two data bits per DQ pin; one data bit for the read data captured by the rising edge of the capture clock and one data bit for the read data captured by the falling edge of the capture clock.

After the read data has been captured, it may be necessary to insert registers in the read datapath between the capture registers and the read data FIFO to help meet timing. These registers are known as pipeline registers and are clocked off the same clock used by the capture registers, the capture clock (`resync_clk_2x`).

Data Demultiplexing

The data demultiplexing for Cyclone III devices is instantiated in the same way as it is with Stratix II devices. Refer to [“Data Demultiplexing” on page 3-2](#) for more information.

Data Mapping

The data alignment for Cyclone III devices is instantiated in the same way as it is with Stratix II devices. Refer to [“Data Mapping Steps” on page 3-3](#) for more information.

Postamble Protection

Postamble protection circuitry is not required in the Cyclone III device implementation as DQS mode capture of the DQ data is not supported. The data capture is done using the clock (`resync_clk_2x`) generated from the ALTPLL megafunction.

Clock and Reset Management

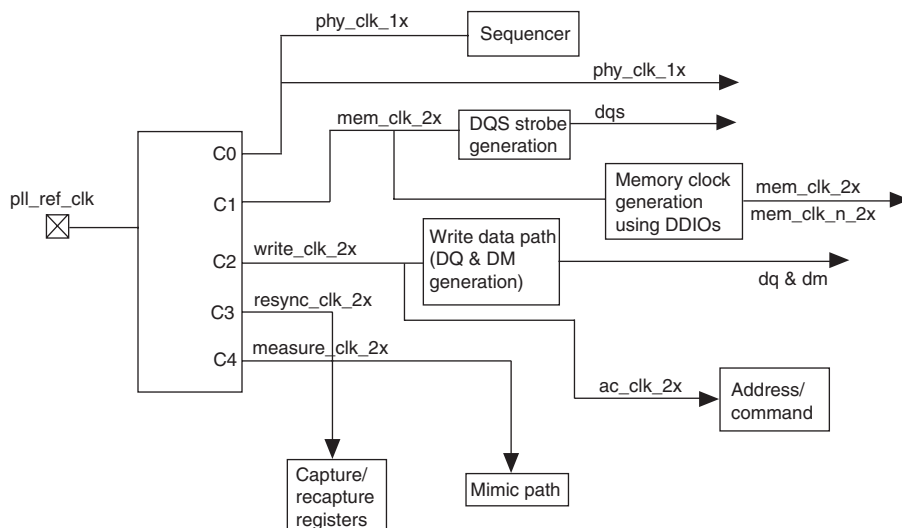
Clock management circuitry is implemented using the ALTPLL megafunction.

PLL

The ALTPLL megafunction is instantiated within the ALTMEMPHY megafunction and is responsible for generating all the clocks used by the ALTMEMPHY and the memory controller. [Table 3-3](#) shows the clocks generated by the ALTPLL megafunction.

Table 3–3. ALTPLL Clocks

Clock Name	Post-Scale Counter	Phase (Degrees)	Half-Rate/ Full-Rate	Clock Network Type	Notes
phy_clk_1x	C0	0	Half-rate	Global	This is the only clock that is made available on the user interface of the ALTMEMPHY to be used by the controller.
mem_clk_2x	C1	0	Full-rate	Global	This clock is used to generate DQS signals and the memory clock.
write_clk_2x	C2	-90	Full-rate	Global	This clock is used for clocking the data (DQ) when you perform a write to the memory. As a result, its phase leads that of the mem_clk_2x by 90°.
resynch_clk_2x	C3	Calibrated	Full-rate	Global	This is a full-rate clock used to capture and resynchronize the captured read data. The capture and resynchronization clock has a variable phase that is controlled via the PLL re-configuration logic by the control sequencer block.
measure_clk_2x	C4	0	Full-rate	Global	This clock is used for VT tracking. This free-running clock is used to measure relative phase shifts between the internal clock(s) and those being fed back through a mimic path. As a result, you can track VT effects on the FPGA and compensate for them.
ac_clk_2x	—	0, 90, 180, 270	Full-rate	Global	This clock is derived from mem_clk_2x or write_clk_2x.

Figure 3–19. Cyclone III ALTPLL Clock Outputs

Reset Management

The reset management for Cyclone III devices is instantiated in the same way as it is with Stratix II devices. Refer to [“Reset Management” on page 3–10](#) for more information.

Write Datapath

The write datapath for Cyclone III devices is instantiated in the same way as it is with Stratix II devices. Refer to [“Write Datapath” on page 3–11](#) for more information.

Address and Command Datapath

The full-rate support for Cyclone III devices is similar to the Stratix II device. Refer to [“Address and Command Datapath” on page 3–12](#) for more information.

Full-Rate Support

The full-rate support for Cyclone III devices is similar to the Stratix II device. Refer to [“Full-Rate Support” on page 3–17](#) for more information.

Read Datapath

The read datapath for Cyclone III devices similar to the Stratix II device. Refer to [“Read Data Path” on page 3–17](#) for more information.

Postamble Protection

There is no postamble protection circuitry.

Clock and Reset Management

The clock and reset management for Cyclone III devices is similar to half-rate support for Stratix II devices except that the `phy_clk_1x` clock defined in [Table 3–3](#), is now a full-rate clock and is derived from `mem_clk_2x`.



`phy_clk_1x` is now full-rate, despite the "1x" naming convention.

Write Data Path

The write data path is free from half-rate-to-full-rate conversion logic that was in the half-rate controller. The IOE block is identical to the half-rate controller. Because of the RAM exclusion, the latency of the write data path is smaller in the full-rate controller as compared to the half-rate controller.



Refer to [“Selection Criteria Between ALTMEMPHY & Legacy Controllers” on page A–1](#) for more information on latency figures.

Address and Command Datapath

The address and command datapath is similar to Stratix II full-rate address and command datapath.

Read Datapath

The read datapath is the same as the Stratix II full-rate datapath.

Postamble Protection

The postamble protection is the same as the Stratix II half-rate support.

Clock and Reset Management

The clock and reset management is similar to half-rate support except for the clock `phy_clk_1x` defined in [Table 3-3](#), is now a full-rate clock and is derived from `mem_clk_2x`.



`phy_clk_1x` is now full-rate, despite the "1x" naming convention.

Write Data Path

The IOE block is identical to the half-rate PHY. The latency of the write data path is smaller in the full-rate PHY as compared to the half-rate PHY because the full-rate PHY is free from the half-rate-to-full-rate conversion logic that was there in the half-rate PHY.



Refer to [“Selection Criteria Between ALTMEMPHY & Legacy Controllers”](#) on page A-1 for more information on latency figures.

Address and Command Datapath

The address and command datapath is the same as that of the Stratix II full-rate address and command datapath.

Calibration

DDR/DDR2 SDRAM

At power-up, the ALTMEMPHY megafunction calibrates out any process variance on the DDR/DDR2 device and the external memory device to establish the resynchronization clock phase which provides the greatest timing margin. This removes many of the uncertainties from the read datapath delay and achieves a higher frequency of operation across process, voltage, and temperature (PVT).

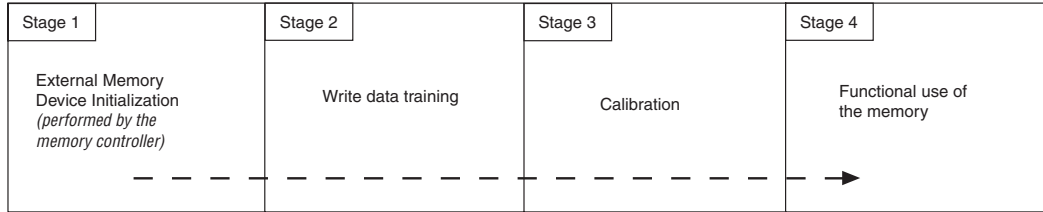
The sequencer is an element of the ALTMEMPHY megafunction designed to perform this path-delay analysis to set up the resynchronization clock and data alignment settings.

[Figure 3-20](#) shows that the various stages of the sequence of operation of the ALTMEMPHY megafunction are further divided into a series of tasks which are performed by the sequencer.



The information in this section applies only to the Stratix II family of FPGA devices.

Figure 3–20. Different Stages of the Calibration Sequence



Stage 1: External Memory Device Initialization

This is the process of initializing the external memory device and is performed by the memory controller.

Stage 2: Write Data Training

During this stage, a specific training data pattern is written to the external memory device as a precursor to the calibration process. The sequencer issues commands to the memory controller which performs writes of the training pattern to the external memory device.

The training pattern is written to the memory device. There are 32 bits of training data (00001111_00000000_11111111_01010101) associated with each data pin. The purpose of the training data is not only to calibrate and identify when the read data is on the output of the read path, but also to counter any adverse affects due to Inter Symbol Interference (ISI) and/or Simultaneous Switching Noise (SSN).

Stage 3: Calibration

Once the training pattern writes have completed, the sequencer reads the training pattern written to the external memory device with different phase-shift settings of the PLL clock. The sequencer uses these results to compute the data valid eye, and subsequently chooses the optimal phase settings for the read-data resynchronization clock to hit the center of the eye.

During calibration, the demultiplexed read data is compared against the training pattern written to the memory after power-up. If the demultiplexed read data exactly matches the training pattern, the

comparison logic block signals a 'pass' to the control sequencer. If the demultiplexed read data does not exactly match the training pattern, the comparison logic block signals a 'fail' to the control sequencer.

Once a training pattern read-and-comparison operation has completed and the pass/fail result has been stored, the control sequencer uses the PLL reconfiguration logic to shift the capture and resynchronization clock phase by one VCO phase step. When the PLL re-configuration has completed, the control sequencer performs another training pattern read-and-comparison operation. This sequence continues until all PLL VCO phase taps have been tested. The training pattern read comparison is done on a by-pin basis to minimize logic. Therefore, for a 64-bit DDR2 SDRAM interface using a single read data demultiplex phase, the control sequencer performs 64 training pattern reads and comparisons before all the pass/fail results have been stored for the memory interface pins.

Once all the pins have been tested, the sequencer increments the resynchronization clock phase by one step. It then repeats the above read/pattern matching procedure for the new resynchronization clock phase.

Additionally, there are two demultiplex phases for the read-data output from the read-data RAM. The sequencer shifts the resynchronization clock through 720° for a half-rate controller and 360° for a full-rate controller. This is guaranteed to provide a correct demux phase.

Once all the pass/fail results have been stored, the control sequencer calculates the optimum resynchronization clock phase such that the resynchronization clock is placed in the center of the data valid window. Once this optimum phase has been calculated, the control sequencer uses the PLL reconfiguration logic to set up the phase of the resynchronization clock to the calculated optimum phase. Auto-calibration is now complete. This is indicated by the assertion of `user_mode_ready`. It also uses the correct read latency value for this clock phase setting to assert the `read_data_valid` signal to indicate when the `local_rdata` bus has valid read data on it.

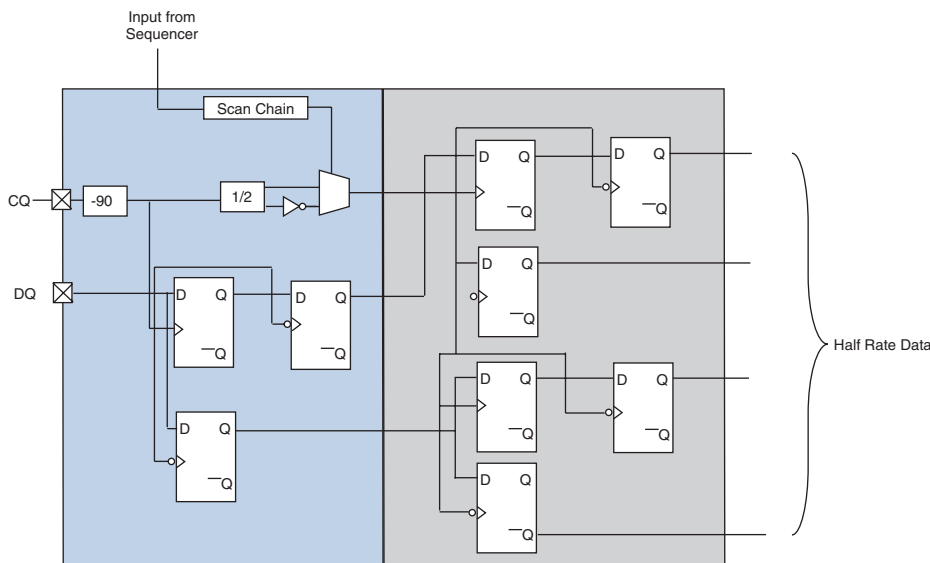
Stage 4: Functional Use of the Memory

This is the normal user mode of the memory. In this stage, the memory interface is fully controlled by the user interface. This is indicated by the assertion of the `user_mode_ready` signal. The memory controller is driven by the sequencer or the memory controller is driven by the user logic.

QDRII/QDRII+ SRAM

Calibration process of a QDRII/QDRII+ SRAM device is considerably simpler as compared to the DDR/DDR2 SDRAM device. The calibration process involves selecting the right phase of the resynchronization clock to capture the read data at half rate. Figure 3–21 shows the generation of the resynchronization clock.

Figure 3–21. Resynchronization Clock



The clock CQ coming from the QDRII SRAM is delayed by 90° and is then divided by two to generate a half-rate clock that will be used to capture the data (DQ) at half rate. As shown in Figure 3–21, either the half-rate clock or the inverted half-rate clock is used to capture the half-rate data.

Calibration Process

At power up, a specific training data pattern is written to the external memory device as a precursor to the calibration process. The sequencer issues commands to the memory controller which performs writes of the training pattern to the external memory device. The sequencer also loads the scan chain, the output of which is used to select a specific phase of the divide-by-two clock. The training pattern is read back and compared to the data written, if the read data is correct, the calibration process is complete. If the read data is not correct, the sequencer selects the inverse

of the divide-by-two clock and reads the half-rate data. This phase should be corrected and selected as the right phase of the resynchronization clock to capture the data.

VT Tracking

DDR/DDR2 SDRAM

VT tracking is a background process that tracks the VT variations to maintain the relationship between the resynchronization clock and the data valid window that were achieved at calibration. This is also referred to as tracking.

Overview

The relationship between the resynchronization clock and the data valid window is maintained by measuring the mimic path variations due to the VT variations and applying the same variation to the resynchronization clock.

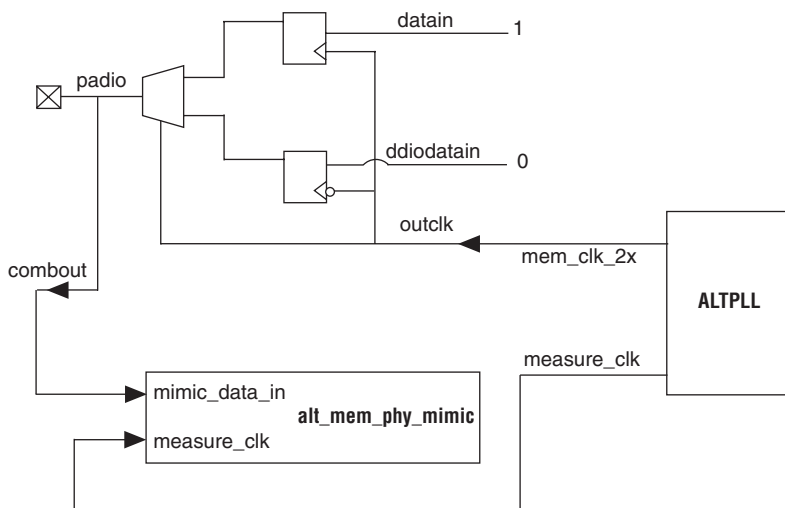
Mimic Path

The mimic path is used to mimic the FPGA portion of the elements of the round-trip delay. This enables the calibration sequencer to track delay variation due to VT changes during the memory read and write transactions without interrupting the operation of the ALTMEMPHY megafunction.

Figure 3–22 shows the mimic path which mimics the delay of the clock outputs to the memory as far as the pads of the FPGA and the delay from the input DQS pads to a register in the FPGA core. During the tracking operation, the calibration sequencer measures the delay of the mimic path by varying the phase of the measure clock. Any change in the delay of the mimic path indicates a corresponding change in the round-trip delay, and a corresponding adjustment is made to the phase of the resynchronization clock.

The assumption made about the mimic path is that the VT variation on the round trip delay path that resides outside of the FPGA is accounted for in the board skew and memory parameters entered in the Megawizard. For the write direction, any VT variation in the memory devices is accounted for by timing analysis.

Figure 3–22. Mimic Path



Tracking Calibration

Tracking calibration takes place once the data calibration phase has completed. During initial calibration, the mimic path is sampled using the measure clock (`measure_clk` has a `_1x` or `_2x` suffix, depending on the target FPGA device). The sampled value is then stored by the sequencer. Once a sample value has been stored, the sequencer uses the PLL reconfiguration logic to change the phase of the measure clock by one VCO phase tap. The control sequencer then stores the sampled value for the new mimic path clock phase. This sequence continues until all mimic path clock phase steps have been swept. Once the control sequencer has stored all the mimic path sample values, it calculates the phase which corresponds to the center of the high period of the mimic path waveform. This is the reference mimic path sampling phase. This optimum sampling phase is used during the VT tracking phase.

Tracking

Tracking is a continuous process that is transparent and is used to maintain a near-optimum resynchronization clock phase as VT varies. In user mode, the control sequencer periodically performs a tracking operation as defined in the tracking calibration description. At the end of the tracking calibration operation, the control sequencer compares the most recent optimum tracking phase against the reference sampling phase. If the sampling phases do not match, the mimic path delays have changed due to voltage and temperature variations.

When the sequencer detects that the mimic path reference and most recent sampling phases do not match, the sequencer uses the PLL reconfiguration logic to change the phase of the resynchronization clock by the VCO taps in the same direction. This allows the tracking process to maintain the near-optimum capture clock phase setup during data tracking calibration as voltage and temperature vary over time.

QDRII/QDRII+ SRAM

VT Tracking

VT tracking is not required because the read strobe from the QDRII memory is continuous. This means that all registers in the I/O to the read RAM path are clocked using a clock that is derived from the QDRII read strobe.

Integrating ALTMEMPHY with Your Own Controller

The ALTMEMPHY megafunction can be integrated with your own controller. This section describes the interface requirement and the handshake mechanism for efficient read and write transactions.

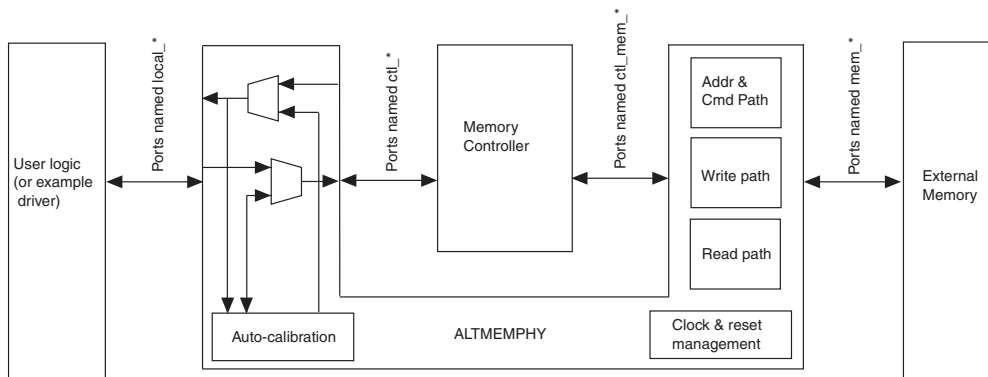
Preliminary Steps

Perform the following steps to generate the ALTMEMPHY megafunction:

1. Generate the ALTMEMPHY megafunction as described in [“Getting Started” on page 2–1](#) by selecting the desired parameters.
2. Compile and verify the timing. This step is optional; refer to [“Compiling in the Quartus II Software” on page 2–16](#) and [“Analyzing Timing” on page 2–19](#) for details.
3. Integrate the top-level ALTMEMPHY design with your controller. Details about integrating your controller with Altera’s ALTMEMPHY are described in the following sections.

Overview

The auto-calibration logic in the ALTMEMPHY megafunction relies on the services of the memory controller to perform its calibration writes and reads, so it must be able to have control of the controller’s local interface during the initial calibration stage. This means that the ALTMEMPHY megafunction has four interfaces that all need to be connected appropriately. [Figure 3–23](#) shows the four interfaces.

Figure 3–23. The Four ALTMEMPHY Megafunction Interfaces

The four ALTMEMPHY interfaces, from left to right, are:

1. The local interface is the interface between the user logic and the memory controller. The signals between user logic and the controller traverse through the ALTMEMPHY. This can either be an Avalon Memory-Mapped slave interface or a Native interface. All the ports on this interface have their names prefixed with `local_*`; for example, `local_init_done`. During the initial calibration period, the auto-calibration logic takes control of this interface and issues the write and read requests that it requires to the memory controller. Once the calibration process is complete, control is handed back to the user logic and normal operation occurs. The ALTMEMPHY megafunction auto-calibration logic does not require any further access to the memory controller once the initial auto-calibration is complete.
2. The ALTMEMPHY-controller local interface is the interface between the ALTMEMPHY megafunction and the controller local interface. All the port names on this interface are prefixed with `ctl_*`; for example, `ctl_init_done`. This interface connects the ALTMEMPHY megafunction to the controller's local interface and is of the same type as the local interface, either an Avalon Memory-Mapped Interface or a Native interface. Once the calibration process is complete, this becomes a straight-through connection and you have complete control of the memory controller.
3. The ALTMEMPHY-controller command interface is the interface between the controller and ALTMEMPHY. All the ports on this interface are prefixed with `ctl_mem_*`; for example, `ctl_mem_rdata`, and are clocked by the `phy_clk`. This interface

contains the memory control and address signals from the controller to the memory. The controller also sends write data to, and receives read data from, the external memory through this interface. All the signals on this interface are clocked at the `phy_clk` rate, and the ALTMEMPHY megafunction converts between this clock and the memory interface clock.

4. The fourth interface is between the ALTMEMPHY megafunction and the external memory devices, and consists of the memory address, command, and data pins. These must be connected directly to the external pins of your Altera FPGA.

Design Considerations

There are some important considerations for implementing your own controller with the ALTMEMPHY megafunction.

Local Interface Requirements

Since the auto-calibration logic makes use of the controller to perform its calibration, your controller will have to take the following into account.

The controller must have at least one Avalon Memory-Mapped slave interface or a Native interface, as defined in the *DDR SDRAM High-Performance User Guide*, which the ALTMEMPHY can control during the initial calibration process. Once calibration is complete, no further access to this interface is required by ALTMEMPHY.

The memory burst length is fixed at four for DDR SDRAM or DDR2 SDRAM devices. For a half-rate controller with the memory clock running twice as fast as the clock provided to the local interface, this means that data buses on the local interface will be four times as wide as the memory data bus. For a full-rate controller, the memory clock runs at the same speed as the clock provided to the local interface, this means that the data buses on the local interface will be two times as wide as the memory data bus. This means that each read or write request on the local interface fits into a single memory read or write command on the memory interface, simplifying the controller design.

Clocks and Resets

The ALTMEMPHY megafunction automatically generates a PLL instance, but you must still provide the reference clock input (`pll_ref_clk`) with a clock of the frequency that you specified in the MegaWizard Plug-In Manager. An active-low global reset input is also provided which you can de-assert asynchronously. The clock and reset management logic synchronizes this to the appropriate clock domains

inside the ALTMEMPHY megafunction. A clock output, which is half the memory clock frequency for a half-rate controller and the same as the memory clock for a full-rate controller, is provided (`phy_clk`) and all inputs and outputs of the ALTMEMPHY megafunction are synchronous to this clock. An active-low synchronous reset is also provided (`reset_phy_clk_n`).

Calibration Process Requirements

Since the auto-calibration logic makes use of the controller to perform its calibration, you should follow these guidelines at power-up. Once the global reset (`global_reset_n`) is released, the clock management logic waits for the PLL to lock and then releases the reset to the rest of the logic, including the controller. Since the PLL locked output is gated inside the PLL, for approximately the first 10,000 cycles (by this time the PLL-locked output is stable) of the PLL reference clock, there will be no activity at this time. Once the reset to the controller (`reset_phy_clk_n`) has been released, the controller begins its normal memory initialization sequence. When this is complete, the controller indicates to the ALTMEMPHY megafunction that it is ready to accept the calibration writes and reads by asserting the `ctl_init_done` and `ctl_ready` signals. The auto-calibration logic then issues a series of writes and reads to the external memory. You do not have access to the memory controller during this period. Once the auto-calibration logic has completed its calibration, ALTMEMPHY asserts `local_init_done` and `local_ready` and you have complete control of the memory controller.

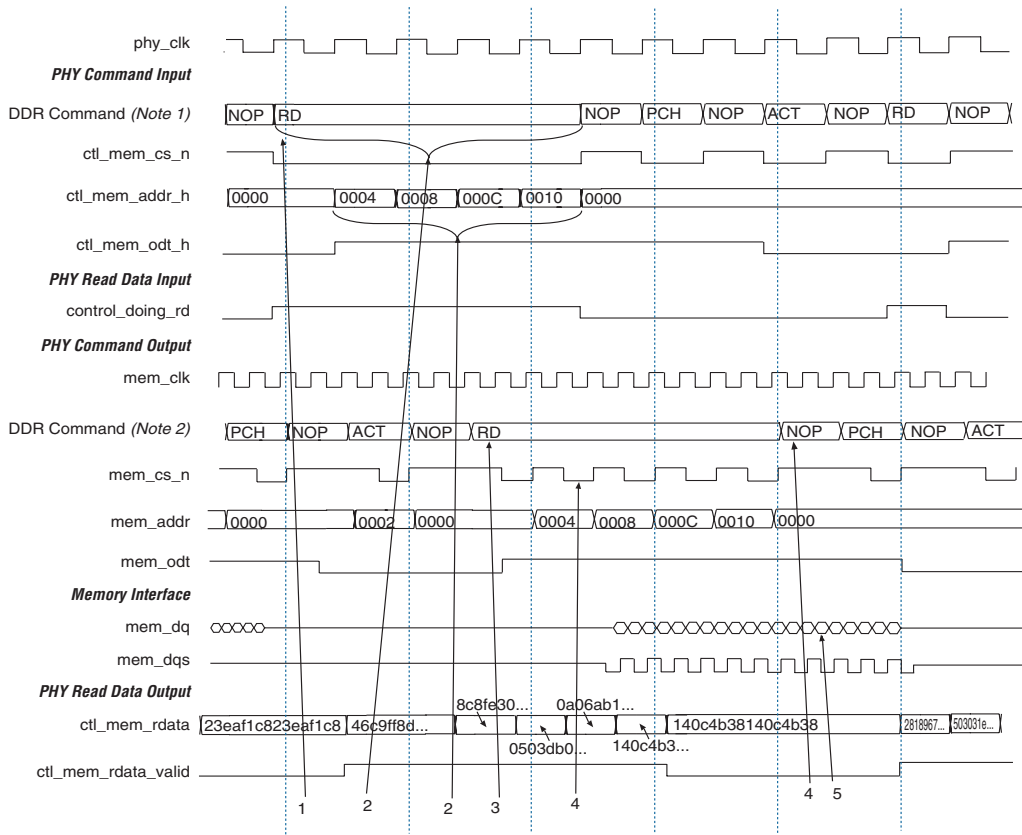
To calibrate the read datapath, the auto-calibration logic repeatedly requests blocks of nine consecutive read requests from the controller. The controller must be able to issue these nine read requests such that the read data, coming back into the system, is a continuous stream of data for nine clock cycles. The calibration logic is able to detect if the reads are not back-to-back and can cope with some interrupted streams; for example, if the controller has to issue a periodic refresh. The auto-calibration logic repeats that block of reads if it detects that the data was not contiguous.

Half Rate Controller

Handshake Mechanism Between Read Commands and Read Data

The controller generates a signal (`ctl_doing_rd`) to ALTMEMPHY which is asserted for one `phy_clk` cycle for every read command it issues. If there are two read commands, the signal `ctl_doing_rd` is asserted for two `phy_clk` cycles. This signal is also used to enable the capture registers and generates the `ctl_mem_rdata_valid` signal. This signal should be issued at the same time the read command is sent to the ALTMEMPHY megafunction. Refer to [Figure 3–24](#).

Figure 3–24. Read Commands and Read Data



Notes to Figure 3–24:

- (1) DDR command shows the command comprised of the command signals (ctl_mem_ras_n, ctl_mem_cas_n, and ctl_mem_we_n) seen at the ALTMEMPHY input.
- (2) DDR command shows the command comprised of the command signals (mem_ras_n, mem_cas_n and mem_we_n) seen at the memory interface.



The signals under the PHY Command Input label are the signals from the controller to the ALTMEMPHY megafunction. The signals under the PHY Command Output label are the signals coming out of the ALTMEMPHY megafunction and input to the memory device.

1. Some of the address and command signals generated by the controller are:

- `ctl_mem_addr_h`
- `ctl_mem_cas_h`
- `ctl_mem_cs_n_h`
- `ctl_mem_ras_n_h`
- `ctl_mem_we_n_h`
- `ctl_mem_odt_h`

Figure 3–24 shows the No Operation (NOP) command followed by a series of five read commands.

2. The controller issues five consecutive read commands with a starting address of 0×0 with increments of four (0000, 0004, 0008, 000c, 0010). This is shown at the top of Figure 3–24 under the PHY Command Input label.
3. The ALTMEMPHY megafunction generates the read command at the memory interface after five-to-seven memory clock (`mem_clk`) cycles. The address and commands are generated using the negative edge of the memory clock. This is shown in the Figure 3–24 under the PHY Command Output label.
4. The address and commands are of 2T period and the chip select is of 1T period (`mem_clk`).
5. The data (`mem_dq`) at the memory interface is presented after three memory clock cycles of read latency. The read latency is equal to the CAS latency. For this example, CAS latency is equal to three.

By default, the read data from the memory bypasses the controller and is sent directly to the user logic. If your controller needs access to the read data after it has been captured, but before it is sent to the user interface (for example, to perform error detection and correction), connect the `ctl_mem_rdata` and `ctl_mem_rdata_valid` outputs from ALTMEMPHY to your controller. The controller must delay both `ctl_mem_rdata` and `ctl_mem_rdata_valid` signals by the same amount. Connect the read data and valid outputs of your controller to the `ctl_rdata` and `ctl_rdata_valid` inputs of the ALTMEMPHY megafunction, which will then be passed straight through to the `local_rdata` and `local_rdata_valid` signals.

Full-Rate Controller

The read operation for a full-rate controller is shown in [Figure 3–25](#). The handshake mechanism remains similar to that of the half-rate controller except for the following differences:

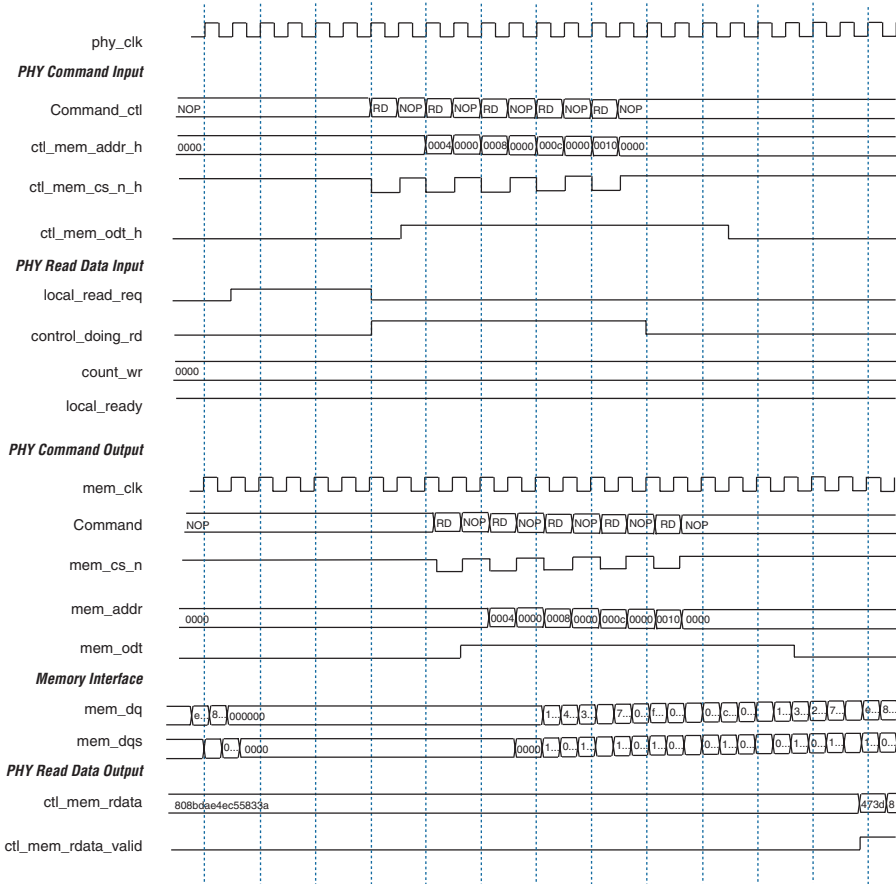
1. 1T versus 2T addressing.

As the burst size is fixed at four on the memory interface, and also the address and command data path is based on 1T addressing, it takes two memory clock cycles to retrieve the data from the memory for each read command, as shown in [Figure 3–25](#). The first memory cycle is the read command and the second memory cycle is the NOP command. Because of this arrangement, you will see a NOP command between the read commands.

2. Assertion of the chip select signal.

The chip select signal is asserted along with the read command because of the 1T addressing.

Figure 3–25. Read Commands for the Full-Rate Controller



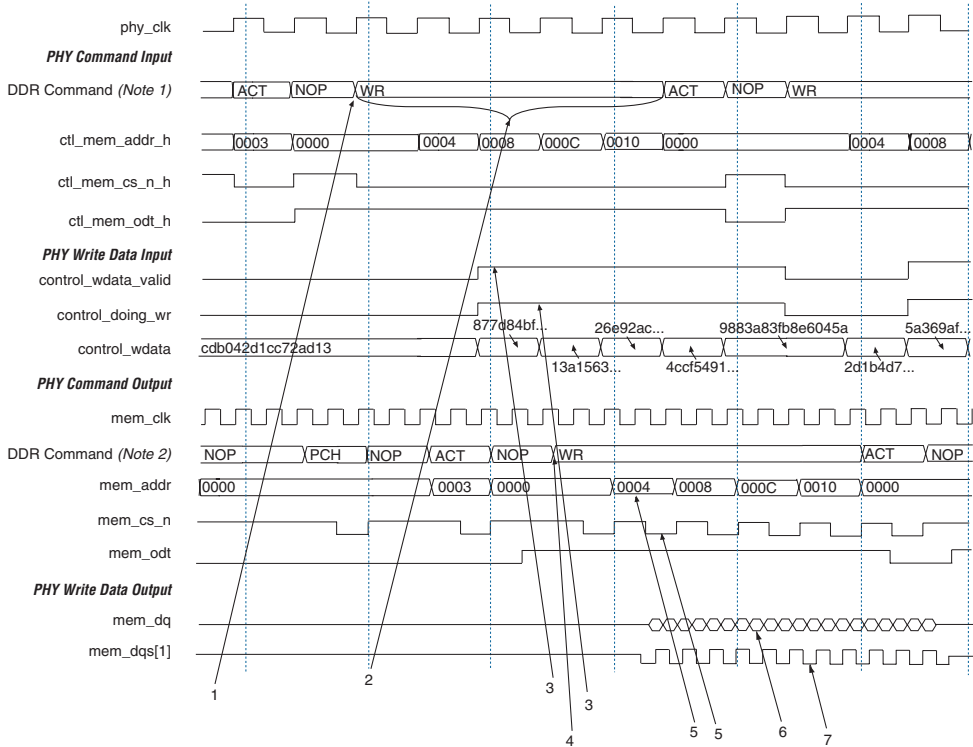
Handshake Mechanism Between Write Commands and Write Data

Half Rate Controller

The controller provides a signal (`ctl_wdata_valid`) to the `ALTMEMPHY` megafunction to tell it when to enable the `mem_dq` and `mem_dqs` output enables. It is the controller's responsibility to control the relative timing of the memory command signals (for example, `mem_cas_n` and `mem_we_n`) and the `ctl_doing_wr` signals, to meet the required memory write latency; therefore, this exact relationship is very important. The `ctl_wdata_valid` signal should be driven with the same signal as `ctl_doing_wr`. The `ctl_mem_dqs_burst` signal is used to manage incomplete write bursts and is required only for the

full-rate version of the ALTMEMPHY megafunction as the half-rate DDR/DDR2 High-Performance Controller does not support incomplete burst transactions.

Figure 3–26. Write Commands and Write Data



Notes to Figure 3–26:

- (1) DDR command shows the command comprised of the command signals (ctl_mem_ras_n, ctl_mem_cas_n, and ctl_mem_we_n) seen at the ALTMEMPHY input.
- (2) DDR command shows the command comprised of the command signals (mem_ras_n, mem_cas_n, and mem_we_n) seen at the memory interface.

Figure 3–26 shows the sequence of operations that happen during the write transactions. The write operation is explained step-by-step below. All the inputs to the ALTMEMPHY megafunction from the controller should be generated using `phy_clk`.



The signals under the PHY command input label are the signals from the controller to the ALTMEMPHY megafunction and the signals under the PHY command output label are the signals coming out of the ALTMEMPHY megafunction and input to the memory device.

1. Some of the address and command signals generated by the controller are:

- `ctl_mem_addr_h`
- `ctl_mem_cas_n_h`
- `ctl_mem_cs_n_h`
- `ctl_mem_ras_n_h`
- `ctl_mem_we_n_h`
- `ctl_mem_odt_h`

As can be seen in the waveform (Figure 3–26), the sequence of commands are PreCharge (PCH), Active (ACT), and No Operation (NOP), followed by a series of write commands.

2. The controller puts the five consecutive write commands with a starting address of $0 \times$ with increments of four (0000, 0004, 0008, 000c, 0010). This is shown at the top of Figure 3–26 under the PHY Command Input label.
3. The controller generates the following signals two clock cycles after the write command: `control_doing_wr` and `control_wdata_valid`, and must supply the data `control_wdata` along with these two signals. Refer to Figure 3–26 under the PHY Write Data Input label.
4. The ALTMEMPHY megafunction generates the write command at the memory interface after five-to-seven memory clock (`mem_clk`) cycles (to accommodate the write delay). The address and commands are generated using the negative edge of the memory clock. This is shown in Figure 3–24 under the PHY Command Output label.
5. The address and commands are of 2T period and the chip select is of 1T period.

6. The data (`mem_dq`) at the memory interface is presented after two memory clock cycles of write latency. The write latency is equal to the CAS latency -1 for DDR2 only (for DDR it is always 1). For this example, CAS latency is equal to three.
7. The generation of DQS signals is controlled using the `control_doing_wr` signal. This is very important as the generation of the DQS signal is also dependent on the CAS latency parameter.

Figure 3–26 shows that the controller state machine asserts the `control_wdata_valid` signal to perform a write transaction. The write data (`control_wdata`) should be available at the same time when both the `control_wdata_valid` and `control_doing_wr` signals are asserted high. The `control_wdata_valid` signal is asserted for five clock cycles (`phy_clk`) or ten clock cycles (`mem_clk`) to transfer five data transfers. The write data is only valid when the `control_wdata_valid` is asserted high and is held in the `wdata` registers until the write occurs. In Figure 3–26, the write data bus (`control_wdata`) is of width 64 and each burst transfer is of the length four. The 64-bit wide data is transferred to the memory as four 16-bit wide data, as shown by `mem_dq`. The DQS clock is twice the frequency of the clock that clocks the `control_wdata` and the DQ data is transferred during both the edges of DQS.

Full Rate Controller

The write operation for the full-rate controller is shown in Figure 3–27. The handshake mechanism remains similar to the half-rate controller except for the following differences:

1. 1T versus 2T addressing.

As the burst size is fixed at four on the memory interface, and also the address and command data path is based on 1T addressing, it takes two memory clock cycles to write data into the memory for each of the write command, as shown in Figure 3–27. The first memory cycle is the write command and the second memory cycle is the NOP command. Because of this arrangement, you will see a NOP command between the write commands.

2. Assertion of the chip select signal.

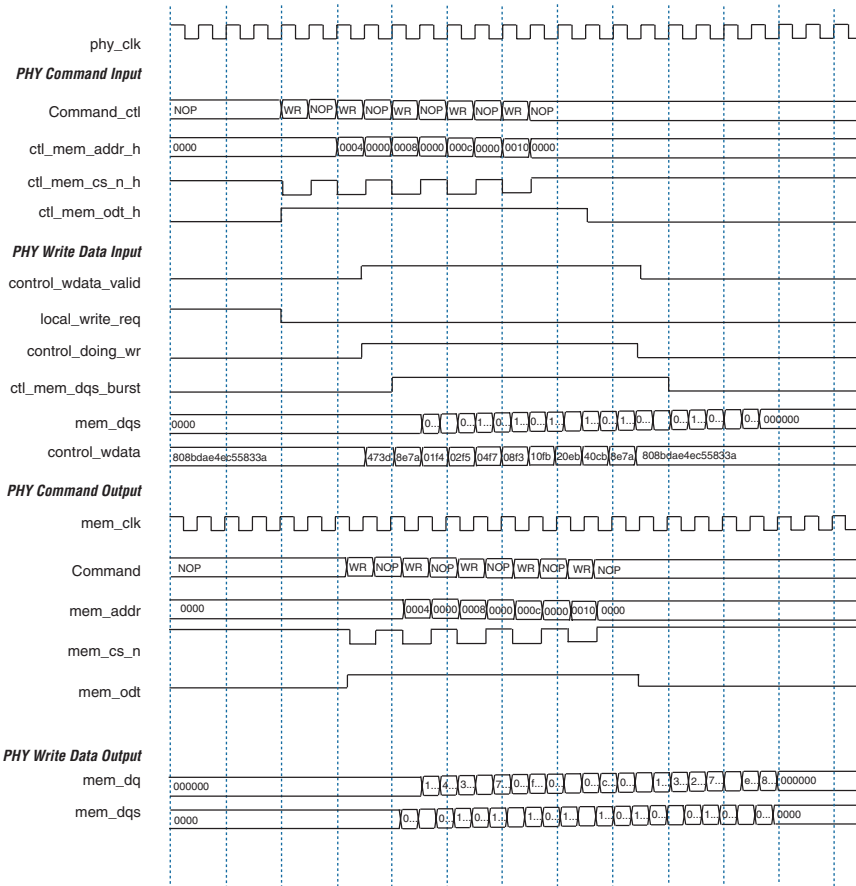
The chip select signal is asserted along with the write command because of the 1T addressing.

3. In order to support full-rate, the ALTMEMPHY megafunction has an extra control signal (`ctl_mem_dqs_burst`) that the controller must provide in addition to `ctl_mem_doing_wr`. In full-rate mode, the PHY allows separates control of the DQ and DQS output enables in order to support incomplete bursts. For example, if the memory burst length is four and the local side burst length is two, you may ask for a write of length one. In order to support this, the controller must be able to enable the DQS outputs for the full memory burst length (two clock cycles, four DQS edges) while only enabling the DQ outputs for the number of cycles that you requested (one clock cycle, two beats of data).



The `ctl_mem_dqs_burst` signal is asserted one cycle after the assertion of the `control_doing_wr` signal.

Figure 3–27. Write Commands for the Full-Rate Controller



For DDR SDRAM, the write latency is fixed at one memory clock cycle, but for DDR2 SDRAM, this value changes with the read CAS latency. Since the controller is running at half the rate of the memory clock, a latency change of one controller clock cycle is actually two memory clock cycles. The ALTMEMPHY megafunction allows you to dynamically insert an extra memory clock of delay in the address and command path to compensate for this. The insertion of delay is controlled by the `ADDR_CMD_ADD_1T` parameter and the `ctl_add_1t_ac_lat` signal. If `ADDR_CMD_ADD_1T` is set to the string `EXT_SELECT`, an extra cycle of latency can be dynamically inserted on the address and command outputs by asserting the `ctl_add_1t_ac_lat` input. This allows run-time control of the address and command latency. If

ADDR_CMD_ADD_1T is set to the string value "TRUE", the extra clock cycle of latency is always present, and if it is set to the string value "FALSE", the extra latency is never added.



The ADDR_CMD_ADD_1T parameter is set in the file `<project_dir>\<variation_name>_alt_mem_phy<family>.vl.vhd`. The family is either Stratix II or Stratix III. The `ctl_add_1t_ac_lat` signal is an input port to the module `<variation>_phy`, and you can drive the appropriate value when you instantiate your variation of the ALTMEMPHY megafunction.

For DDR2 SDRAM interfaces using un-buffered DIMMs or discrete devices, the value of ADDR_CMD_ADD_1T should be **TRUE** for odd CAS latencies (CL3 or CL5) and **FALSE** for even CAS latencies (CL4). For registered DIMMs, the value of ADDR_CMD_ADD_1T should be **FALSE** for odd CAS latencies (CL3 or CL5) and **TRUE** for even CAS latencies (CL4) shown in [Table 3-4](#).

For DDR SDRAM interfaces, the write latency is fixed at one cycle. You should use the settings for CAS latencies shown in [Table 3-4](#).

[Table 3-4](#) shows the setting of ADDR_CMD_ADD_1T for different values of CAS latency and DIMM settings.

<i>Table 3-4. ADDR_CMD_ADD_1T Settings</i>		
Memory and CL	DIMM Type	ADDR_CMD_ADD_1T
DDR SDRAM	Unbuffered	FALSE
	Registered	TRUE
DDR2 SDRAM, CL3	Unbuffered	TRUE
	Registered	FALSE
DDR2 SDRAM, CL4	Unbuffered	FALSE
	Registered	TRUE
DDR2 SDRAM, CL5	Unbuffered	TRUE
	Registered	FALSE

The timing of the ODT signal can be controlled in the same way but is independent of the address and command latency. If the ODT_ADD_1T parameter is set to **EXT_SELECT**, an extra cycle of latency can be dynamically inserted on the ODT command outputs by asserting the `ctl_add_1t_odt_lat` input. This allows separate run-time control of the latency of the ODT signal. If ODT_ADD_1T is set to **TRUE**, the extra clock cycle of latency is always present. If ODT_ADD_1T is set to **FALSE**, the extra latency is never added.

GUI Parameters Tables 4–1 through 4–3 show the GUI parameters that are:

- Common to All Memory Types
- DDR/DDR2 Specific
- QDRII Specific

Table 4–1. Parameters Common to All Memory Types (Part 1 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
PLL_REF_CLK_MHZ	integer	see ALTPLL	Frequency of PLL Reference Clock (MHz).	General Settings
FAMILY	string	Stratix II, Cyclone III, Stratix III, Stratix II GX	Target FPGA family for the new PHY.	General Settings
MEM_IF_CLK_MHZ	double	50 - 500 MHz	Frequency of Memory Clock (MHz).	General Settings
LOCAL_IF_CLK_MHZ	double	25 - 500 MHz	Frequency of Local Interface Clock (MHz).	General Settings
LOCAL_IF_DRATE	string	FULL, HALFT	Specifies whether the datapath is full or half-rate.	General Settings
MEM_IF_MEMTYPE	string	DDR SDRAM, DDR2 SDRAM, QDRII, RLDRAMII	This is mostly a GUI control which will set up a number of other defaults. It may be used to set up default pin names for the generated wrapper file.	General Settings
SPEED_GRADE	integer	Stratix II: 3, 4, 5 Cyclone III: Stratix III:	Speed grade of selected device. Necessary for checking PLL settings.	General Settings
MEM_BL	integer	2, 4, 8 QDRII = 4, DDR/2 = 4 if MEM_IF_DWIDTH_R ATIO = 4 or 2, 4 if MEM_IF_DWIDTH_R ATIO = 2	Burst length setting of the memory.	Memory Init
MEM_TCL	string	2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0 (DDR) 2.0, 2.5 (QDRII)	Sets the memory CAS latency.	Memory Init
MEM_IF_CLK_PAIR_COUNT	integer	1 to 16	Specifies the width of the output clock bus (in differential pairs) for driving off the FPGA to the memory.	Memory Settings

Table 4–1. Parameters Common to All Memory Types (Part 2 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
MEM_IF_CS_WIDTH	string	1, 2, 4, 8 (DDR) 1, 2, (QDRII)	Number of chipselects of memory (depth).	Memory Settings
MEM_IF_DM_PINS_EN	boolean	TRUE, FALSE	Set to TRUE if DM pins and DM logic are required.	Memory Settings
MEM_IF_DQSN_EN	boolean	TRUE, FALSE	Set to TRUE if DQSN pins are required.	Memory Settings
MEM_IF_DQ_PER_DQS	integer	4, 8 (DDR) 8, 9, 16, 18, 32, 36 (QDRII)	Number of DQ[] or D[] bits per DQS output pin.	Memory Settings
MEM_IF_DWIDTH	integer	4 to <i>unbounded in steps of MEM_IF_DQ_PER_DQS</i>	Width of external memory read and write databus.	Memory Settings
MEM_IF_PRESET	string	From memory editor	Memory editor preset name. Allows selecting, editing, deleting, and adding new sets of presets in a memory editor window.	Memory Settings
MEM_IF_ROWADDR_WIDTH	integer	8, 10, 12, 13, etc. (DDR) 15 - 23 (QDRII)	Number of address bits.	Memory Settings
AC_CLK_SELECT	String	0, 90, 180, 270 dedicated	Used to select the clock used for launching the address and command signals.	PHY Settings
AC_PHASE	integer	0 - 359	When <code>ac_clk_select</code> is set to dedicated , this sets the phase shift used by the PLL for generating the address and command clock. Otherwise, the GUI displays the phase value corresponding to the selected <code>ac_clk_select</code> value.	PHY Settings
DLL_EXTERNAL	boolean	TRUE, FALSE	If TRUE - the DLL instance resides outside of PHY and all the necessary signals are imported from PHY inputs. If FALSE - the DLL instance is inside the PHY and no DLL signals are exported.	PHY Settings
BOARD_SKEW_PS	integer	0 - 200	Skew on users board between all traces between the Memory and FPGA (ps).	PHY Settings

Table 4–1. Parameters Common to All Memory Types (Part 3 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
DEDICATED_MEMORY_CLK_EN	boolean	FALSE	If TRUE, the memory clock uses a dedicated PLL output. If FALSE, the memory clock uses the DDIO output.	PHY Settings
FAST_SIMULATION_EN	boolean	TRUE, FALSE	May be used to calibrate using just one DQ pin. It enables faster simulation of the calibration sequence.	PHY Settings
DLL_EXTERNAL	boolean	TRUE, FALSE	If TRUE, the DLL is not instanced internally in the PHY and must be connected up externally. The <code>dqs_delay_ctrl_import</code> and the <code>dll_reference_clk</code> signals must then be connected up to a DLL instance.	PHY Settings
PLL_RECONFIG_PORTS_EN	boolean	TRUE, FALSE	If TRUE, the multiplexor to the PLL reconfig block shall be switched, dependant upon the <code>pll_reconfig_enable</code> input.	PHY Settings

Table 4–2. Parameters that are DDR/DDR2 Specific (Part 1 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
ENABLE_ECC	boolean	TRUE, FALSE	Enables ECC functionality.	Local Interface
LOCAL_IF_TYPE_AVALON	string	TRUE, FALSE	Boolean flag specifying if the interface is Avalon or not.	Local Interface
LOCAL_IF_BURST_LENGTH	integer	1, 2, 4	The burst length of the Avalon interface.	Memory Init
MEM_BTYPE	string	Sequential or interleaved	Sets the memory burst order of the memory.	Memory Init
MEM_DLL_EN	string	Yes or No	Enables the DLL in the memory device.	Memory Init
MEM_DRV_STR	string	Normal or reduced	Sets the memory drive strength	Memory Init
MEM_ODT	string	Disabled, 50, 75, and 150	Sets the memory ODT value.	Memory Init

Table 4–2. Parameters that are DDR/DDR2 Specific (Part 2 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
MEM_IF_COLADDR_WIDTH	Integer	8 - 13	Number of column address bits	Memory Settings
MEM_IF_PCHADDR_BIT	integer	8 or 10	Which bit of the address bus to use as the precharge address bit	Memory Settings
MEM_IF_BANKADDR_WIDTH	interger	2, 3	Number of bank address bits.	Memory Settings
MEM_IF_CS_PER_DIMM	integer	1, 2	Number of chipselects on each DIMM.	Memory Settings
MEM_IF_TINIT_US	double	See the memory device datasheet	Memory initialisation time (us).	Memory Timing
MEM_IF_TMRD_NS	double	See the memory device datasheet	Memory mode register load period (ns).	Memory Timing
MEM_IF_TREFI_US	double	See the memory device datasheet	Memory refresh interval (us).	Memory Timing
MEM_IF_TRFC_NS	double	See the memory device datasheet	Memory refresh period (us)	Memory Timing
MEM_TAC_PS	integer	400 - 600	DQ output access time from CK/CK# (ps)	Memory Tlming
USER_REFRESH_EN	boolean	TRUE, FALSE	Allows the user to control when the refresh happens.	Local Interface
MEM_TDHA_PS	integer	200 - 500	DQ and DM input hold time relative to DQS (ps)	Memory Timing
MEM_TDQSK_PS	integer	300 - 600	DQS output access time from CK/CK# (ps).	Memory Timing
MEM_TDQSQ_PS	integer	200 - 400	DQS-DQ skew, DQS to last DQ valid, per group, per access (ps).	
MEM_TDQSS_CK	double	0.25	Positive DQS latching edge to associated clock edge (t_{CK}).	Memory Timing
MEM_TDSA_PS	integer	200 - 500	DQ and DM input setup time relative to DQS (ps)	Memory Timing
MEM_TDSH_CK	double	0.2	DQS falling edge to CK rising - hold time (t_{CK}).	Memory Timing
MEM_TDSS_CK	double	0.2	DQS falling edge to CK rising - setup time (t_{CK}).	Memory Timing
MEM_TIHA_PS	integer	300 - 700	Address and control input hold time (ps).	Memory Timing
MEM_TISA_PS	integer	300 - 700	Address and control input setup time (ps).	Memory Timing
MEM_TQHS_PS	integer	300 - 500	DQ hold skew factor (ps).	Memory Timing

Table 4–2. Parameters that are DDR/DDR2 Specific (Part 3 of 3)

Parameter Name	Type	Valid Range	Description	GUI Panel
MEM_IF_TRP_NS	double	See the memory device datasheet	Memory row precharge period (ns).	Memory Timing
MEM_IF_TWR_NS	double	See the memory device datasheet	Memory write recovery time (ns)	Memory Timing
MEM_IF_TWR_CK	integer	See the memory device datasheet	Memory write recovery time (t_{CK}).	Memory Timing
MEM_IF_TWTR_CK	integer	See the memory device datasheet	Memory write to read period (t_{CK}).	Memory Timing

Table 4–3. Parameters that are QDRII Specific

Parameter Name	Type	Valid Range	Description	GUI Panel
MEM_TSA_PS	integer	200 - 500	Address setup time to K CLock Rise (t_{SA}).	Memory Timing
MEM_TSC_PS	integer	200 - 500	Control setup time to K Clock Rise (t_{SC}).	Memory Timing
MEM_THA_PS	integer	200 - 500	Address hold time after K Clock Rise (t_{CH}).	Memory Timing
MEM_THC_PS	integer	200 - 500	Control hold time after K Clock Rise (t_{HC}).	Memory Timing
MEM_TSD_PS	integer	200 - 500	D setup time to K Clock Rise (t_{SD}).	Memory Timing
MEM_THD_PS	integer	200 - 500	D hld time to K CLock Rise (t_{HD}).	Memory Timing
MEM_TCQHQV_PS	integer	200 - 500	Echo clock high to data valid (t_{CQHQV}).	Memory Timing
MEM_TCQHQX_PS	integer	200 - 500	Echo clock high to data invalid (t_{CQHQX}).	Memory Timing

DDR/DDR2/ DDR3 Port Lists

Tables 4–4 through 4–11 show the DDR/DDR2 port list parameters for:

- Clocking
- PLL Reconfiguration Interface (Optional - for Stratix II Series Only)
- External DLL Interface (Optional - for Stratix II Series Only)
- Interface to the Memory Controller
- User Interface for the Controller
- Datapath Interface for the Controller
- I/O Interface to the External Memory Device
- ALTMEMPHY Calibration Status Interface

Signal Name	Type	Width	Description
global_reset_n	input	1	The asynchronous reset input to the controller. All other reset signals are derived from resynchronized versions of this. This signal holds the complete ALTMEMPHY, including the PLL, in reset while low.
soft_reset_n	input	1	The asynchronous reset input to reset controller. This reset causes the PHY to pulse the reset to the PLL on detection of a falling edge, and holds the rest if the ALTMEMPHY in reset while the signal is low.
phy_clk	output	1	The ALTMEMPHY clock provided to the user. All user inputs and outputs to the ALTMEMPHY are synchronous to this clock.
pll_ref_clk	input	1	The reference clock input to PLL.
reset_phy_clk_n	output	1	Asynchronous Reset - asserted asynchronously and de-asserted synchronously to associated clock domain.
reset_request_n	output	1	Reset request output that indicates when the PLL outputs are not locked. Use this as a reset request input to any system-level reset controller you may have. Note that this signal is always low while the PLL is locking, and so any reset logic using it is advised to detect a reset request on a falling-edge rather than by level detection.

Table 4-5. Port Lists (PLL Reconfiguration Interface – Optional, for Stratix II Series Only)

Signal Name	Type	Width	Description
pll_reconfig_enable	input	1	Allows access to the PLL Reconfig block. Hold this signal low in normal operation. While the ALTMEMPHY is held in reset (via the <code>soft_reset_n</code> signal), and the <code>reset_request_n</code> signal is 1, it is safe to reconfigure the PLL. To reconfigure the PLL, set this signal to 1 and use the other <code>pll_reconfig</code> signals to access the PLL. When finished reconfiguring, set this signal to 0 , and then set the <code>soft_reset_n</code> signal to 1 to bring the ALTMEMPHY out of reset. Note that for this signal to work, the <code>PLL_RECONFIG_PORTS_EN</code> GUI parameter must be set to true .
pll_reconfig_write_param	input	9	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_read_param	input	9	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig	input	1	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_counter_type	input	4	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_counter_param	input	3	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_data_in	input	9	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_busy	output	1	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_data_out	output	9	See the <i>ALTPLL_RECONFIG User Guide</i> for more information.
pll_reconfig_clk	output	1	Synchronous clock to use for any logic accessing the <code>pll_reconfig</code> interface.
pll_reconfig_reset	output	1	Synchronous clock to use for any logic accessing the <code>pll_reconfig</code> interface.

Table 4–6. Port Lists (External DLL Interface – Optional, for Stratix II Series Only)

Signal Name	Type	Width	Description
dqs_delay_ctrl_export	output	6	Allows sharing DLL in this ALTMEMPHY instance with another ALTMEMPHY instance. Connect the <code>export</code> port on the ALTMEMPHY instance with a DLL to the <code>import</code> port on the other ALTMEMPHY instance.
dqs_delay_ctrl_import	input	6	Allows the use of DLL in another ALTMEMPHY instance in this ALTMEMPHY instance. Connect the <code>export</code> port on the ALTMEMPHY instance with a DLL to the <code>import</code> port on the other ALTMEMPHY instance.
dll_reference_clk	output	1	Reference clock to feed to an externally instantiated DLL.

Table 4–7. Port Lists (Interface to the Memory Controller) *Note (1)* (Part 1 of 3)

Signal Name	Type	Width	Description
ctl_add_1t_ac_lat	input	1	When asserted, one extra address and command clock cycle (1T) of latency is inserted in the address and command path if <code>ADDR_CMD_ADD_1T</code> is set to EXT_SELECT .
ctl_add_intermediate_regs	Input	1	When asserted, an additional intermediate register or registers is included in the address and command path if <code>ADDR_CMD_ADD_INTERMEDIATE_REGS</code> is set to EXT_SELECT . When the GUI generates an ALTMEMPHY, this signal is automatically set to meet core timing requirements, dependant upon the <code>AC_PHASE</code> being used.
ctl_address	output	LOCAL_IF_AWIDTH	The address corresponding to a write or read request.
ctl_be	output	LOCAL_IF_DWIDTH/8	The output to the controller indicating the byte-enable flags.
ctl_doing_rd	input	1	The active-high signal from the controller specifying that a read command has been issued to the external RAM.

Table 4–7. Port Lists (Interface to the Memory Controller) Note (1) (Part 2 of 3)

Signal Name	Type	Width	Description
ctl_init_done	input	1	The active-high signal specifying that the controller has initialized the memory and the calibration process should begin.
ctl_negedge_en	input	1	This signal is used if ADDR_CMD_NEGEDGE_EN is set to EXT_SELECT . If true, the address and command signals are output on the falling edge of the address and command clock, ac_clk_2x. If false, the address and commands signals are output on the rising edge of the address and command clock. When set to EXT_SELECT , the ctl_negedge_en top level input determines whether the edge is used.
ctl_read_req	output	1	The active-high signal requesting a read command to the address on the ctl_address bus.
ctl_ready	input	1	The controller-ready signal which indicates that the currently asserted read or write request has been accepted. The address of the request is sampled when both the ready and request signals are high.
ctl_size	output	LOCAL_BURST_LEN_BITS	The output to the controller indicating the size (length) of the burst transfer, fixed at 1 for this version.
ctl_usr_mode_rdy	output	1	The active-high signal specifying the ALTMEMPHY has finished its calibration and is ready to accept user read or write requests.
ctl_wdata	output	MEM_IF_DWIDTH * DWIDTH_RATIO	The write data from the ALTMEMPHY to the controller.
ctl_wdata_req	input	1	The controller-request for write data; not required when the controller has an Avalon interface.
ctl_write_req	output	1	The active-high signal specifying that a write command should be issued to the address on the ctl_address signal.
ctl_refresh_ack	input	1	The active-high valid signal from the controller acknowledging the refresh request.
ctl_refresh_req	output	1	The output to the controller requesting a refresh.

Table 4–7. Port Lists (Interface to the Memory Controller) Note (1) (Part 3 of 3)			
Signal Name	Type	Width	Description
ctl_burstbegin	output	1	The output to the controller indicating the start of a burst.
ctl_rdata	input	MEM_IF_DWIDTH * DWIDTH_ RATIO	The read data from the controller.
ctl_rdata_valid	input	1	The active-high valid signal for the controller read data.
ctl_add_1t_odt_lat	input	1	When asserted one extra address and command clock cycle (1T) of latency is inserted in the address and command ODT path if ODT_ADD_1T is set to EXT_SELECT .

Note to Table 4–7:

(1) Interface signals to the controller either through the sequencer or user interface.

Table 4–8. Port Lists (User Interface for the Controller) (Part 1 of 2) Note (1),			
Signal Name	Type	Width	Description
local_address	input	LOCAL_IF_A WIDTH	The address corresponding to a write or read request.
local_be	input	LOCAL_IF_D WIDTH / 8	The input to ALTMEMPHY indicating the byte-enable flags.
local_read_req	input	1	The active-high signal requesting a read command to the address on the ctl_address bus.
local_ready	output	1	The controller-ready signal which indicates that the currently asserted read or write request has been accepted. The address of the request is sampled when both the ready and request signals are high.
local_size	input	LOCAL_ BURST_LEN_ BITS	The output to the controller indicating the size (length) of the burst transfer, fixed at 1 for this version.
local_wdata	input	LOCAL_IF_ DWIDTH	The write data from the user to/from the ALTMEMPHY megafunction.
local_wdata_req	output	1	The controller request for write data; not required when the controller has an Avalon interface.

Table 4–8. Port Lists (User Interface for the Controller) (Part 2 of 2) Note (1),

Signal Name	Type	Width	Description
local_write_req	input	1	The active-high signal specifying that a write command should be issued to the address on the <code>ctl_address</code> signal.
local_refresh_req	input	1	The ALTMEMPHY receives refresh requests from the local interface and passes them to the controller via <code>ctl_refresh_req</code> when in user mode (<code>ctl_usr_mode</code> output is high).
local_burstbegin	input	1	The ALTMEMPHY receives the <code>burstbegin</code> signal from the local interface and passes it to the controller via <code>ctl_burstbegin</code> when in user mode (<code>ctl_usr_mode</code> output is high).
local_rdata	output	LOCAL_IF_DWIDTH	When <code>ctl_usr_mode</code> is high, this output passes through the read data from the controller to the local interface. Otherwise, it is tied low.
local_rdata_valid	output	1	When <code>ctl_usr_mode</code> is high, this output passes through the read data valid signal (<code>ctl_rdata_valid</code>) from the controller to the local interface. Otherwise, it is tied low.
local_init_done	output	1	When <code>ctl_usr_mode</code> is high, this output passes through the controller's initialization done signal (<code>ctl_init_done</code>) from the controller to the local interface. Otherwise, it is tied low.
local_refresh_ack	output	1	When <code>ctl_usr_mode</code> is high, this output passes through the controller's refresh acknowledge signal (<code>ctl_refresh_ack</code>) from the controller to the local interface. Otherwise, it is tied low.

Note to Table 4–8:

(1) Passed through PHY to the controller.

Table 4–9. Port Lists (Datapath Interface for the Controller – address/cmd and wdata/rdata) (Part 1 of 2)
Note (1), (2)

Signal Name	Type	Width	Description
ctl_mem_addr_h	input	MEM_IF_ROW_ADDR_WIDTH	The row or column address which is sent to the external memory.
ctl_mem_addr_l	input	MEM_IF_ROW_ADDR_WIDTH	The row or column address which is sent to the external memory.
ctl_mem_ba_h	input	MEM_IF_BANKADDR_WIDTH	The bank address which is sent to the external memory.
ctl_mem_ba_l	input	MEM_IF_BANKADDR_WIDTH	The bank address which is sent to the external memory.
ctl_mem_be	input	MEM_IF_DM_WIDTH / 8	The optional byte-enable signals for the write data to the external memory. The ALTMEMPHY megafunction converts the byte enables into memory mem_dm signals. If mem_dm pins are not required (mem_dm_pins set to FALSE), the mem_dm logic is not generated and the mem_dm pins are not instantiated.
ctl_mem_cas_n_h	input	1	The column-address strobe signal from the controller to the memory.
ctl_mem_cas_n_l	input	1	The column-address strobe signal from the controller to the memory.
ctl_mem_cke_h	input	MEM_IF_CS_WIDTH	The clock-enable signal from the controller to the memory.
ctl_mem_cke_l	input	MEM_IF_CS_WIDTH	The clock-enable signal from the controller to the memory.
ctl_mem_cs_n_h	input	MEM_IF_CS_WIDTH	The chip-select signal from the controller to the memory.
ctl_mem_cs_n_l	input	MEM_IF_CS_WIDTH	The chip select signal from the controller to the memory.
ctl_mem_dqs_burst	input	1	Controls the DQS output enables of the DQS pins. See the <i>ALTMEMPHY User Guide</i> for specific details of the timing of this signal.
ctl_mem_odt_h	input	MEM_IF_CS_WIDTH	The on-die termination signal from the controller to the memory.
ctl_mem_odt_l	input	MEM_IF_CS_WIDTH	The on-die termination signal from the controller to the memory.

Table 4–9. Port Lists (Datapath Interface for the Controller – address/cmd and wdata/rdata) (Part 2 of 2)
Note (1), (2)

Signal Name	Type	Width	Description
ctl_mem_ras_n_h	input	1	The row-address strobe signal from the controller to the memory.
ctl_mem_ras_n_l	input	1	The row-address strobe signal from the controller to the memory.
ctl_mem_rdata	output	LOCAL_IF_DWIDTH	Captured, resynchronized, and demultiplexed read data from the ALTMEMPHY to the controller.
ctl_mem_rdata_valid	output	1	Indicates when the <code>ctl_mem_rdata</code> is valid.
ctl_mem_wdata	input	LOCAL_IF_DWIDTH * DWIDTH_RATIO	The write data bus, which has valid data in the same clock cycles that <code>control_wdata_valid</code> is asserted.
ctl_mem_wdata_valid	input	1	Used to generate the <code>mem_dq</code> output enable. See the <i>ALTMEMPHY User Guide</i> for specific details on the timing of this signal.
ctl_mem_we_n_h	input	1	The write-enable signal from the controller to the memory.
ctl_mem_we_n_l	input	1	The write-enable signal from the controller to the memory.

Note to Table 4–9:

- (1) address/cmd and wdata/rdata
- (2) “_h” and “_l” stand for high and low. They signify in which half of the clock cycle the data is output. The _h data is output when the corresponding clock, for example `ac_clk_2x` is high. The _l data is output when the `ac_clk_2x` clock is low.

Table 4–10. Port Lists (I/O Interface to the External Memory Device) Note (1) (Part 1 of 2)

Signal Name	Type	Width	Description
mem_addr	output	MEM_IF_ROWADDR_WIDTH	The memory row and column address bus.
mem_ba	output	MEM_IF_BANKADDR_WIDTH	The memory bank address bus.
mem_cas_n	output	1	The memory column address strobe.
mem_cke	output	MEM_IF_CS_WIDTH	The memory clock enable.
mem_clk	output	MEM_IF_CLK_PAIR_COUNT	The memory clock, positive edge clock.
mem_clk_n	output	MEM_IF_CLK_PAIR_COUNT	The memory clock, negative edge clock.
mem_cs_n	output	MEM_IF_CS_WIDTH	The memory chip select signal.

Table 4–10. Port Lists (I/O Interface to the External Memory Device) Note (1) (Part 2 of 2)

Signal Name	Type	Width	Description
mem_dm	output	MEM_IF_DM_WIDTH	The optional memory data mask bus.
mem_dq	bidi	MEM_IF_DWIDTH	The memory bidirectional data bus.
mem_dqs	bidi	MEM_IF_DWIDTH / MEM_IF_DQ_PER_DQS	The memory bidirectional data strobe bus.
mem_dqsn	bidi	MEM_IF_DWIDTH / MEM_IF_DQ_PER_DQS	The memory bidirectional data strobe bus.
mem_odt	output	MEM_IF_CS_WIDTH	The memory on-die termination control signal.
mem_ras_n	output	1	The memory row address strobe.
mem_reset_n	output	1	The memory-reset signal.
mem_we_n	output	1	The memory write-enable signal.

Note to Table 4–10:

(1) Connected to WYSIWYGS/pad atoms.

Table 4–11. Port Lists (ALTMEMPHY Calibration Status Interface)

Signal Name	Type	Width	Description
resynchronisation_successful	output	1	Active-high signal that is set to indicate successful calibration of the read data resynchronisation clock phase.
postamble_qsSuccessful	output	1	Active-high signal that is set to indicate successful read postamble calibration.
tracking_successful	output	1	Active-high signal that is set to indicate successful mimic path VT variation tracking operation.
tracking_adjustment_up	output	1	Active-high signal that is pulsed to indicate that the mimic path tracking has adjusted the resynchronisation clock phasing upwards.
tracking_adjustment_down	output	1	Active-high signal that is pulsed to indicate that the mimic path tracking has adjusted the resynchronisation clock phasing downwards.

QDRII Port Lists

Tables 4–12 through 4–16 show the QDRII port list parameters for:

- Clocking
- Interface to Memory Controller
- Datapath Interface for the Controller
- I/O Interface to the External Memory Device
- PHY Calibration Status Interface

Table 4–12. QDRII Port List (Clocking)

Signal Name	Type	Width	Description
global_reset_n	input	1	Asynchronous reset input to reset the controller. All other reset signals are derived from resynchronised versions of this. This signal holds the complete PHY including the PLL in reset while low.
reset_request_n	output	1	Reset request output that indicates when the PLL outputs are not locked. Use this as a reset request input to any system-level reset controller you may have.
soft_reset_n	input	1	Asynchronous reset input to reset the controller. This reset causes the PHY to pulse the reset to the PLL on detection of a falling edge, and it holds the rest if the PHY in reset while the signal is low.
phy_clk	output	1	PHY clock provided to the user, all user inputs and outputs are synchronous to this clock.
pll_ref_clk	input	1	Reference clock input to PLL.
reset_phy_clk_n	output	1	Asynchronous Reset - asserted asynchronously and de-asserted synchronously to associated clock domain.

Table 4–13. QDRII Port List (Interface to the Memory Controller) *Note (1)*

Signal Name	Type	Width	Description
ctl_usr_mode_rdy	output	1	Active high signal specifying the PHY has finished its calibration and is ready to accept user read or write requests.

Note to Table 4–13:

(1) Calibration control or passed through from the user interface.

Table 4–14. QDRII Port List (Datapath Interface for the Controller) Note (1)			
Signal Name	Type	Width	Description
ctl_mem_addr_h	input	MEM_IF_ROW_ADDR_WIDTH	Write address from the controller to the external memory.
ctl_mem_addr_l	input	MEM_IF_ROW_ADDR_WIDTH	Read address from the controller to the external memory.
ctl_mem_be	input	LOCAL_IF_DWIDTH / 8	Optional byte enable signals for the write data to the external memory. The PHY converts the byte enables into memory DM signals. If DM pins are not required (MEM_DM_PINS set to false), the DM logic is not generated and the DM pins are not instantiated.
ctl_mem_rdata	output	LOCAL_IF_DWIDTH	Captured, resynchronised, and de-multiplexed read data from the PHY to the controller.
ctl_mem_rdata_valid	output	1	Indicates when the <code>ctl_mem_rdata</code> is valid.
ctl_mem_wdata	input	MEM_IF_DWIDTH * DWIDTH_RATIO	The write databus, which has valid data in the same clock cycles that <code>control_wdata_valid</code> is asserted.
ctl_mem_wdata_valid	input	1	Used to generate the DQ output enable. See the <i>ALTMEMPHY User Guide</i> for specific details on the timing of this signal.
ctl_mem_wps_n	input	1	Write enable signal from the controller to the memory (QDRII). When this signal is asserted, a write request is issued to the address presented on the <code>ctl_mem_addr_h</code> port.
ctl_mem_rps_n	input	1	Read enable signal from the controller to the memory (QDRII). When this signal is asserted, a read request is issued to the address presented on the <code>ctl_mem_addr_l</code> port.

Note to Table 4–14:

(1) Address and command and wdata/rdata.

Table 4–15. QDRII Port List (I/O Interface to the External Memory Device) Note (1)

Signal Name	Type	Width	Description
mem_addr	output	MEM_IF_ROW_ADDR_WIDTH	Memory address bus.
mem_clk	output	MEM_IF_CLK_PAIR_COUNT	Memory clock, positive edge clock (K).
mem_clk_n	output	MEM_IF_CLK_PAIR_COUNT	Memory clock, positive edge clock (K#) 180° offset from mem_clk.
mem_d	output	MEM_IF_DQI_DTH	Memory data bus. D input to QDRII device.
mem_dm	output	MEM_IF_DM_WIDTH	Memory write select. BWS# input to QDRII device.
mem_dq	input	MEM_IF_DWI_DTH	Memory data bus. Q output from QDRII device.
mem_dqs	input	MEM_IF_DWI_DTH / MEM_IF_DQ_PER_DQS	Memory read clock (CQ).
mem_dqsn	input	MEM_IF_DWI_DTH / MEM_IF_DQ_PER_DQS	Memory read clock (CQ#).
mem_doff_n	output	1	Memory DLL disable control.
mem_rps_n	output	MEM_IF_CS_WIDTH	Memory read enable signal.
mem_wps_n	output	MEM_IF_CS_WIDTH	Memory write enable signal.

Note to Table 4–15:

(1) Connected to WYSIWYGS/pad atoms.

Table 4–16. QDRII Port List (PHY Calibration Status Interface)

Signal Name	Type	Width	Description
resynchronisation_successful	output	1	Active high signal that shall be set to indicate successful calibration of the read data resynchronisation clock phase.

Latency Numbers

There are two types of latencies that exist while designing with memory controllers, they are read and write latencies. Altera® defines the read and write latencies as follows:

- Read Latency—the amount of time it takes for the read data to appear at the user/local interface after you initiate the read request.
- Write Latency—the amount of time it takes for the write data to appear at the memory interface after you initiate the write request.

The basic assumptions made while calculating the latencies are:

- Reading and writing to the rows that are already open
- Local Ready signal is asserted high (no wait states)
- Latency is defined using the user (local) side frequency and absolute time (ns)



For the half-rate controller, the user (local) side frequency is half of the memory interface frequency. For the full-rate controller, the user (local) side frequency is equal to the memory interface frequency.

Altera defines the read and write latencies both in terms of the local interface clock frequency and the absolute time. This applies to the Stratix® II, Stratix III, and Cyclone® III device families and the following memory controllers:

- Legacy DDR/DDR2 controller
- High Performance half-rate controller
- High Performance full-rate controller

Tables A-1 and A-2 list the latency for the legacy DDR2 full-rate controller for the Stratix II and Cyclone II device families, respectively.

Table A-1. Latency for Legacy DDR2 Full-Rate Controller (for Stratix II)		
<i>Note (1) (Part 1 of 2)</i>		
Latency Type	Latency in Cycles	Latency in Time (ns)
Read	13	49

Table A-1. Latency for Legacy DDR2 Full-Rate Controller (for Stratix II)
Note (1) (Part 2 of 2)

Latency Type	Latency in Cycles	Latency in Time (ns)
Write	9	34

Note to Table A-1:

(1) DDR2 memory interface frequency = 267 MHz.

Table A-2. Latency for Legacy DDR2 Full-Rate Controller (for Cyclone II)
Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	13	78
Write	9	54

Note to Table A-2:

(1) DDR2 memory interface frequency = 167 MHz.

The read and write latency as applied to high-performance controllers. Refer to [Table A-3](#) for the glossary of terms..

Table A-3. Glossary of Terms

Term	Description
Controller latency	local_read_req to control_doing_rd.
Command output latency	control_doing_rd to mem_cs_n.
CAS latency	Read command to DQ data appearing on the bus.
ALTMEMPHY read data input latency	Read data appearing on the local interface.
Write data latency	Write data appearing on the memory interface.

Read Latency

The read latency in the high-performance controllers is made out of four components:

Read Latency = Controller latency + Command output latency + CAS latency + PHY read data input latency

Write Latency

The write latency in the high-performance controllers is made out of three components:

Write Latency = Controller Latency + Write Data latency



The latencies due to the above components are listed (in the same order) in [Tables A-4 through A-8](#).

Table A-4. Latency for DDR2 Half-Rate High-Performance Controller (for Stratix II) Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	$6 + 4 + 1.5 + 8.5 = 20$	60
Write	$8 + 3 = 11$	33

Note to [Table A-4](#):

(1) DDR2 memory interface frequency = 333 MHz.

Table A-5. Latency for DDR2 Full-Rate High-Performance Controller (for Stratix II) Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	$6 + 4 + 1.5 + 8.5 = 20$	75
Write	$8 + 2 = 10$	33

Note to [Table A-5](#):

(1) DDR2 memory interface frequency = 267 MHz.

Table A-6. Latency for DDR2 Half-Rate High-Performance Controller (for Stratix III) Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	$6 + 4 + 1.5 + 8.5 = 20$	60
Write	$8 + 3 = 11$	33

Note to [Table A-6](#):

(1) DDR2 memory interface frequency = 333 MHz.

Table A-7. Latency for DDR2 Half-Rate High-Performance Controller (for Cyclone III) Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	$6 + 4 + 1.5 + 5.5 = 17$	85
Write	$8 + 3 = 11$	55

Note to Table A-7:

- (1) DDR2 memory interface frequency = 200 MHz.

Table A-8. Latency for DDR2 Full-Rate High-Performance Controller (for Cyclone III) Note (1)

Latency Type	Latency in Cycles	Latency in Time (ns)
Read	$5 + 3 + 3 + 8 = 19$	114
Write	$8 + 2 = 10$	60

Note to Table A-8:

- (1) DDR2 memory interface frequency = 167 MHz.