

# RLDRAM II Controller

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## MegaCore Function User Guide



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UG-RLDRAM-8.0



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# 1. About This MegaCore Function

## Release Information

Table 1–1 provides information about this release of the Altera® RLDRAM II Controller MegaCore® function.

<b>Table 1–1. Release Information</b>	
<b>Item</b>	<b>Description</b>
Version	9.0
Release Date	March 2009
Ordering Code	IP-RLDRAMII
Product ID	00AC
Vendor ID	6AF7



For more information about this release, refer to the [MegaCore IP Library Release Notes and Errata](#).

Altera verifies that the current version of the Quartus® II software compiles the previous version of each MegaCore function. The [MegaCore IP Library Release Notes and Errata](#) report any exceptions to this verification. Altera does not verify compilation with MegaCore function versions older than one release.

## Device Family Support

MegaCore functions provide either full or preliminary support for target Altera device families:

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

Table 1–2 shows the level of support offered by the RLDRAM II Controller MegaCore function to each Altera device family.

<b>Table 1–2. Device Family Support</b>	
<b>Device Family</b>	<b>Support</b>
HardCopy® II	Preliminary
Stratix® II	Full
Stratix II GX	Full
Other device families	No support

## Features

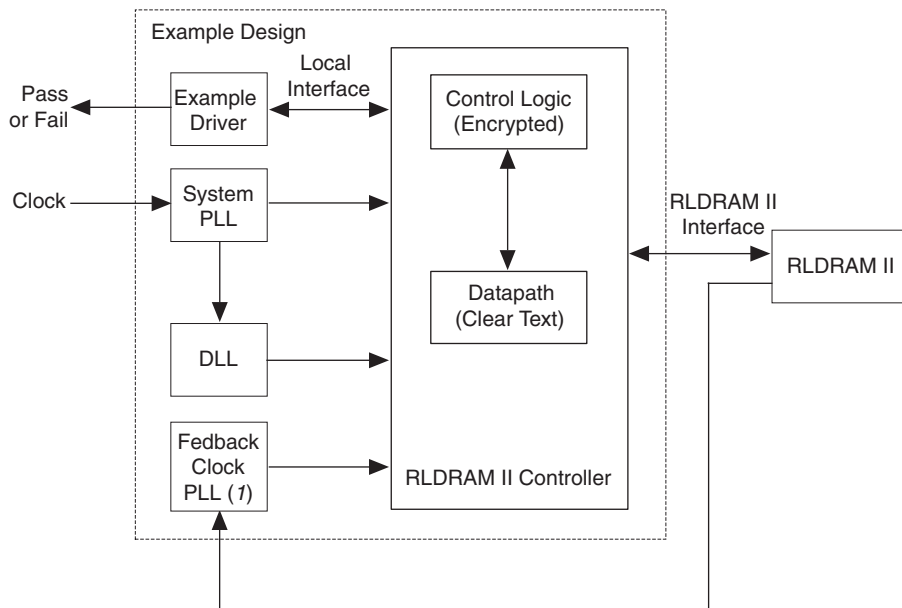
- Common I/O (CIO) and separate I/O (SIO) device support
- Memory burst length 2, 4, and 8-beat support
- Nonmultiplexed addressing
- Datapath generation
- Data strobe signal (DQS) and non-DQS capture modes
- Automatic constraint generation
- Easy-to-use IP Toolbench interface
- IP functional simulation models for use in Altera-supported VHDL and Verilog HDL simulators
- Support for OpenCore Plus evaluation

## General Description

The RLDRAM II controller MegaCore function handles the complex aspects of using RLDRAM II—initializing the memory devices and translating read and write requests from the local interface into all the necessary RLDRAM II command signals.

The RLDRAM II controller is optimized for Altera Stratix II devices and has preliminary support for Stratix II GX and HardCopy II devices. The advanced features available in these devices allow you to interface directly to RLDRAM II devices.

Figure 1–1 on page 1–3 shows a system-level diagram including the example design that the RLDRAM II Controller MegaCore function creates for you.

**Figure 1–1. RLDRAM II Controller System-Level Diagram**

**Note to Figure 1–1:**

(1) Non-DQS mode only.

IP Toolbench generates the following items:

- A testbench, which instantiates the example design
- A synthesizable example design which instantiates the following modules:
  - RLDRAM II controller:
    - Encrypted control logic, which takes transaction requests from the local interface and issues writes, reads, and refreshes to the memory interface
    - A clear-text datapath
  - Example driver—generates write, read and refresh requests and outputs a `pass_fail` signal to indicate that the tests are passing or failing
  - System phase-locked loop (PLL)—generates the RLDRAM II controller clocks
  - Delay locked loop (DLL)—instantiated in DQS mode and generates the DQS delay control signal for the dedicated DQS delay circuitry

- Optional feedback clock PLL—instantiated in non-DQS mode and generates a capture clock for the datapath read capture and logic path

## OpenCore Plus Evaluation

With Altera's free OpenCore Plus evaluation feature, you can perform the following actions:

- Simulate the behavior of a megafunction (Altera MegaCore function or AMPP<sup>SM</sup> megafunction) within your system
- Verify the functionality of your design, as well as evaluate its size and speed quickly and easily
- Generate time-limited device programming files for designs that include MegaCore functions
- Program a device and verify your design in hardware

You only need to obtain a license for the megafunction when you are completely satisfied with its functionality and performance, and want to take your design to production.



For more information on OpenCore Plus hardware evaluation using the RLDRAM II controller, refer to [“OpenCore Plus Time-Out Behavior”](#) on page 2–13 and [AN 320: OpenCore Plus Evaluation of Megafunctions](#).

## Performance and Resource Utilization

Table 1–3 shows typical expected performance for the RLDRAM II Controller MegaCore function, with the Quartus II software.

<i>Table 1–3. Performance</i>		
Device	Capture Mode	f <sub>MAX</sub> (MHz)
Stratix II (EP2S60F1020C3)	Non-DQS	200
	DQS	300
Stratix II GX (EP2SGX30CF780C3)	Non-DQS	200
	DQS	300



Stratix II and Stratix II GX devices support RLD RAM at up to 300 MHz. [Table 1–4](#) shows the clock frequency support for Stratix II and Stratix GX device families, with the Quartus II software.

<b>Table 1–4. RLD RAM II Maximum Clock Frequency Support in Stratix II &amp; Stratix GX Devices</b>	
<b>Speed Grade</b>	<b>Frequency (MHz)</b>
–3	300
–4	250
–5	200

[Table 1–5](#) shows typical sizes in combinational adaptive look-up tables (ALUTs) and logic registers for the RLD RAM II controller.

<b>Table 1–5. Typical Size</b> <i>Note (1)</i>			
<b>Device</b>	<b>Memory Width (Bits)</b>	<b>Combinational ALUTs</b>	<b>Logic Registers</b>
Stratix II and Stratix II GX	9	127	169
	18	130	209
	36	151	287
	72	185	444

**Notes to [Table 1–5](#):**

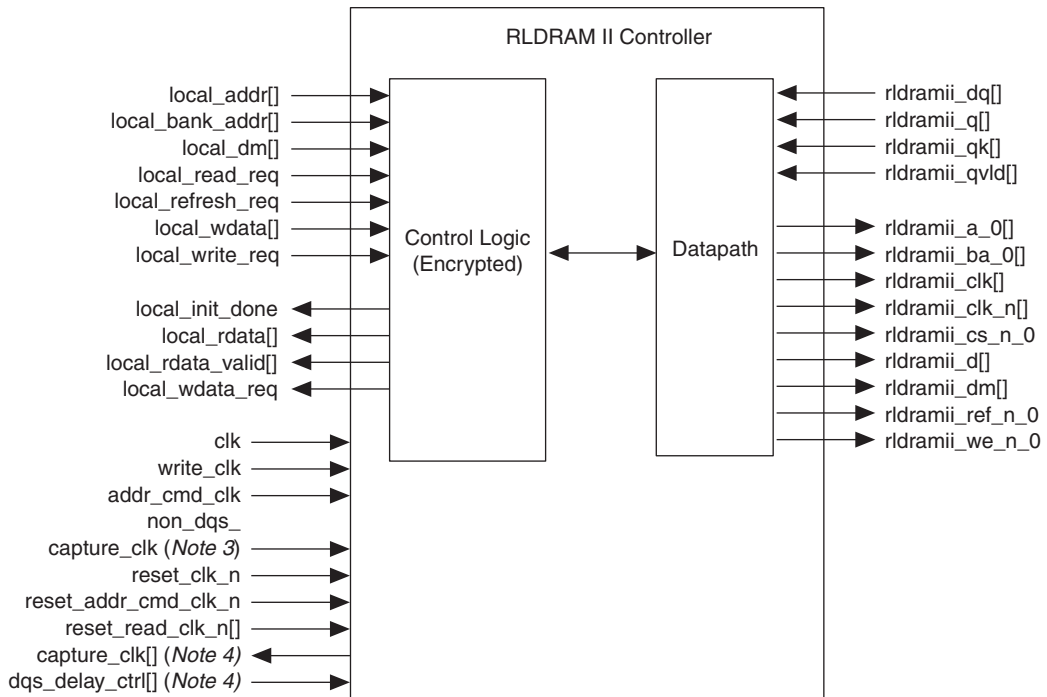
- (1) These sizes are a guide only and vary with different choices of parameters.



### Block Description

Figure 2–1 shows the RLDram II Controller MegaCore function block diagram.

**Figure 2–1. RLDram II Controller Block Diagram** Note (1), (2)



**Notes to Figure 2–1:**

- (1) You can edit the `rldramii_` prefix in IP Toolbench.
- (2) The default signal is `<signal>_0`. When you specify additional address and command busses, both `<signal>_0` and `<signal>_1` are present.
- (3) Non-DQS mode only.
- (4) DQS mode only.

The RLDRAM II controller comprises the following two blocks:

- Control logic (encrypted)
- Datapath (clear text)

The control logic performs the following actions:

- Generates initialization sequence using the RLDRAM II initialization values set in IP Toolbench
- Generates write, read, or refresh accesses when requested at the local interface
- Generates datapath control signals that ensure that the write data is output on the memory `rldramii_dq[ ]` (CIO devices) or `rldramii_d[ ]` (SIO devices) bus during the correct clock cycles

The datapath performs the following actions:

- Interfaces to common I/O (CIO) or separate I/O (SIO) RLDRAM II devices
- Generates RLDRAM II clocks
- Places RLDRAM II commands onto the memory command bus using one of the following system PLL clocks on either the rising or falling edge:
  - System clock
  - Write clock
  - Dedicated clock
- Places write data onto the `rldramii_dq[ ]` or `rldramii_d[ ]` bus during the correct clock cycles
- Captures the read data using dedicated data strobe signal (DQS) delay circuitry during DQS mode or an external capture clock in non-DQS mode

### Control Logic

The control logic is responsible for controlling transactions at the memory interface. The control logic accepts read, write, and refresh requests and executes them immediately as RLDRAM II transactions.

In addition to reads, writes, and refreshes the control logic is also responsible for controlling initialization of the RLDRAM II devices.



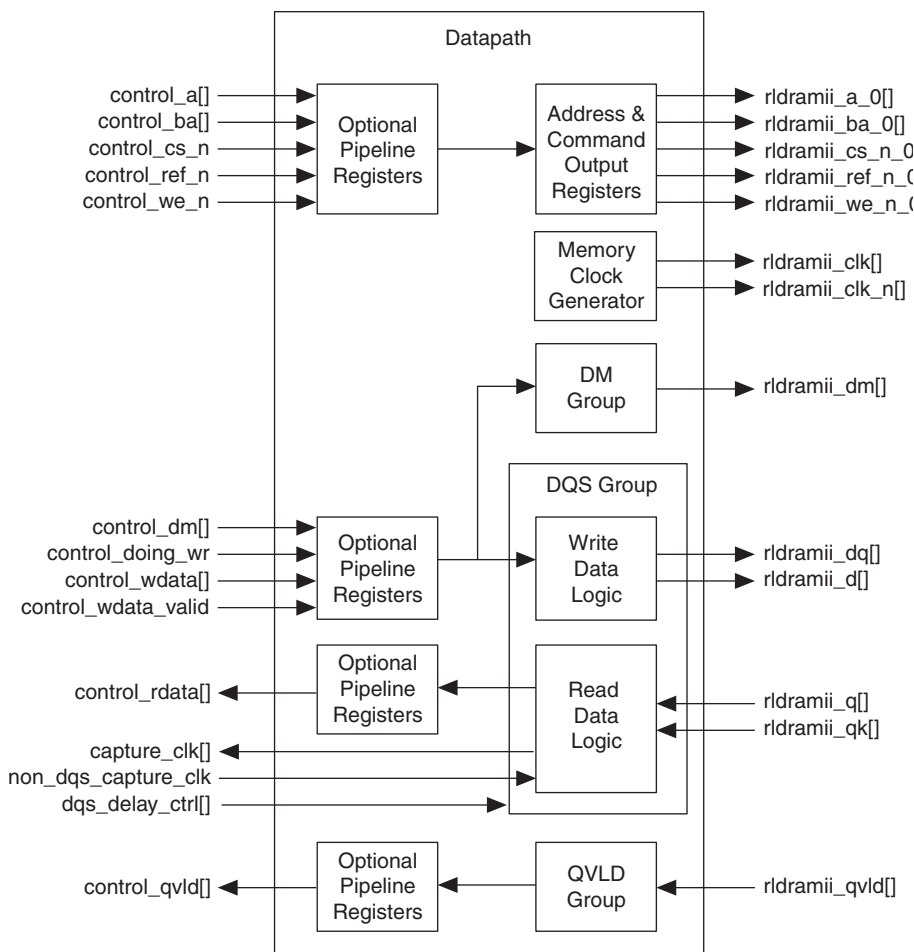
For more information on reads, writes, refreshes, and initialization, see [“Interfaces” on page 2–17](#).

Table 2–1 shows the RLDRAM II control signals generated by the control logic for each operation.

<i>Table 2–1. Control Signals</i>						
Operation	Acronym	rldramii _cs_n_0	rldramii _we_n_0	rldramii _ref_n_0	rldramii _a_0[20:0]	rldramii _ba_0[2:0]
Idle	NOP	High	Don't care	Don't care	Don't care	Don't care
Mode Register Set	MRS	Low	Low	Low	See your RLDRAM data sheet	Don't care
Read	READ	Low	High	High	Address	Bank address
Write	WRITE	Low	Low	High	Address	Bank address
Auto Refresh	AREF	Low	High	Low	Don't care	Bank address

## Datapath

Figure 2–2 on page 2–4 shows the datapath block diagram.

**Figure 2–2. Datapath Block Diagram** *Note (1)*

**Note to Figure 2–2:**

- (1) The default signal is <signal>\_0. When you specify additional address and command busses, both <signal>\_0 and <signal>\_1 are present.

The datapath performs the following functions:

- Interfaces to CIO or SIO RLDRAM II devices
- Outputs write data to the RLDRAM II interface
- Captures RLDRAM II read data and data valid (QVLD) signals with:
  - In DQS mode, a delayed rldramii\_qk[] generated by the dedicated DQS delay circuitry
  - In non-DQS mode, an external capture clock

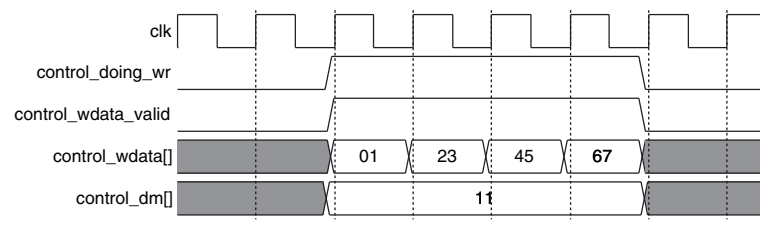
- Generates the RLDRAM II clocks
- Generates addresses and commands on:
  - System, dedicated, or write clock
  - Rising or falling edge
- Inserts pipeline registers in address and command and write data path
- Inserts pipeline registers in read data and QVLD path

The datapath provides the interface between the read and write data busses of the datapath interface and the double-clocked, bidirectional data bus of the memory interface. The datapath data busses are twice the width of the memory data bus, because the memory interface transfers data on both the rising and falling edges of the clock.

IP Toolbench generates a clear-text VHDL or Verilog HDL datapath, which matches your custom variation. If you are designing your own controller, Altera recommends that you use this module as your datapath.

Figure 2–3 shows the write control signals timing relationship when writing to the datapath.

**Figure 2–3. Datapath Write Control Signal Timing**



### Memory Clock Generator

The memory clock generator generates memory clocks. There can be up to four memory clocks and they are generated with an `altdio_out_megafunction`.

### Address & Command Output Registers

The address and command output registers can have the following options:

- System, write, or dedicated clock clocking for the output registers.
- Rising or falling edge clocking

### Pipeline Registers

IP Toolbench can insert pipeline registers into the datapath to help meet timing at higher frequencies. IP Toolbench offers the following pipeline options:

- Insert address and command and write data pipeline registers. The pipeline depth is the same for the write-data path and the address and command path. The write data and address and command pipeline registers are clocked off the system clock.
- Insert read data and QVLD pipeline registers. The pipeline depth is the same for the read-data path and the QVLD path. The read data and QVLD pipeline registers are clocked off the clock that captures the read data—the delayed `rldramii_qk[ ]` signal in DQS mode; the external capture clock in non-DQS mode.

### DQS Group

The datapath instantiates one or more DQS groups, which generates write data, `rldramii_dq[ ]` (CIO devices), or `rldramii_d[ ]` (SIO devices) and captures read data `rldramii_dq[ ]` (CIO devices), or `rldramii_q[ ]` (SIO devices). The IP Toolbench **DQ per DQS** (CIO devices) or **Q per DQS** (SIO devices) parameter determines the DQS group width. For example, if **DQ per DQS** is 9 bits, the `control_wdata[ ]` and `control_rdata[ ]` signals are 18-bits wide. To build larger widths, the datapath instantiates multiple DQS group modules to increase the data-bus width in increments of **DQ per DQS** (or **Q per DQS**) bits.



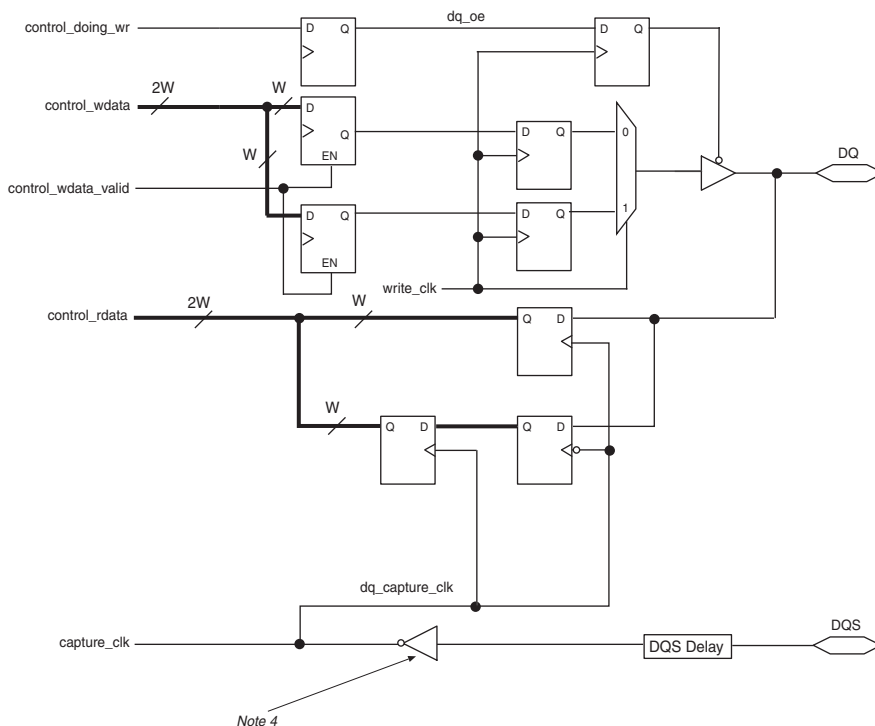
The datapath generates the DM output, `rldramii_dm[ ]`, in the DM group module. It generates the DM output in the same way as the write data.



The datapath captures the QVLD input, `rldramii_qvld[ ]`, in the QVLD group module. The `rldramii_qvld[ ]` signal is captured in the same way that the DQS group module captures the read data. In DQS mode, the delayed `rldramii_qk[ ]` captures `rldramii_qvld[ ]`; in non-DQS mode, the external clock captures `rldramii_qvld[ ]`.

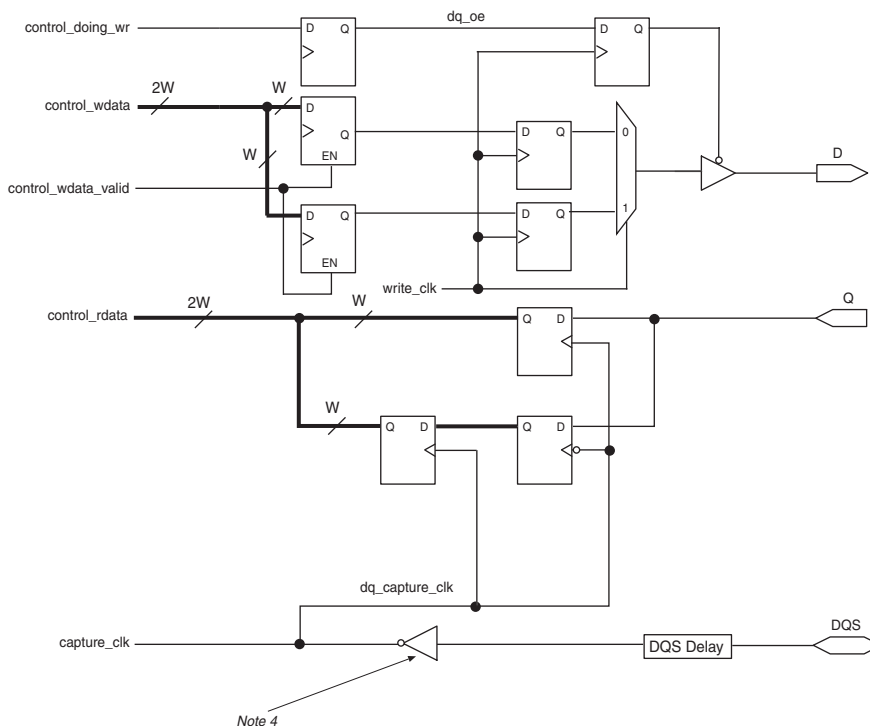
Figure 2-4 on page 2-7 shows the Stratix II series and HardCopy II devices DQS group block diagram (DQS mode, CIO devices).



**Figure 2–4. DQS Group Block Diagram—DQS Mode, CIO Devices** *Note (1), (2), (3)*

**Notes to Figure 2–4:**

- (1) This figure shows the logic for one DQ output only.
- (2) All clocks are `clk`, unless marked otherwise.
- (3) Bus width `W` is dependent on the **DQ per DQS** parameter.
- (4) Invert combout of the I/O element (IOE) for the `dqs` pin before feeding in to `inclock` of the IOE for the DQ pin. This inversion is automatic if you use an `altdq` megafunction for the DQ pins.

Figure 2–5 on page 2–8 shows the Stratix II series and HardCopy II devices DQS group block diagram (DQS mode, SIO devices).

**Figure 2–5. DQS Group Block Diagram—DQS Mode, SIO Devices** *Note (1), (2), (3)***Notes to Figure 2–4:**

- (1) This figure shows the logic for one Q output and one D input only.
- (2) All clocks are `clk`, unless marked otherwise.
- (3) Bus width `W` is dependent on the **Q per DQS** parameter.
- (4) Invert combout of the I/O element (IOE) for the `dqs` pin before feeding in to `inclock` of the IOE for the Q pin. This inversion is automatic if you use an `altdq` megafunction for the Q pins.

**Datapath Example**

Figure 2–6 shows an example datapath. The example RLD RAM II controller and memory configuration has the following parameters:

- DQS mode
- Two 18-bit CIO RLD RAM II devices. Each RLD RAM II device has two `rldramii_qk[ ]` data strobes, each associated with 9-bits of data
- 36-bit RLD RAM II interface, which requires a 72-bit datapath interface

Figure 2–6. Example Datapath

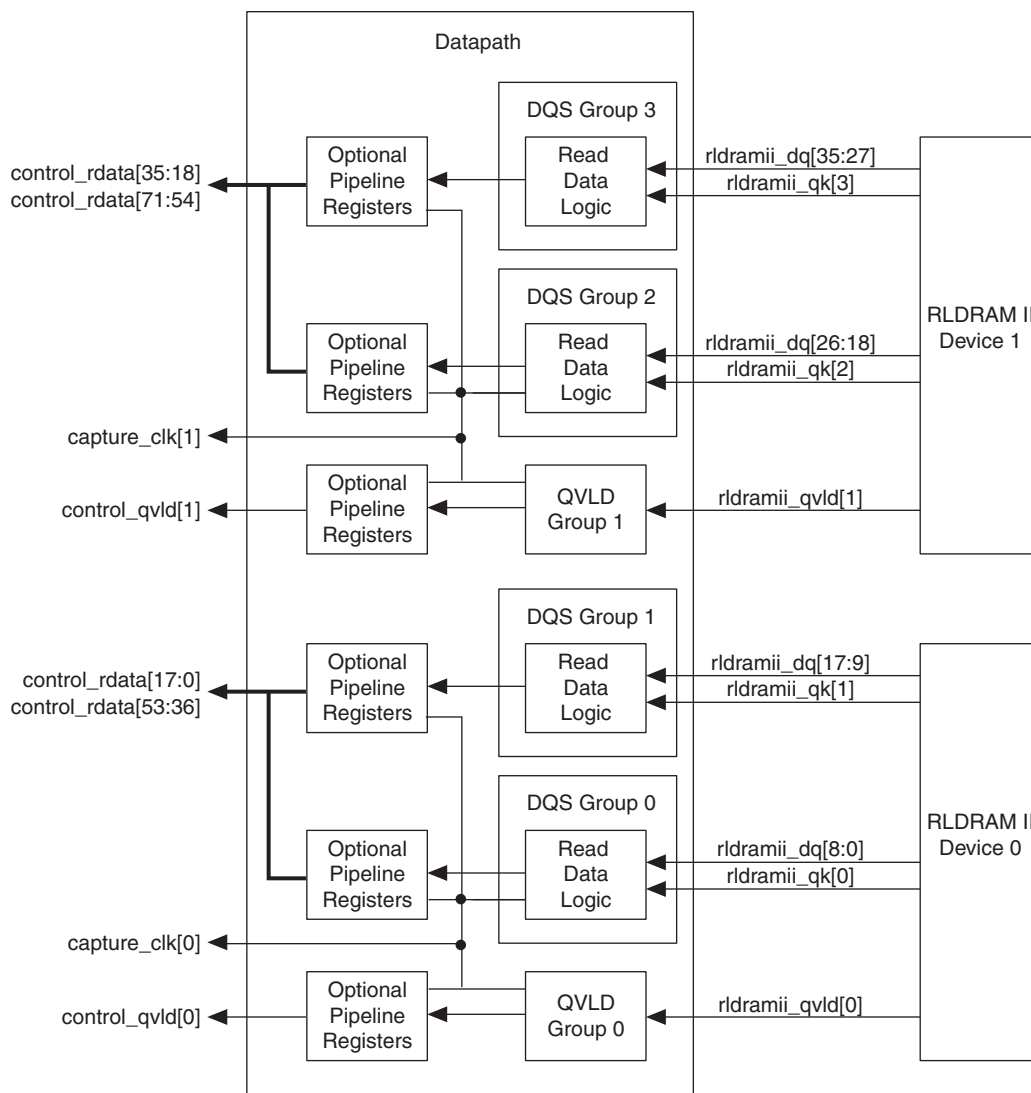


Figure 2–6 shows the following points, which are applicable for all interface configurations:

- Each DQS `rldramii_dq[ ]` byte group is captured by the delayed version of its associated `rldramii_qk[ ]` data strobe:

- `rldramii_dq[8:0]` is captured by the delayed `rldramii_qk[0]`
- `rldramii_dq[17:9]` is captured by the delayed `rldramii_qk[1]`
- `rldramii_dq[26:18]` is captured by the delayed `rldramii_qk[2]`
- `rldramii_dq[35:27]` is captured by the delayed `rldramii_qk[3]`
- QVLD is always captured by the delayed version of `rldramii_qk[0]` for the associated RLD RAM II device. In [Figure 2-6](#) there are four `rldramii_qk[ ]` signals. Only `rldramii_qk[0]` per RLD RAM II device captures the associated QVLD signal:
  - `rldramii_qvld[0]` is captured by the delayed `rldramii_qk[0]`
  - `rldramii_qvld[1]` is captured by the delayed `rldramii_qk[2]`
- After the capture registers all captured read data is clocked off the undelayed `rldramii_qk[ ]` signal that captures the QVLD signal for a particular RLD RAM II device:
  - All RLD RAM II 0 captured data is clocked off the undelayed `rldramii_qk[0]`
  - All RLD RAM II 1 captured data is clocked off the undelayed `rldramii_qk[2]`
- Only one `capture_clk[ ]` per attached RLD RAM II device is output from the datapath:
  - RLD RAM II 0 capture data is associated with `capture_clk[0]`, which is the delayed `rldramii_qk[0]`
  - RLD RAM II 1 capture data is associated with `capture_clk[1]`, which is the delayed `rldramii_qk[2]`

### *Read Data Capture Clock Association*

[Figure 2-7](#) shows the read data and data strobes at the memory interface for the example datapath in [Figure 2-6](#). [Figure 2-8](#) shows how the `capture_clk[ ]` associates with the captured read data, `control_rdata[ ]` at the datapath interface.

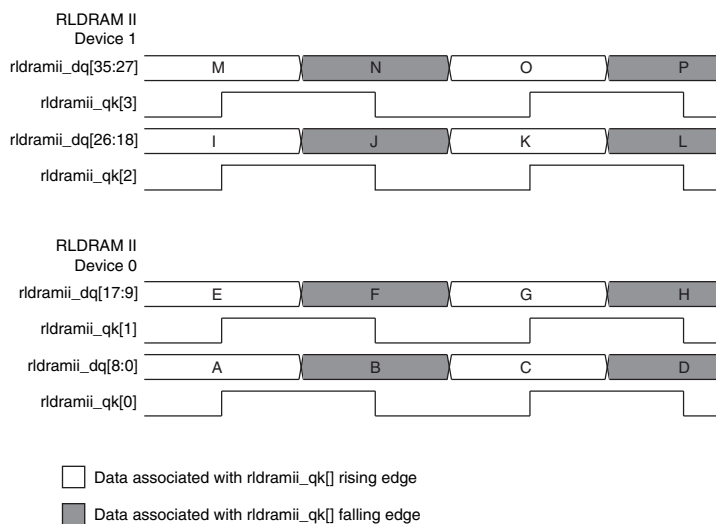
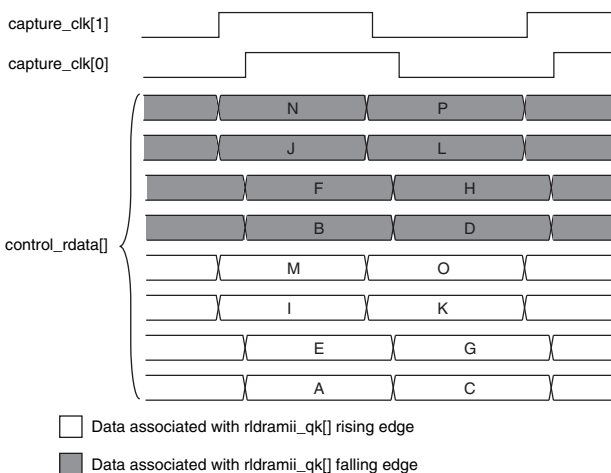
**Figure 2–7. Memory Interface****Figure 2–8. Datapath Interface**

Figure 2–8 shows that any read data captured on the rising edge of the delayed `rldramii_qk[]` signal is located in the lower half-bit locations of `control_rdata[]`. Any read data captured on the falling edge of the delayed `rldramii_qk[]` signal is located in the upper half-bit locations

of `control_rdata[ ]`, which means different bit ranges of the `control_rdata[ ]` are associated with different `capture_clk[ ]` signals.



Figure 2–8 is a specific example but the mapping and clock association applies to any RLD RAM II controller interface and memory configuration.

## Timing Assignments

When generating an RLD RAM II controller that connects to RLD RAM II devices that have more than a single pair of QK output read strobes (18-bit or 36-bit RLD RAM II devices), you must apply timing assignments to the project. These timing assignments guarantee safe data transfer between the capture QK clock domain and another QK clock domain inside the FPGA. IP Toolbench automatically generates the timing assignments that are applied to the Quartus II project.



For more information on the IP Toolbench-generated timing assignments, see [“Constraints” on page 2–17](#)

The following example is for a 18-bit RLD RAM II controller that is connected to an 18-bit RLD RAM II device, for example an MT49H16M18FM-25. The read data, `DQ[17:9]` is captured by `QK[1]` and is transferred to the `QK[0]` clock domain inside the FPGA.

From the datasheet the skew between `QK[0]` and `QK[1]` is given by the following equation:

$$\begin{aligned} \text{Skew} &= t_{\text{QKQ}} - (t_{\text{QKQ0}} \text{ or } t_{\text{QKQ1}}) \\ &= \pm 300 \text{ ps} - \pm 200 \text{ ps} \\ &= \pm 100 \text{ ps} \end{aligned}$$

So the worst case skew between `QK[0]` and `QK[1]` is  $\pm 100$  ps. Therefore, you must apply a clock uncertainty of  $\pm 100$  ps to the RLD RAM II interface when transferring between `QK[1]` and `QK[0]` clock domains. With a  $\pm 50$ -ps board skew, you can set the following `clock_setup_uncertainty` and `clock_hold_uncertainty` timing assignments in the Quartus II Assignment Editor for your project:

```
rldramii_qk[1] rldramii_qk[0] Clock Setup Uncertainty 0.15 ns Yes
rldramii_qk[1] rldramii_qk[0] Clock Hold Uncertainty 0.15 ns Yes
```

These assignments are required for each attached 18 or 36-bit RLDRAM II device from the capture QK clock domain to the target QK clock domain.

## OpenCore Plus Time-Out Behavior

OpenCore Plus hardware evaluation can support the following two modes of operation:

- *Untethered*—the design runs for a limited time
- *Tethered*—requires a connection between your board and the host computer. If tethered mode is supported by all megafunctions in a design, the device can operate for a long time or indefinitely

All megafunctions in a device time out simultaneously when the most restrictive evaluation time is reached. If there is more than one megafunction in a design, a specific megafunction's time-out behavior may be masked by the time-out behavior of the other megafunctions.



For MegaCore functions, the untethered time out is 1 hour; the tethered time out value is indefinite.

Your design stops working after the hardware evaluation time expires and the controller issues no read commands at the memory interface.



For more information on OpenCore Plus hardware evaluation, see [“OpenCore Plus Evaluation” on page 1–4](#) and [AN 320: OpenCore Plus Evaluation of Megafunctions](#).

## Device-Level Configuration

This section describes the following topics:

- [“PLL Configuration” on page 2–13](#)
- [“Example Design” on page 2–15](#)
- [“Constraints” on page 2–17](#)

## PLL Configuration

IP Toolbench creates up to two example PLLs in your project directory, which you can parameterize to meet your exact requirements. IP Toolbench generates the example PLLs with an input to output clock ratio of 1:1 and a clock frequency you entered in IP Toolbench. In addition IP Toolbench sets the correct phase outputs on the PLLs' clocks. You can edit the PLLs to meet your requirements with the `altpll` MegaWizard™ Plug-In. IP Toolbench overwrites your PLLs in your project directory unless you turn off **Update example design system PLL**.

The external clocks are generated using standard I/O pins in double data rate I/O (DDIO) mode (using the `altddio_out` megafunction). This generation matches the way in which the write data is generated and allows better control of the skew between the clock and the data to meet the timing requirements of the RLDRAM II device.

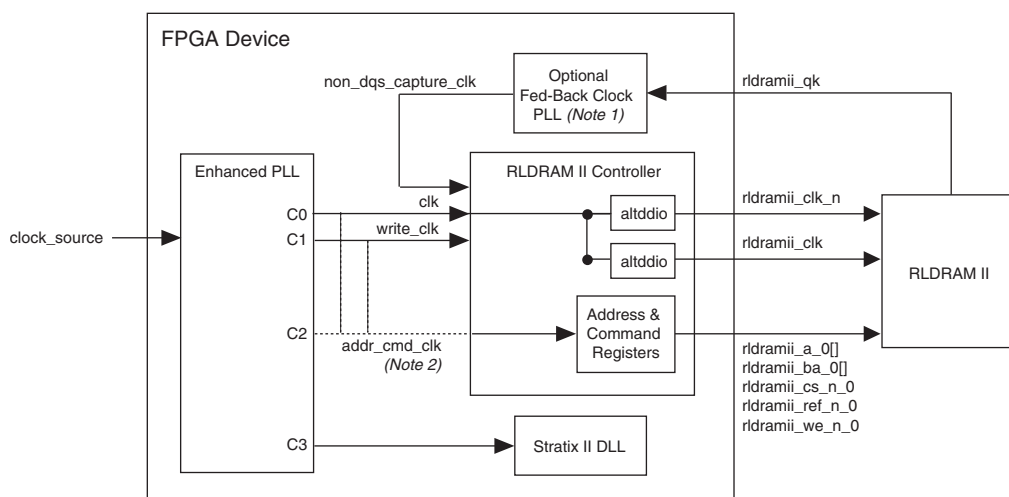
The PLL has the following outputs:

- Output c0 drives the system clock that clocks most of the controller including the control logic and datapath.
- Output c1 drives the write clock that lags the system clock.
- Output c2 optionally drives the address and command clock.
- Output c3 drives the DQS DLL clock.

The recommended configuration for implementing the RLDRAM II controller in Stratix II series and HardCopy II devices is to use a single enhanced PLL to produce all the required clock signals. No external clock buffer is required as the Altera device can generate clock signals for the RLDRAM II devices.

Figure 2–9 on page 2–14 shows the recommended PLL configuration.

**Figure 2–9. PLL Configuration**



**Notes to Figure 2–9:**

- (1) Non-DQS mode only.
- (2) You can connect the `addr_cmd_clk` RLDRAM II controller input to `clk`, `write_clk` or to the dedicated PLL output C2.



## Example Design

IP Toolbench creates an example design that shows you how to instantiate and connect up the RLDRAM II controller to an example driver. The example design is a working system that can be compiled and used for both static timing checks and board tests. It also instantiates an example PLL that generates all the required clocks for the controller. In DQS mode, a DLL is instantiated that controls the DQS capture delay phase. In non-DQS mode, the example design instantiates a feedback PLL. The output of the feedback PLL is a phase-shifted `rlramii_qk[ ]` data strobe, which captures the read data.

The example driver is a self-checking test generator for the RLDRAM II controller. It uses a state machine to write data patterns to all memory banks. It then reads back the data and checks that the data matches. If any read data fails the comparison, the `pnf_per_byte` output transitions low for one cycle and the `pnf_persist` permanent output transitions low and stays low.

Figure 2–10 shows a testbench and an example design.

**Figure 2–10. Testbench & Example Design**

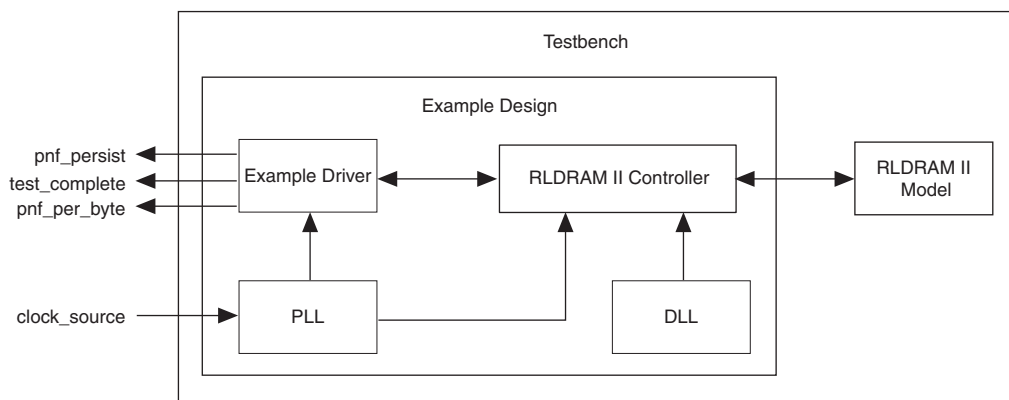


Table 2–2 describes the files that are associated with the example design and the testbench.

<b>Table 2–2. Example Design &amp; Testbench Files</b>	
<b>Filename</b>	<b>Description</b>
<code>&lt;top-level name&gt;_tb.v</code> or <code>.vhd</code> (1)	Testbench for the example design.
<code>&lt;top-level name&gt;.vhd</code> or <code>.v</code> (1)	Example design.
<code>rlDRAMii_pll_&lt;device name&gt;.vhd</code> or <code>.v</code>	Example PLL, which you should configure to match your frequency.
<code>rlDRAMii_fbpll_&lt;device name&gt;.vhd</code> or <code>.v</code>	Feedback PLL
<code>&lt;variation name&gt;_example_driver.v</code> or <code>.vhd</code> (2)	Example driver.
<code>&lt;variation name&gt;.v</code> or <code>.vhd</code> (2)	RLDRAM II controller.

**Notes to Table 2–2:**

- (1) `<top-level name>` is the name of the Quartus II project top-level entity.
- (2) `<variation name>` is the variation name.

The testbench instantiates an RLDRAM II model and generates a reference clock for the PLL.



Altera does not provide a memory simulation model. You must download one or use your own.



For more details on how to run the simulation script, see “[Simulate the Example Design](#)” on page 3–11.

## Constraints

The constraints scripts set the following constraints:

- Sets IO standards:
  - 1.5 or 1.8-V HSTL voltage selection
  - Address and command—HSTL Class I
  - Data CIO mode—HSTL Class II
  - Data SIO mode—HSTL Class I
- Sets output capacitance
- Places data pins as per selection in pin placement constraints floor plan. Allows automatic placement for DQS and non-DQS modes
- Places all DM pins
- Sets up correct output enable groups
- Sets `rldramii_a_0`, `rldramii_ba_0`, `rldramii_cs_n_0`, `rldramii_ref_n_0` and `rldrainii_we_n_0` as fast output registers (see note 1 in [Table 2-5](#))
- Sets `rldramii_qk[ ]` non-global signal in DQS capture mode
- Sets up timing assignments to ensure safe data transfer between the capture `rldramii_qk[ ]` capture clock domain and the internal `rldramii_qk[ ]` clock domain, when the attached RLDRAM II devices are 18 or 36-bits wide. The timing assignments assume a  $\pm 100$ -ps skew between the `rldramii_qk[ ]` read clocks per RLDRAM II device and a  $\pm 50$ -ps board trace skew between the `rldramii_qk[ ]` signals. If you expect these parameters to be different to the generated timing assignments, you must modify values of the timing assignments in the Quartus II Assignment Editor



For more details on the timing assignments, see [“Timing Assignments” on page 2-12](#).

## Interfaces

This section describes the following RLDRAM II commands:

- Initialization
- Writes
- Reads
- Refreshes

### Initialization

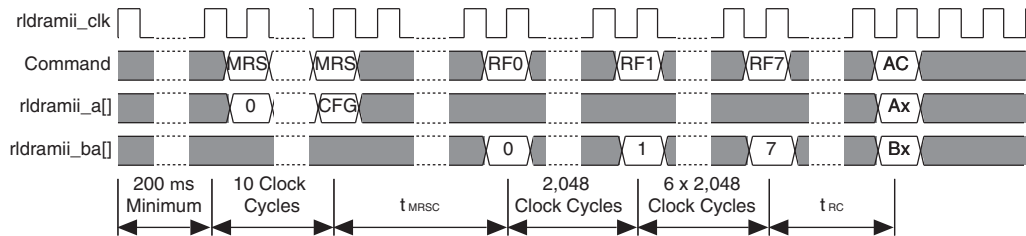
The control logic initializes the RLDRAM II devices. During initialization the mode register is set and each bank is refreshed in turn. IP Toolbench sets the following RLDRAM II initialization features:

- On-die termination (ODT)
- Impedance matching resistor

- DLL enable
- RLDRAM II configuration

Figure 2–11 shows the initialization sequence.

**Figure 2–11. RLDRAM II Initialization Sequence**



MRS = Mode Register Set  
 CFG = Mode Register Configuration Data  
 RFx = Refresh  
 AC = User Command

The mode register set (MRS) command configures the RLDRAM II devices. In the ten-cycle MRS sequence, the first nine MRS commands are dummy commands and all address bits are held at zero, to reset the RLDRAM II DLL; the final MRS command configures the memory. The RLDRAM II configuration data (CFG) is output on the `rldramii_a_0[]` bus during the final MRS command. The following memory parameters are setup during the final MRS command cycle:

- RLDRAM II termination
- Impedance matching resistor
- DLL enable/disable
- RLDRAM II configuration

## Writes

When you assert `local_write_req`, the control logic issues the write transaction immediately at the memory interface. The control logic then requests write data by asserting `local_wdata_req`, so that the RLDRAM II  $t_{WL}$  period is satisfied during write transactions. This functionality means that the write request is decoupled from the write data.

Figure 2–12 shows three write requests at the local and SIO RLDram II interface. In this example, the memory burst length is set to eight beats. The RLDram II device is setup with a  $t_{RC}$  of six-clock cycles (configuration two).

**Figure 2–12. Write Example**

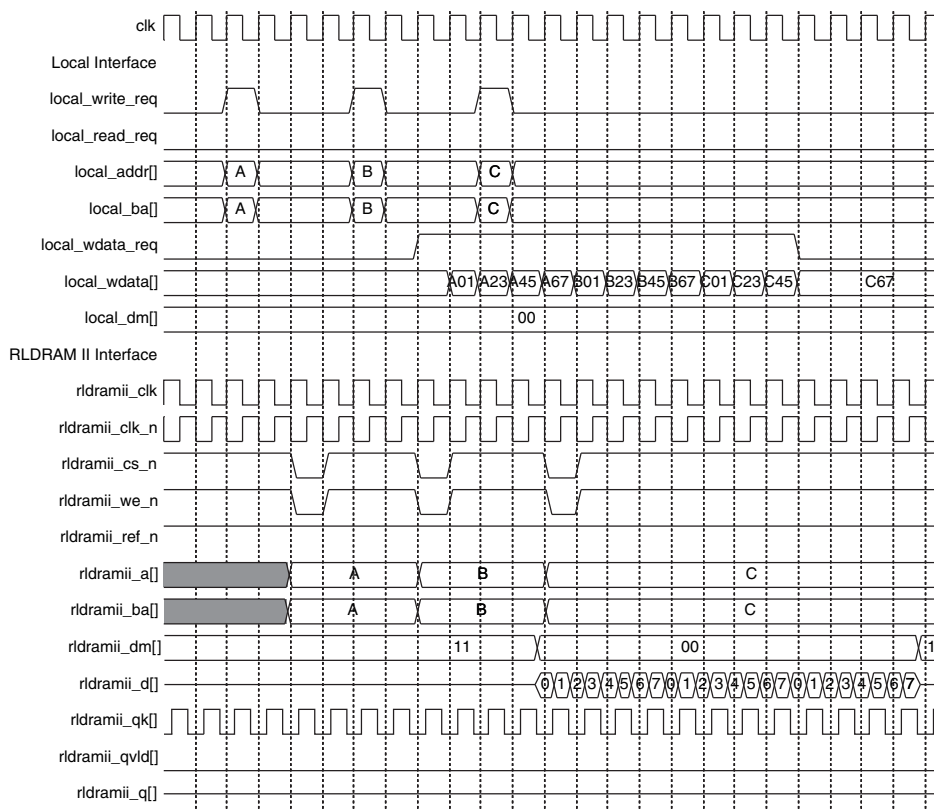


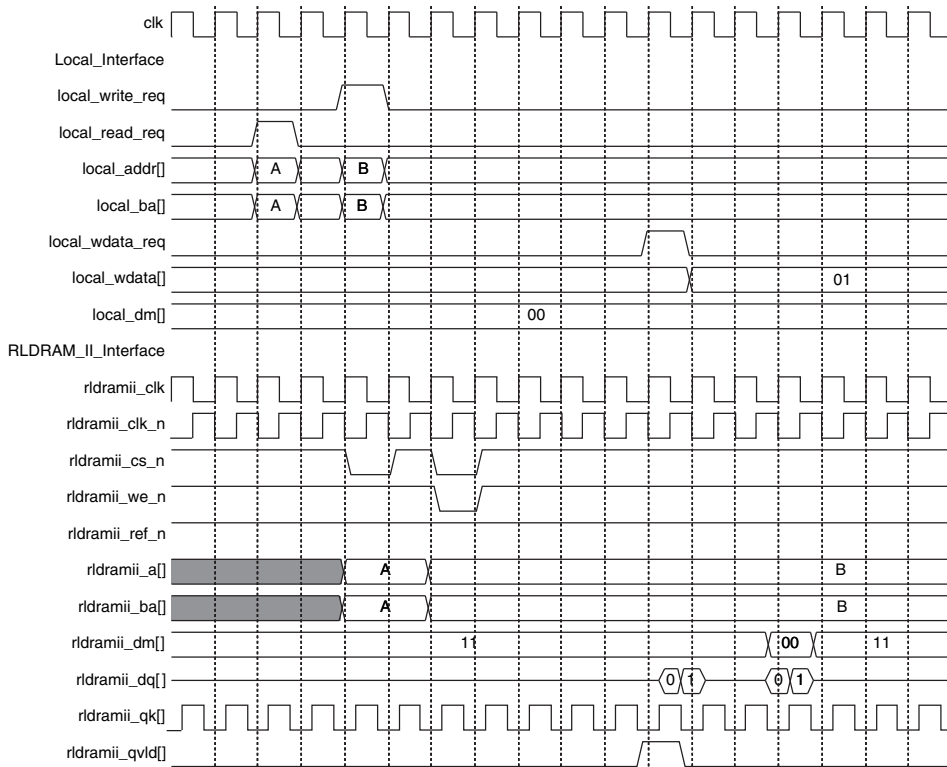
Figure 2–12 shows the transactions at the local interface are separated by the correct number of clock cycles for the target RLDram II device configuration. If transaction requests are supplied to the RLDram II controller with the incorrect spacing the controller executes these transactions as requested, which can result in incorrect behavior.

Figure 2–13 shows an example of a write following a read at a CIO RLDram II interface. In this example, the memory burst length is set to two beats. The RLDram II device is setup with a  $t_{RC}$  of six-clock cycles (configuration two).



For more information about bus turnaround timing calculations with CIO devices, refer to *AN 325: Interfacing RLD RAM II with Stratix II, Stratix & Stratix GX Devices*.

**Figure 2–13. Write Following a Read**



## Reads

When you assert `local_read_req`, the control logic issues the read transaction immediately at the memory interface.

In DQS mode the read data, `rldramii_dq[]` (CIO devices) or `rldramii_q[]` (SIO devices), and the QVLD signals, `rldramii_qvld[]`, are captured using the delayed `rldramii_qk[]` data strobes that have been phase shifted using the dedicated DQS delay circuitry.

In non-DQS mode the read data, `rldramii_dq[]` or `rldramii_q[]`, and the QVLD signals, `rldramii_qvld[]`, are captured using an external capture clock.

During reads, the local interface indicates that read data is valid by asserting the `local_rdata_valid[]` signal. All captured read data is clocked off the clock that captures the RLD RAM II read data. In DQS mode, this clock is the delayed DQS signal, `capture_clk[]`, sourced from the dedicated DQS delay circuitry. In non-DQS mode this clock is the external capture clock, `non_dqs_capture_clk`.

Figure 2–14 shows an example of a read at an SIO RLD RAM II interface. In this example, the memory burst length is set to eight beats. The RLD RAM II device is setup with a  $t_{RC}$  of six-clock cycles (configuration two).

**Figure 2–14. Read Example**

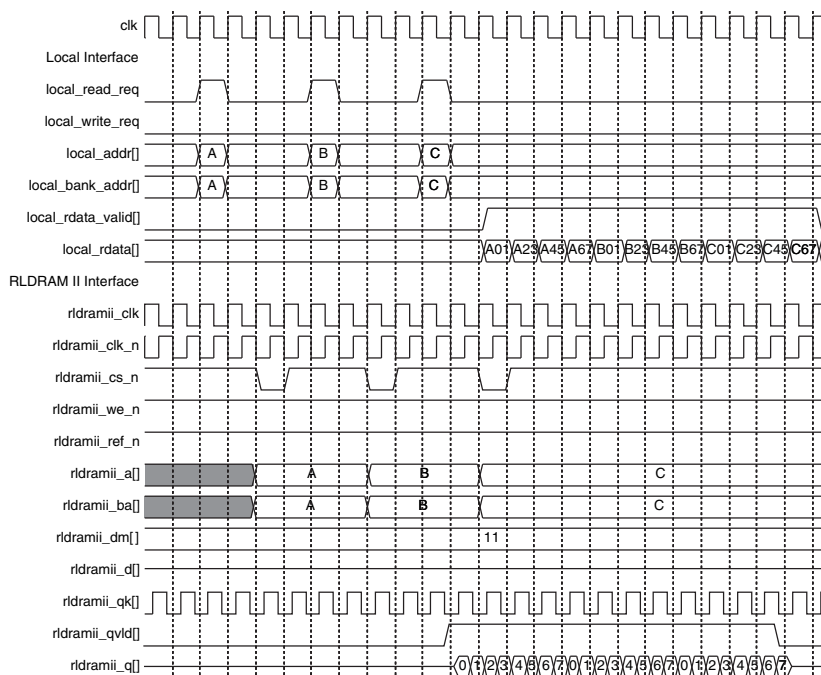
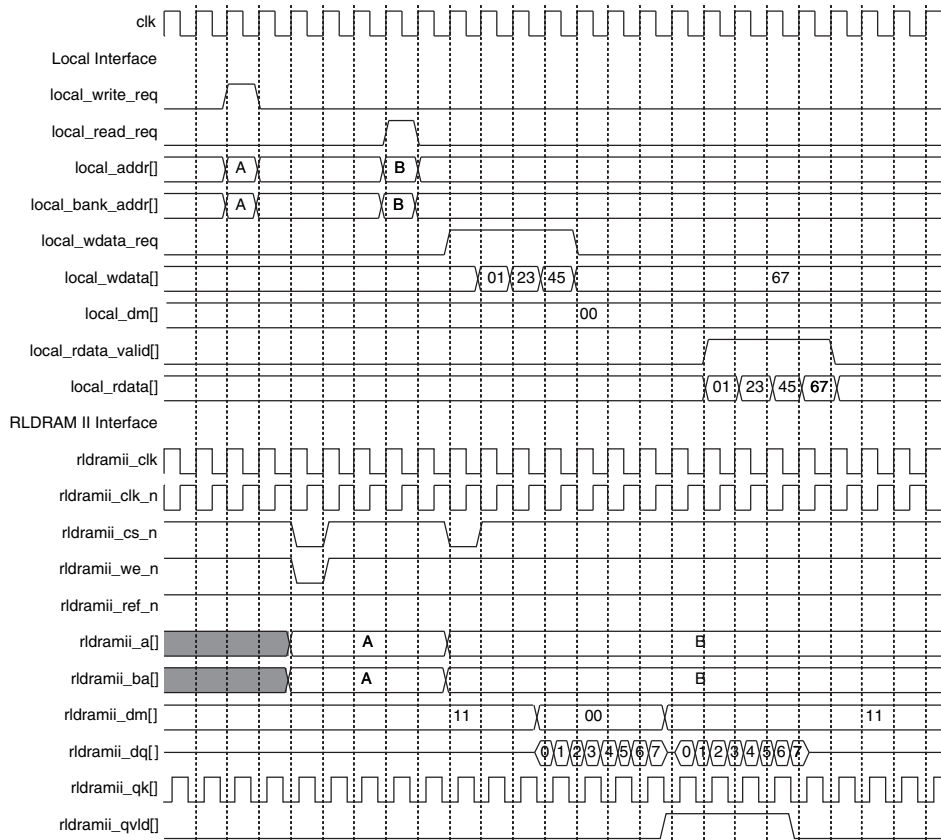


Figure 2–15 shows an example of a read following a write at a CIO RLD RAM II interface. In this example, the memory burst length is set to eight beats. The RLD RAM II device is setup with a  $t_{RC}$  of six-clock cycles (configuration two).



For more information about bus turnaround timing calculations with CIO devices, refer to *AN 325: Interfacing RLD RAM II with Stratix II, Stratix & Stratix GX Devices*.

**Figure 2–15. Read Following a Write**



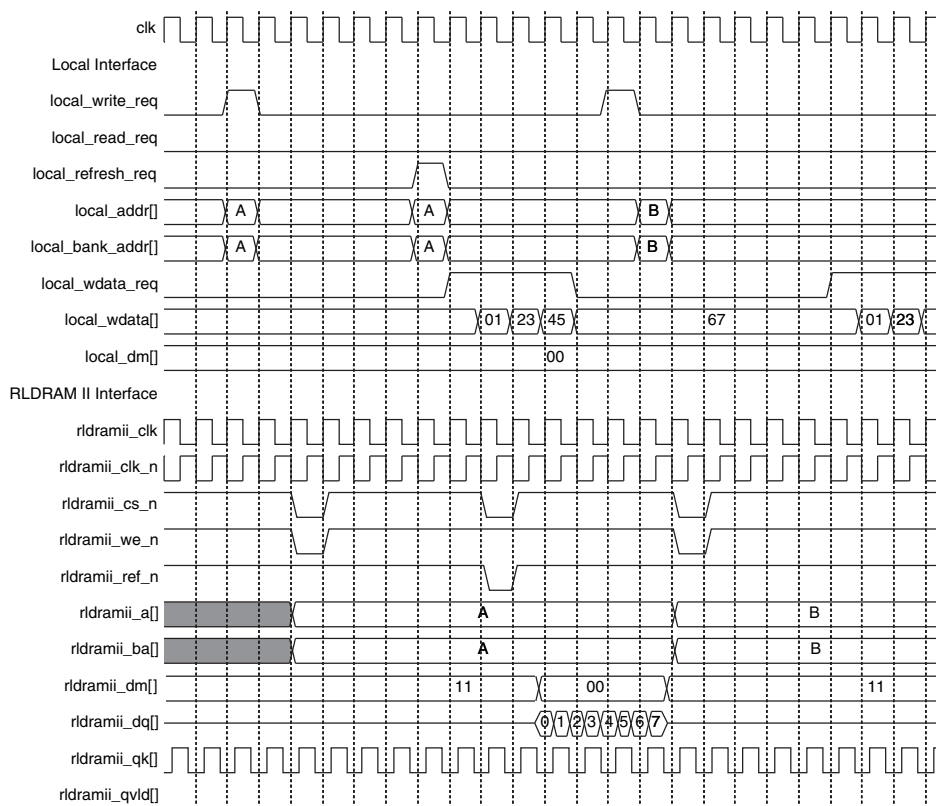
## Refreshes

You must issue refreshes to the RLD RAM II devices at periodic intervals. When a refresh is required, assert `local_refresh_req` and the RLD RAM II controller issues the refresh command immediately to the requested bank address on `local_bank_addr[ ]` input. You must correctly insert the refresh request and ensure that the  $t_{RC}$  timing parameter is not violated. You can issue single or ganged refreshes. For ganged refreshes assert `local_refresh_req` for  $X$  clock cycles, where  $X$  is the number of refreshes that you require.



Figure 2–16 shows a single refresh command:

**Figure 2–16. Single Refresh Command**



## Signals

Table 2–3 shows the system signals.

<b>Table 2–3. System Signals (Part 1 of 3)</b>			
<b>Name</b>	<b>Width (Bits)</b>	<b>Direction</b>	<b>Description</b>
<code>clk</code>	1	Input	System clock for the control logic and datapath.
<code>write_clk</code>	1	Input	Shifted clock that center aligns write data to the memory.

**Table 2–3. System Signals (Part 2 of 3)**

Name	Width (Bits)	Direction	Description
addr_cmd_clk	1	Input	<p>Address and command output register clock. The addr_cmd_clk clock frequency must be the same as the system clock, clk, and the write clock, write_clk, frequencies.</p> <p>In addition, when there is a separate address and command clock phase, no timing paths related to this clock should be cut, to ensure that any paths using a separate clock for address and command are timing analysed.</p>
dqs_delay_ctrl[]	6	Input	Delay bus for DLL to shift DQS inputs. DQS mode only.
non_dqs_capture_clk	1	Input	Optional clock that captures read data and clocks read data logic. Non-DQS mode only.
reset_clk_n	1	Input	Reset input for logic on the system clock domain. The reset_clk_n can be asserted asynchronously but must be deasserted synchronous to the rising edge of the system clock.
reset_addr_cmd_clk_n	1	Input	Reset input for logic on the address and command clock domain. The reset_addr_cmd_clk_n can be asserted asynchronously but must be deasserted synchronous to the rising edge of the address and command clock.

**Table 2–3. System Signals (Part 3 of 3)**

Name	Width (Bits)	Direction	Description
<code>reset_read_clk_n[ ]</code>	DQS mode: the number of RLDRAM II devices attached to the memory interface  Non-DQS mode: 1	Input	Reset input for logic on the capture clock domain. In DQS mode, the capture clock domain is <code>capture_clk[ ]</code> ; in non-DQS mode, it is <code>non_dqs_capture_clk</code> . In DQS mode, each <code>reset_read_clk_n[ ]</code> is associated with the corresponding <code>capture_clk[ ]</code> clock domain. The <code>reset_read_clk_n[ ]</code> can be asserted asynchronously but must be deasserted synchronous to the rising edge of the capture clock.
<code>capture_clk[ ]</code>	The number of RLDRAM II devices attached to memory interface	Output	Undelayed DQS clock used by capture circuitry to capture RLDRAM II read data. There is one <code>capture_clk[ ]</code> per attached RLDRAM II device. DQS mode only.

Table 2–4 shows the local interface signals.

**Table 2–4. Local Interface Signals (Part 1 of 2)**

Name	Width (Bits)	Direction	Description
<code>local_addr[ ]</code>	Device dependant	Input	RLDRAM II address. IP Toolbench refers to the <b>memory.dat</b> file and selects the address width appropriate to the device.
<code>local_bank_addr[ ]</code>	3	–	RLDRAM II bank address.
<code>local_dm[ ]</code>	The number of RLDRAM II devices attached to the memory interface × 2	Input	Optional local data mask (DM). Twice the width of the memory <code>rlDRAMii_dm[ ]</code> bus. When all high, all writes are masked.
<code>local_read_req</code>	1	Input	Read request signal.
<code>local_refresh_req</code>	1	Input	User controlled refresh request. This allows complete control over when refreshes are issued to the memory. The refresh is issued to the bank address on <code>local_bank_addr[ ]</code> .

**Table 2–4. Local Interface Signals (Part 2 of 2)**

Name	Width (Bits)	Direction	Description
local_wdata[ ]	Data-bus width × 2	Input	Write data bus. The local interface must request local_wdata[ ] over multiple clock cycles to construct the write data for any requested write bursts. If the memory burst length is set to two beats, the write data is requested in a single clock cycle at the local interface.
local_write_req	1	Input	Write request signal.
local_init_done	1	Output	Memory initialization complete signal which is asserted when the controller has completed its initialization of the memory. Reads and writes should not be requested until local_init_done is asserted.
local_rdata[ ]	Data-bus width × 2	Output	Read data bus. The controller returns local_rdata[ ] over multiple clock cycles for any requested read transactions. If the memory burst length is set to two beats, the read data is returned in a single clock cycle at the local interface.
local_rdata_valid[ ]	The number of RLDRAM II devices attached to memory interface	Output	Read data valid signal, which indicates that valid data is present on the read data bus. The local_rdata_valid[ ] signal is aligned with the local read data, local_rdata[ ]. There is only one local_rdata_valid[ ] per attached RLDRAM II device.
local_wdata_req	1	Output	Write data request signal. When the local interface asserts local_wdata_req, all the write data for the burst should be available in contiguous clock cycles.

Table 2–5 shows the memory interface signals.

**Table 2–5. Memory Interface Signals (Part 1 of 2)**

Name	Width (Bits)	Direction	Description
rldramii_dq[ ]	Data-bus width	Bidirectional	Memory data bus. CIO devices only.
rldramii_qk[ ]	1 to 9	Bidirectional	In DQS mode, the memory data strobe signal that captures read data into the Altera device; in non-DQS mode, the RLDRAM II controller does not use rldramii_qk[ ].
rldramii_q[ ]	Data-bus width	Input	Memory read data bus. SIO devices only.

**Table 2–5. Memory Interface Signals (Part 2 of 2)**

Name	Width (Bits)	Direction	Description
rldramii_qvld[ ]	The number of RLD RAM II devices attached to memory interface	Input	Read data valid flag.
rldramii_a_0[ ] rldramii_a_1[ ] (1)	local_addr[ ]	Output	Memory address signals.
rldramii_ba_0[ ] rldramii_ba_1[ ] (1)	3	Output	Memory bank address signals.
rldramii_clk[ ], rldramii_clk_n[ ]	1 to 3 (with dedicated PLL clocks) or 1 to 8 otherwise	Output	Memory command output clock.
rldramii_cs_n_0 rldramii_cs_n_1 (1)	1	Output	Memory chip select signal.
rldramii_d[ ]	Data-bus width	Output	Memory write data bus. SIO devices only.
rldramii_dm[ ]	The number of RLD RAM II devices attached to memory interface	Output	Memory DM (optional).
rldramii_ref_n_0 rldramii_ref_n_1 (1)	1	Output	Memory refresh request signal.
rldramii_we_n_0 rldramii_we_n_1 (1)	1	Output	Memory write enable signal.

**Note to Table 2–5:**

- (1) The default signal is *<signal>\_0*. When you specify additional address and command busses, both *<signal>\_0* and *<signal>\_1* are present.

Table 2–6 shows the datapath interface signals.

<b>Table 2–6. Datapath Interface Signals</b>			
<b>Name</b>	<b>Width (Bits)</b>	<b>Direction</b>	<b>Description</b>
<code>control_a[]</code>	<code>local_addr[]</code>	Input	Address bits.
<code>control_ba[]</code>	3	Input	Bank address bits.
<code>control_cs_n</code>	1	Input	Chip select signal.
<code>control_dm[]</code>	The number of RLD RAM II devices attached to the memory interface × 2	Input	The DM bus, which has valid data in the same clock cycles that <code>control_wdata_valid</code> is asserted.
<code>control_doing_wr</code>	1	Input	<code>Control_doing_wr</code> is asserted when the controller is writing to the RLD RAM II devices and controls the output enables on <code>rlDRAMII_dq[]</code> or <code>rlDRAMII_d[]</code> .
<code>control_ref_n</code>	1	Input	Refresh signal.
<code>control_wdata[]</code>	Data-bus width × 2	Input	The write data bus, which has valid data in the same clock cycles that <code>control_wdata_valid</code> is asserted.
<code>control_wdata_valid</code>	1	Input	Enables the write data bus and DM enable registers so that they are only updated when valid data and enables are available.
<code>control_we_n</code>	1	Input	Write enable signal.
<code>control_qvld[]</code>	The number of RLD RAM II devices attached to the memory interface	Output	The read data valid flag. There is only one QVLD flag per RLD RAM II device. The <code>control_qvld[]</code> signal is aligned with the valid <code>control_rdata[]</code> and is asserted during this period. The <code>control_qvld[]</code> signal has the same functionality as <code>local_rdata_valid[]</code> .
<code>control_rdata[]</code>	Data-bus width × 2	Output	The captured read data (same as <code>local_rdata[]</code> ).

## Parameters

The parameters can only be set in IP Toolbench (see “[Step 1: Parameterize](#)” on page 3–5).

## Memory

Table 2–7 shows the memory type parameters.

<b>Table 2–7. Memory Type Parameters</b>			
<b>Parameter</b>	<b>Range</b>	<b>Units</b>	<b>Description</b>
RLDRAM II device	Part number	—	A part number for a particular memory device. Choosing an entry sets many of the parameters in the wizard to the correct value for the specified part. You can add your own devices to this list by editing the <b>memory_types.dat</b> file in the <b>\constraints</b> directory.
Clock speed	100 to 400	MHz	The memory controller clock frequency. The constraints script and the datapath use this clock speed. It must be set to the value that you intend to use. The first time you use IP Toolbench or if you turn on <b>Update example design system PLL</b> , it uses this value for the IP Toolbench-generated PLL's input and output clocks.
Interface voltage	1.5 or 1.8	V	The RLDRAM II interface voltage.
DQ per DQS	8, 9, 16, 18	Bits	Number of DQ bits per DQS input pin. CIO devices only.
Q per DQS	8, 9, 16, 18	Bits	Number of Q bits per DQS input pin. SIO devices only.
Data-bus width	Device dependent	Bits	The width of the memory interface.  For more information about supported interface data widths, refer to <i>AN 325: Interfacing RLDRAM II with Stratix II, Stratix &amp; Stratix GX Devices</i> .

Table 2–8 shows the memory initialization options.

<b>Table 2–8. Memory Initialization Options</b>		
<b>Parameter</b>	<b>Range</b>	<b>Description</b>
Memory configuration	1, 2, or 3.	Refer to your RLDRAM II data sheet.
Burst length	2, 4, or 8	Number of beats in the burst at the memory interface. The number of beats at the local interface is half this value.
Manually enter initialization clock cycles	On or off	The wizard takes the number of initialization clock cycles from the <b>memory.dat</b> file in the <b>constraints</b> directory. The number is calculated from the initialization entry time and the clock speed. You can manually enter a number for the initialization clock cycles if you turn on <b>Manually enter initialization clock cycles</b> .
Number of initialization clock cycles	16 to 80,000	
Enable on-die termination	On or off	Refer to your RLDRAM II data sheet.

**Table 2–8. Memory Initialization Options**

Parameter	Range	Description
Enable external impedance matching	On or off	Refer to your RLDRAM II data sheet.
Enable memory device DLL	On or off	Refer to your RLDRAM II data sheet.

Table 2–9 shows the memory interface parameters.

**Table 2–9. Memory Interface Parameters**

Parameter	Range	Units	Description
Number of address and command busses from FPGA to memory for multiple devices	1 or 2	–	Depends on the number of devices. If you connect only one device there can be only one address and command bus. (1)
Generate DM pins	On or off	–	Adds DM pins and logic to the design.
Use dedicated PLL outputs	On or off	–	Turn on to use dedicated PLL outputs to generate the clocks, which is recommended for HardCopy II devices. When turned off <code>altddio</code> outputs generate the clock outputs.
Number of clock pairs from FPGA to memory	1 to 8	–	The number of RLDRAM II clock output pairs generated in the datapath. When you turn on <b>Use dedicated clock outputs</b> , only values of 1 to 3 are valid.

**Note to Table 2–9:**

- (1) The default signal is `<signal>_0`. When you specify additional address and command busses, both `<signal>_0` and `<signal>_1` are present.



## Timing

Table 2–10 shows the pipeline options.

<i>Table 2–10. Pipeline Options</i>		
Parameter	Range	Description
Number of address and command and write data pipeline registers	0, 1, 2 or 3	When you choose 1, 2, or 3 the wizard inserts 1, 2, or 3 pipeline registers between the memory controller and the command and address output registers and the write data output registers. These registers may help to achieve the required performance at higher frequencies.
Number of read data pipeline registers	0, 1, 2 or 3	When you choose 1, 2, or 3 the wizard inserts 1, 2, or 3 pipeline registers between the read capture registers and the memory controller. These registers may help to achieve the required performance at higher frequencies.

Table 2–11 shows the clocking modes.

<i>Table 2–11. Clocking Modes</i>		
Parameter	Range	Description
Address and command clock	System, write, or dedicated	The clock for the address and command output registers. For <code>system_clk</code> choose <b>System</b> ; for <code>write_clk</code> , choose <b>Write</b> , and for a separate clock, choose <b>Dedicated</b> .  If you choose <b>Dedicated</b> for the clock, ensure the clock phase allows the Quartus II software to meet the setup time on the address and command output registers.
Address and command clock edge	Falling or rising	The clock edge on which the addresses and commands are output.
Dedicated address and command clock PLL phase offset	$\pm 180^\circ$	Sets the dedicated address and command clock PLL phase for better timing.
Enable DQS mode	On or off	Turn on for DQS mode; otherwise the controller is in non-DQS mode (Stratix II and Stratix II GX devices only). HardCopy II devices allow DQS mode only.
Use migratable byte groups	On or off	When turned on, you can migrate the design to a migration device. When turned off the wizard allows much greater flexibility in the placement of byte groups. You can only turn on this option when <b>Enable DQS mode</b> is turned off.
Feedback PLL phase offset	$\pm 180^\circ$	Sets the feedback clock PLL phase for read capture (non-DQS mode only).

Table 2–12 shows the pin loading parameters.

<b>Table 2–12. Pin Loading Parameters</b>		
<b>Parameter</b>	<b>Range (pF)</b>	<b>Description</b>
Pin loading on FPGA DQ/DQS pins	0 to 100	Enter the pin loading to match your board and memory devices.
Pin loading on FPGA address and command pins	0 to 100	Enter the pin loading to match your board and memory devices.
Pin loading on FPGA clock pins	0 to 100	Enter the pin loading to match your board and memory devices.

## Project Settings

Table 2–13 shows the example design settings.

<b>Table 2–13. Example Design Settings</b>	
<b>Parameter</b>	<b>Description</b>
Automatically apply RLDRAM II controller-specific constraints to the Quartus II project	When this option is turned on, the next time you compile, the Quartus II software automatically runs the add constraints script. Turn off this option if you do not want the script to run automatically.
Update the example design file that instantiates the RLDRAM II controller variation	<p>When this option is turned on, IP Toolbench parses and updates the example design file. It only updates sections that are between the following markers:</p> <pre>&lt;&lt;START MEGAWIZARD INSERT &lt;tagname&gt; &lt;&lt;END MEGAWIZARD INSERT &lt;tagname&gt;</pre> <p>If you edit the example design file, ensure that your changes are outside of the markers or remove the markers. Once you remove the markers, you must keep the file updated, because IP Toolbench can no longer update the file.</p>
Update example design system PLL	When this option is turned on, IP Toolbench automatically overwrites the PLL. Turn off this option, if you do not want the wizard to overwrite the PLL.

Table 2–14 shows the variation path parameters.

<b>Table 2–14. Variation Path Parameters</b>	
<b>Parameter</b>	<b>Description</b>
Enable hierarchy control	The constraints script analyzes your design, to automatically extract the hierarchy to your variation. To prevent the constraints script analyzing your design, turn on <b>Enable Hierarchy Control</b> , and enter the correct hierarchy path to your datapath.
Hierarchy path to RLDRAM II controller datapath	The hierarchy path is the path to your RLDRAM II controller datapath, minus the top-level name. The hierarchy entered in the wizard must match your design, because the constraints scripts rely on this path for correct operation.

Table 2–15 shows the device pin prefixes parameter.

<b>Table 2–15. Device Pin Prefixes</b>	
<b>Parameter</b>	<b>Description</b>
Prefix all RLDRAM II pins on the device with	This string prefixes the pin names for the FPGA pins that are connected to the RLDRAM II controller.

## MegaCore Verification

MegaCore verification involves simulation testing and hardware testing.

### Simulation Environment

Altera has carried out extensive functional tests using industry-standard models to ensure the functionality of the RLDRAM II controller. In addition, Altera has carried out a wide variety of gate-level tests on the RLDRAM II controller to verify the post-compilation functionality of the controller.

### Hardware Testing

Table 2–16 shows the Altera development board on which Altera hardware tested the RLDRAM II controller.

<b>Table 2–16. Altera Development Boards</b>		
<b>Development Board</b>	<b>Altera Device</b>	<b>Memory Device</b>
Stratix II Memory Demonstration Board 1	EP2S60F1020C3	Micron 18-bit CIO and SIO RLDRAM II devices



### Design Flow

To evaluate the RLDRAM II Controller MegaCore function using the OpenCore Plus feature, include these steps in your design flow:

1. Obtain and install the RLDRAM II Controller MegaCore Function.

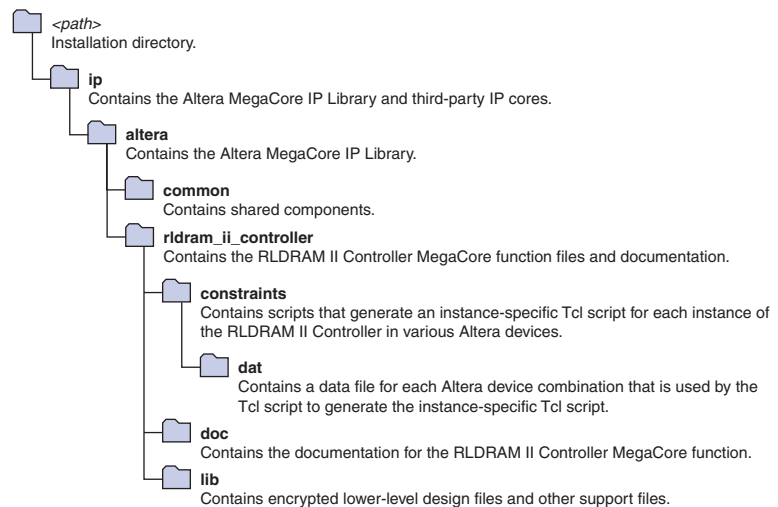
The RLDRAM II Controller is part of the MegaCore IP Library, which is distributed with the Quartus II software and downloadable from the Altera website, [www.altera.com](http://www.altera.com).



For system requirements and installation instructions, refer to *Quartus II Installation & Licensing for Windows and Linux Workstations*.

Figure 3–1 shows the directory structure after you install the RLDRAM II Controller, where *<path>* is the installation directory. The default installation directory on Windows is **c:\altera\<version>**; on Linux it is **/opt/altera<version>**.

**Figure 3–1. RLDRAM II Controller Directory Structure**



2. Create a custom variation of the RLDRAM II Controller MegaCore function using IP Toolbench.



IP Toolbench is a toolbar from which you quickly and easily view documentation, specify parameters, and generate all of the files necessary for integrating the parameterized MegaCore function into your design.

3. Implement the rest of your design using the design entry method of your choice.
4. Use the IP Toolbench-generated IP functional simulation model to verify the operation of your design.



For more information on IP functional simulation models, refer to the *Simulating Altera IP in Third-Party Simulation Tools* chapter in volume 3 of the *Quartus II Handbook*.

5. Edit the PLL.
6. Use the Quartus II software to add constraints to the example design and compile the example design.
7. Perform gate-level timing simulation, or if you have a suitable development board, you can generate an OpenCore Plus time-limited programming file, which you can use to verify the operation of the example design in hardware.
8. Either obtain a license for the RLDRAM II controller MegaCore function or replace the encrypted RLDRAM II controller control logic with your own logic and use the clear-text datapath.



If you obtain a license for the RLDRAM II controller, you must set up licensing.

9. Generate a programming file for the Altera device(s) on your board.
10. Program the Altera device(s) with the completed design.

## RLDRAM II Controller Walkthrough

This walkthrough explains how to create a RLDRAM II controller using the Altera RLDRAM II controller IP Toolbench and the Quartus II software on a PC. When you are finished generating a custom variation of the RLDRAM II controller MegaCore function, you can incorporate it into your overall project.

This walkthrough requires the following steps:

- “Create a New Quartus II Project” on page 3–3
- “Launch IP Toolbench” on page 3–4

- “Step 1: Parameterize” on page 3–5
- “Step 2: Constraints” on page 3–7
- “Step 3: Set Up Simulation” on page 3–8
- “Step 4: Generate” on page 3–8

## Create a New Quartus II Project

You need to create a new Quartus II project with the **New Project Wizard**, which specifies the working directory for the project, assigns the project name, and designates the name of the top-level design entity. To create a new project follow these steps:

1. Choose **Programs > Altera > Quartus II <version>** (Windows Start menu) to run the Quartus II software. Alternatively, you can use the Quartus II Web Edition software.
2. Choose **New Project Wizard** (File menu).
3. Click **Next** in the **New Project Wizard Introduction** page (the introduction page does not display if you turned it off previously).
4. In the **New Project Wizard: Directory, Name, Top-Level Entity** page, enter the following information:
  - a. Specify the working directory for your project. For example, this walkthrough uses the `c:\altera\projects\rldram_project` directory.
  - b. Specify the name of the project. This walkthrough uses **project** for the project name.



The Quartus II software automatically specifies a top-level design entity that has the same name as the project. Do not change it.

5. Click **Next** to close this page and display the **New Project Wizard: Add Files** page.



When you specify a directory that does not already exist, a message asks if the specified directory should be created. Click **Yes** to create the directory.

6. If you installed the MegaCore IP Library in a different directory from where you installed the Quartus II software, you must add the user libraries:
  - a. Click **User Libraries**.

- b. Type `<path>\ip` into the **Library name** box, where `<path>` is the directory in which you installed the RLDRAM II controller.
  - c. Click **Add to** add the path to the Quartus II project.
  - d. Click **OK** to save the library path in the project.
7. Click **Next** to close this page and display the **New Project Wizard: Family & Device Settings** page.
8. On the **New Project Wizard: Family & Device Settings** page, choose the target device family in the **Family** list.
9. The remaining pages in the **New Project Wizard** are optional. Click **Finish** to complete the Quartus II project.

You have finished creating your new Quartus II project.

## Launch IP Toolbench

To launch IP Toolbench in the Quartus II software, follow these steps:

1. Start the MegaWizard® Plug-In Manager by choosing **MegaWizard Plug-In Manager** (Tools menu). The **MegaWizard Plug-In Manager** dialog box displays.



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

2. Specify that you want to create a new custom megafunction variation and click **Next**.
3. Expand the **Interfaces > Memory Controllers** directory, then click **RLDRAM II Controller v9.0**.
4. Select the output file type for your design; the wizard supports VHDL and Verilog HDL.
5. The MegaWizard Plug-In Manager shows the project path that you specified in the **New Project Wizard**. Append a variation name for the MegaCore function output files `<project path>\<variation name>`.



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

6. Click **Next** to launch IP Toolbench.



## Step 1: Parameterize

To parameterize your MegaCore function, follow these steps:



For more information on parameters, refer to [“Parameters” on page 2–28](#).

1. Click **Step 1: Parameterize** in IP Toolbench .
2. Choose the memory type.
  - a. Choose the memory device.



You can add your own memory devices to this list by editing the **memory\_types.dat** file in the **\constraints** directory.

- b. Enter the clock speed.
  - c. Choose the interface voltage.
  - d. Choose the data bus width.
  - e. Choose the **DQ per DQS** (CIO devices), or the **Q per DQS** (SIO devices).
3. Choose the memory initialization options.
4. Choose your memory interface parameters.
5. Click the Timing tab.



For more information on timing parameters, refer to [“Timing” on page 2–31](#).

6. Enter the datapath pipeline options.
7. Choose the clocking modes.
8. Turn on the appropriate capture mode—DQS or non-DQS capture mode. If you turn off **Enable DQS mode** (non-DQS capture mode), you can turn on **Use migratable bytegroups**.
9. Click the Project Settings tab.



For more information on project settings, refer to [“Project Settings” on page 2–32](#).

10. Altera recommends that you turn on **Automatically apply RLDRAM II controller-specific constraints to the Quartus II project** so that the Quartus II software automatically applies the constraints script when you compile the example design.



You must turn on this option, the first time you run IP Toolbench.

11. Ensure **Update the example design file that instantiates the RLDRAM II controller variation** is turned on, for IP Toolbench to automatically update the example design file.



You must turn on this option, the first time you run IP Toolbench.

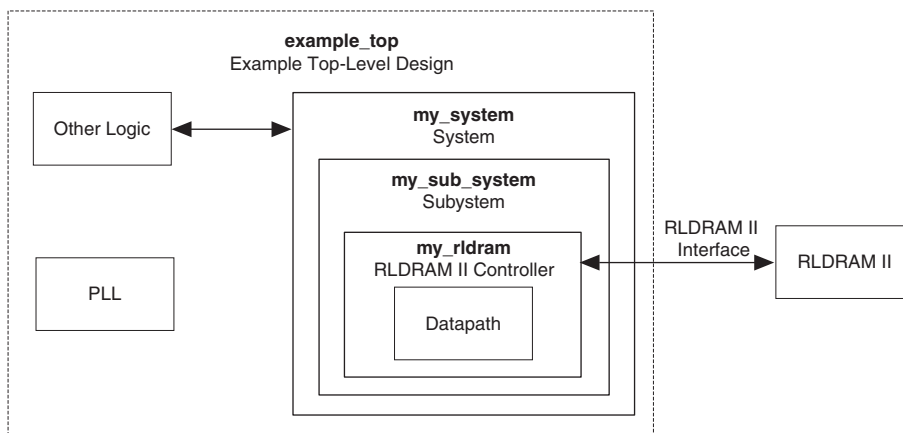
12. Turn off **Update example design system PLL**, if you have edited the PLL and you do not want the wizard to regenerate the PLL when you regenerate the variation.



You must turn on this option, the first time you run IP Toolbench.

13. The constraints script automatically detects the hierarchy of your design. The constraints script analyzes and elaborates your design to automatically extract the hierarchy to your variation. To prevent the constraints script analyzing and elaborating your design, turn on **Enable Hierarchy Control**, and enter the correct hierarchy path to your datapath. [Figure 3–2](#) shows the following example hierarchy:

```
my_system:my_system_inst|my_sub_system:my_sub_system_inst|  
my_rldramii:my_rldramii_inst|datapath:datapath_inst|
```

**Figure 3–2. System Naming**

14. IP Toolbench uses a prefix (for example, **rldramii\_**) for the names of all memory interface pins. Enter a prefix for all memory interface pins associated with this custom variation.
15. Enter the pin loading for the FPGA pins.



You must enter suitable values for the pin loading, because the values affect timing.

16. Click **Finish**.

## Step 2: Constraints

To choose the constraints for your device, follow these steps:

1. Click **Step 2: Constraints** in IP Toolbench.
2. Choose the positions on the device for each of the RLDRAM II byte groups. To place a byte group, select the byte group in the drop-down box at your chosen position.



The floorplan matches the orientation of the Quartus II floorplanner. The layout represents the die as viewed from above. A byte group consists of data (DQ) pins for CIO devices; or data (Q) pins for SIO devices, and a data strobe signal (DQS) pin. The number of data pins per byte group matches your choice of **DQ** (or **Q**) per **DQS**.

### Step 3: Set Up Simulation

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



You may only use these simulation model output files for simulation purposes and expressly not for synthesis or any other purposes. Using these models for synthesis will create a nonfunctional design.

To generate an IP functional simulation model for your MegaCore function, follow these steps:

1. Click **Step 3: Set Up Simulation** in IP Toolbench.
2. Turn on **Generate Simulation Model**.
3. Choose the language in the **Language** list.
4. Some third-party synthesis tools can use a netlist that contains only the structure of the MegaCore function, but not detailed logic, to optimize performance of the design that contains the MegaCore function. If your synthesis tool supports this feature, turn on **Generate netlist**.
5. Click **OK**.

### Step 4: Generate

To generate your MegaCore function, click **Step 4: Generate** in IP Toolbench.

Table 3–1 describes the generated files and other files that may be in your project directory. The names and types of files specified in the IP Toolbench report vary based on whether you created your design with VHDL or Verilog HDL

**Table 3–1. Generated Files (Part 1 of 2)** *Note (1), (2), (3)*

Filename	Description
<code>&lt;variation name&gt;.vhd</code> , or <code>.v</code>	A MegaCore function variation file, which defines a VHDL or Verilog HDL description of the custom MegaCore function. Instantiate the entity defined by this file inside of your design. Include this file when compiling your design in the Quartus II software.
<code>&lt;variation name&gt;.cmp</code>	A VHDL component declaration file for the MegaCore function variation. Add the contents of this file to any VHDL architecture that instantiates the MegaCore function.
<code>&lt;variation name&gt;.bsf</code>	Quartus II symbol file for the MegaCore function variation. You can use this file in the Quartus II block diagram editor.
<code>&lt;variation name&gt;.sdc</code>	A Synopsys Design Constraints (SDC) file. Use this SDC file with the DDR timing wizard (DTW)-generated SDC file when using TimeQuest. You must copy the contents of this file into the DTW-generated SDC file, so the example design has the correct timing constraints when using TimeQuest.
<code>altera_vhdl_support.vhd</code>	A VHDL package that contains functions for the generated entities. This file may be shared between MegaCore functions.
<code>&lt;variation name&gt;_example_driver.vhd</code> or <code>.v</code>	Example driver.
<code>&lt;top-level name&gt;.vhd</code> or <code>.v</code>	Example design file.
<code>add_constraints_for_&lt;variation name&gt;.tcl</code>	Add constraints script.
<code>rldramii_pll_&lt;device name&gt;.vhd</code> or <code>.v</code>	System PLL.
<code>rldramii_fbpll_&lt;device name&gt;.vhd</code> or <code>.v</code>	Feedback PLL.
<code>&lt;variation name&gt;_auk_rldramii_addr_cmd_reg.vhd</code> or <code>.v</code>	Address and command output registers.
<code>&lt;variation name&gt;_auk_rldramii_clk_gen.vhd</code> or <code>.v</code>	Memory clock generator.
<code>&lt;variation name&gt;_auk_rldramii_controller_ipfs_wrapper.vhd</code> or <code>.v</code>	A file that instantiates the controller.
<code>&lt;variation name&gt;_auk_rldramii_controller_ipfs_wrapper.vho</code> or <code>.vo</code>	VHDL or Verilog HDL IP functional simulation model.
<code>&lt;variation name&gt;_auk_rldramii_datapath.vhd</code> or <code>.v</code>	Datapath.

**Table 3–1. Generated Files (Part 2 of 2)** *Note (1), (2), (3)*

Filename	Description
<variation name>_auk_rldramii_dm_group.vhd or .v	Data mask (DM) group.
<variation name>_auk_rldramii_dqs_group.vhd or .v	DQS group.
<variation name>_auk_rldramii_pipeline_addr_cmd.vhd or .v	Address and command pipeline registers.
<variation name>_auk_rldramii_pipeline_qvld.vhd or .v	Valid data flag (QVLD) pipeline registers.
<variation name>_auk_rldramii_pipeline_rdata.vhd or .v	Read data pipeline registers.
<variation name>_auk_rldramii_pipeline_wdata.vhd or .v	Write data pipeline registers.
<variation name>_auk_rldramii_qvld_group.vhd or .v	QVLD group.
<variation name>.html	MegaCore function report file.
<variation name>.qip	Contains Quartus II project information for your MegaCore function variations.

**Notes to Table 3–1:**

- (1) <top-level name> is the name of the Quartus II project top-level entity.
- (2) <variation name> is the name you assign.
- (3) <device name> is the device family name.

1. After you review the generation report, click **Exit** to close IP Toolbench.



The Quartus II IP File (**.qip**) is a file generated by the MegaWizard interface, and contains information about the generated IP core. You are prompted to add this **.qip** file to the current Quartus II project at the time of file generation. In most cases, the **.qip** file contains all of the necessary assignments and information required to process the core or system in the Quartus II compiler. Generally, a single **.qip** file is generated for each MegaCore function or system in the Quartus II compiler.

Now, simulate the example design (refer to “[Simulate the Example Design](#)” on page 3–11), edit the PLL(s), and compile (refer to “[Compile the Example Design](#)” on page 3–14).

## Simulate the Example Design

This section describes the following simulation techniques:

- [Simulate with IP Functional Simulation Models](#)
- [Simulating in Third-Party Simulation Tools Using NativeLink](#)

### Simulate with IP Functional Simulation Models

You can simulate the example design using the IP Toolbench-generated IP functional simulation models. IP Toolbench generates a VHDL or Verilog HDL testbench for your example design, which is in the **testbench** directory in your project directory.



For more information on the testbench, refer to [“Example Design” on page 2–15](#).

You can use the IP functional simulation model with any Altera-supported VHDL or Verilog HDL simulator. To simulate the example design with the ModelSim® simulator, follow these steps:

1. Obtain a memory model that matches your chosen parameters and save it to the *<directory name>\testbench* directory. For example, you can download a RLDRAM II model from the Micron web site at [www.micron.com](http://www.micron.com).



Before running the simulation you may also need to edit the testbench to match the chosen RLDRAM II model.

2. Start the ModelSim-Altera simulator.
3. Change your working directory to your IP Toolbench-generated file directory *<directory name>\testbench\modelsim*.
4. To simulate with an IP functional simulation model simulation, type the following command:

```
source <variation name>_vsim.tcl ←
```



Before running the simulation, you may have to edit the set memory model parameter in the *<variation name>\_vsim.tcl* file to match the selected RLDRAM II model.

5. For a gate-level timing simulation (VHDL or Verilog HDL ModelSim output from the Quartus II software), type the following commands:

```
set use_gate_model 1 ←
```

```
source <variation name>_vsim.tcl
```

## Simulating in Third-Party Simulation Tools Using NativeLink

You can perform a simulation in a third-party simulation tool from within the Quartus II software, using NativeLink.



For more information on NativeLink, refer to the *Simulating Altera IP in Third-Party Simulation Tools* chapter in volume 3 of the *Quartus II Handbook*.

To set up simulation in the Quartus II software using NativeLink, follow these steps:

1. Create a custom variation with an IP functional simulation model.
2. Obtain and copy an RLDRAM II model to a suitable location, for example, the testbench directory.



Before running the simulation you may also need to edit the testbench to match the chosen RLDRAM II model.

3. Check that the absolute path to your third-party simulator executable is set. On the Tools menu click **Options** and select **EDA Tools Options**.
4. On the Processing menu, point to **Start** and click **Start Analysis & Elaboration**.
5. On the Assignments menu click **Settings**, expand **EDA Tool Settings** and select **Simulation**. Select a simulator under **Tool Name** and in **NativeLink Settings**, select **Compile Test Bench** and click **Test Benches**.
6. Click **New**.
7. Enter a name for the **Test bench name**.
8. Enter the name of the automatically generated testbench, *<project name>\_tb*, in **Test bench entity**.
9. Enter the name of the top-level instance in **Instance**.
10. Change **Run for** to 80  $\mu$ s.



11. Add the testbench files. In the **File name** field browse to the location of the RLDRAM II model and the testbench, *<project name>\_tb*, click **OK** and click **Add**.
12. Click **OK**.
13. Click **OK**.
14. On the Tools menu point to **EDA Simulation Tool** and click **Run EDA RTL Simulation**.

## Edit the PLL

The IP Toolbench-generated example design includes a PLL, which has an input to output clock ratio of 1:1 and a clock frequency that you entered in IP Toolbench. In addition, IP Toolbench correctly sets all the phase offsets of all the relevant clock outputs for your design. You can edit the PLL input clock to make it conform to your system requirements. If you re-run IP Toolbench and wish to save your PLL edits, turn off **Update example design system PLL**.



If you turn off **Enable DQS mode**, IP Toolbench generates a second PLL—the feedback PLL. You need not edit the feedback PLL.



For more information on the PLL, refer to [“PLL Configuration” on page 2–13](#).

To edit the example PLL, follow these steps:

1. Choose **MegaWizard Plug-In Manager** (Tools menu).
2. Select **Edit an existing custom megafunction variation** and click **Next**.
3. In your Quartus II project directory, for VHDL choose **rldramii\_pll\_<device name>.vhd**; for Verilog HDL choose **rldramii\_pll\_<device name>.v**.
4. Click **Next**.
5. Edit the PLL parameters in the **altpll** MegaWizard Plug-In.



For more information on the **altpll** megafunction, refer to the Quartus II Help or click **Documentation** in the **ALTPLL** MegaWizard Plug-In.

## Compile the Example Design

Before the Quartus II software compiles the example design it runs the IP Toolbench-generated Tcl constraints script, **auto\_add\_rldramii\_constraints.tcl**, which calls the **add\_constraints\_for\_<variation name>.tcl** script for each variation in your design. The **add\_constraints\_for\_<variation name>.tcl** script checks for any previously added constraints, removes them, and then adds constraints for that variation.

The constraints script analyzes and elaborates your design, to automatically extract the hierarchy to your variation. To prevent the constraints script analyzing and elaborating your design, turn on **Enable Hierarchy Control** in the wizard, and enter the correct hierarchy path to your datapath (refer to step 13 on page 3-6).

When the constraints script runs, it creates another script, **remove\_constraints\_for\_<variation name>.tcl**, which you can use to remove the constraints from your design.

To compile the example instance, follow these steps:

1. Choose **Start Compilation** (Processing menu), which runs the add constraints scripts, compiles the example design, and performs timing analysis.
2. View the Timing Analyzer to verify your design meets timing.

If the compilation does not reach the frequency requirements, follow these steps:

1. Choose **Settings** (Assignments menu).
2. Expand **Analysis and Synthesis Settings** in the category list.
3. Select **Speed** in Optimization Technique.
4. Expand **Fitter Settings**.
5. Turn on **Optimize Hold Timing** and select **All Paths**.
6. Turn on **Fast-corner timing**.
7. Click **OK**.
8. Re-compile the example design by choosing **Start Compilation** (Processing menu).



To achieve a higher frequency, increase the number of address and command and write data pipeline registers, or increase the number read data pipeline registers, refer to step 6 on [page 3–5](#).

To view the constraints in the Quartus II Assignment Editor, choose **Assignment Editor** (Assignments menu).



If you have “?” characters in the Quartus II Assignment Editor, the Quartus II software cannot find the entity to which it is applying the constraints, probably because of a hierarchy mismatch. Either edit the constraints script, or enter the correct hierarchy path in the Project Settings tab (refer to step 13 on [page 3–6](#)).



For more information on constraints, refer to [“Constraints” on page 2–17](#).

## Program a Device

After you have compiled the example design, you can perform gate-level simulation (refer to [“Simulate the Example Design” on page 3–11](#)) or program your targeted Altera device to verify the example design in hardware.

With Altera's free OpenCore Plus evaluation feature, you can evaluate the RLDRAM II Controller MegaCore function before you obtain a license. OpenCore Plus evaluation allows you to generate an IP functional simulation model, and produce a time-limited programming file.



For more information on OpenCore Plus hardware evaluation using the RLDRAM II Controller MegaCore function, refer to [“OpenCore Plus Evaluation” on page 1–4](#), [“OpenCore Plus Time-Out Behavior” on page 2–13](#), and [AN 320: OpenCore Plus Evaluation of Megafunctions](#).

## Implement Your Design

In the MegaWizard flow, to implement your design based on the example design, replace the example driver in the example design with your own logic.



A FIFO buffer is not implemented in the core; you must implement a FIFO buffer.

## Set Up Licensing

You need to obtain a license for the MegaCore function only when you are completely satisfied with its functionality and performance, and want to take your design to production.

After you obtain a license for RLDRAM II controller, you can request a license file from the Altera web site at [www.altera.com/licensing](http://www.altera.com/licensing) and install it on your computer. When you request a license file, Altera emails you a **license.dat** file. If you do not have Internet access, contact your local Altera representative.



### Revision History

The table below displays the revision history for the chapters in this user guide.

Date	Version	Changes Made
March 2009	9.0	Updated the release information.
November 2008	8.1	Updated the release information.
May 2008	8.0	<ul style="list-style-type: none"><li>Added timing assignment information for capture to first level resynchronization registers</li><li>Registers clocked by DQS in the core now use undelayed DQS</li></ul>
May 2007	7.1	No changes.
March 2007	7.0	No changes.
December 2006	6.1	<ul style="list-style-type: none"><li>Added timing assignment information for 18 and 36-bit RLDRAM II devices</li><li>Updated device initialization sequence</li></ul>
April 2006	1.1.0	Updated format.
October 2005	1.0.0	First published.

### How to Contact Altera

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






Information Type	Contact <i>Note (1)</i>
Technical support	<a href="http://www.altera.com/mysupport/">www.altera.com/mysupport/</a>
Technical training	<a href="http://www.altera.com/training/">www.altera.com/training/</a>
Technical training services	<a href="mailto:custrain@altera.com">custrain@altera.com</a>
Product literature	<a href="http://www.altera.com/literature">www.altera.com/literature</a>
FTP site	<a href="ftp://ftp.altera.com">ftp.altera.com</a>

*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
<b>Bold Type with Initial Capital Letters</b>	Indicates command names, dialog box titles, dialog box options, and other GUI labels. For example, <b>Save As</b> dialog box.
<b>bold type</b>	Indicates directory names, project names, disk drive names, file names, file name extensions, and software utility names. For example, <b>qdesigns</b> directory, <b>d:</b> drive, and <b>chiptrip.gdf</b> file.
<i>Italic Type with Initial Capital Letters</i>	Indicates document titles. For example, <i>AN 519: Stratix IV Design Guidelines</i> .
<i>Italic type</i>	Indicates variables. For example, $n + 1$ .  Variable names are enclosed in angle brackets (< >). For example, <file name> and <project name>.pof file.
Initial Capital Letters	Indicates keyboard keys and menu names. For example, Delete key, and the Options menu.
"Subheading Title"	Quotation marks indicate references to sections within a document and titles of Quartus II Help topics. For example, "Typographic Conventions."
Courier type	Indicates signal, port, register, bit, block, and primitive names. For example, data1, tdi, and input . Active-low signals are denoted by suffix n. For example, resetn.  Indicates command line commands and anything that must be typed exactly as it appears. For example, c:\qdesigns\tutorial\chiptrip.gdf.  Also, indicates sections of an actual file, such as a Report File, references to parts of files (for example, the AHDL keyword SUBDESIGN), and logic function names (for example, TRI).
1., 2., 3., and a., b., c., etc.	Numbered steps indicate a list of items when the sequence of the items is important, such as the steps listed in a procedure.
■ ● ●	Bullets indicate a list of items when the sequence of the items is not important.
	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 your work.
	A warning calls attention to a condition or possible situation that can cause you injury.
	The angled arrow instructs you to press Enter.
	The feet direct you to more information about a particular topic.