Spartan-6 FPGA Clocking Resources

User Guide

UG382 (v1.3) February 22, 2010

XILINX®



Xilinx is disclosing this user guide, manual, release note, and/or specification (the "Documentation") to you solely for use in the development of designs to operate with Xilinx hardware devices. You may not reproduce, distribute, republish, download, display, post, or transmit the Documentation in any form or by any means including, but not limited to, electronic, mechanical, photocopying, recording, or otherwise, without the prior written consent of Xilinx. Xilinx expressly disclaims any liability arising out of your use of the Documentation. Xilinx reserves the right, at its sole discretion, to change the Documentation without notice at any time. Xilinx assumes no obligation to correct any errors contained in the Documentation, or to advise you of any corrections or updates. Xilinx expressly disclaims any liability in connection with technical support or assistance that may be provided to you in connection with the Information.

THE DOCUMENTATION IS DISCLOSED TO YOU “AS-IS” WITH NO WARRANTY OF ANY KIND. XILINX MAKES NO OTHER WARRANTIES, WHETHER EXPRESS, IMPLIED, OR STATUTORY, REGARDING THE DOCUMENTATION, INCLUDING ANY WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NONINFRINGEMENT OF THIRD-PARTY RIGHTS. IN NO EVENT WILL XILINX BE LIABLE FOR ANY CONSEQUENTIAL, INDIRECT, EXEMPLARY, SPECIAL, OR INCIDENTAL DAMAGES, INCLUDING ANY LOSS OF DATA OR LOST PROFITS, ARISING FROM YOUR USE OF THE DOCUMENTATION.

© 2009–2010 Xilinx, Inc. XILINX, the Xilinx logo, Virtex, Spartan, ISE, and other designated brands included herein are trademarks of Xilinx in the United States and other countries. All other trademarks are the property of their respective owners.

Revision History

The following table shows the revision history for this document.

Date	Version	Revision
06/24/09	1.0	Initial Xilinx release.
08/17/09	1.1	In Chapter 1: Deleted Figure 1-1, Overview of Global Clock Connections. Changed the Global Clocking Infrastructure section including revisions in Table 1-1 and Table 1-2, page 15. Revised the Spanning a Full Bank with a Single I/O Clock and Clock Inputs discussions and Figure 1-5 and Figure 1-6. Added Figure 1-8, page 25. Removed BUFIO2 from Table 1-8. Removed exception from BUFGMUX_1, page 36. Added Clock Buffers for the High Speed I/O Clock Region, page 40 including Table 1-14 and Table 1-15. Updated Table 1-16 through Table 1-23 and added or revised Figure 1-26, Figure 1-27, Figure 1-29, and Figure 1-30. Added section: Examples of High Speed I/O Clock Network Connections, page 29. In Chapter 2: Updated XC6SLX4 resources in Table 2-1 and Table 2-2. Added note to Table 2-3, clarified descriptions in Phase Shift, page 58. Updated CLKIN_PERIOD description in Table 2-6. Updated the DCM_CLKGEN Primitive feature list. Updated Table 2-10 to all frequency ranges. In Chapter 3: Updated CLKIN2 and CLKINSEL descriptions in Table 3-4. Updated discussion leading to Figure 3-5. Typographical edits in Figure 3-15.
01/04/10	1.2	Added clarification to the Clock Resources section. Updated Table 1-1 and Table 1-2. Added Figure 1-2. Added Table 1-3, Table 1-4, and Table 1-5. Fixed Figure 1-5, Figure 1-6, and Figure 1-7. Added Table 1-6. Added Clocking Structure Guidelines. Moved Examples of High Speed I/O Clock Network Connections. Added Figure 1-16. Added Table 1-12 and Figure 1-19 and Figure 1-20. Updated I/O Clock Network Inputs for BUFIO2 and BUFIO2_2CLK in Table 1-15. Added GTP_DUAL to Table 1-15. Updated BUFGMUX_1 section.Updated the definition of the input on Table 1-16. Updated Figure 1-26, Figure 1-27, and Figure 1-30. Updated GCLK description in Table 1-20. Added ENABLE_SYNC to Table 1-21 and Table 1-23. Added Table 1-12 and Figure 1-15 and Figure 1-16. In Table 2-8, updated SPREAD_SPECTRUM, added CLKFX_MD_MAX, and Note 1. Updated Spread-Spectrum Clock Generation section. Updated Figure 3-1. Added clarification on BUFIO2FB under Equation 3-1. Updated description of CLKOUT[0:5]_PHASE. Added BUFIO2 to PLL Clock Input Signals.
02/22/10	1.3	Updated the BUFIO2 clocking regions in Table 1-3, Table 1-4, Figure 1-5, Figure 1-7 and Figure 1-8. Removed note 1 from Table 1-6. Revised Figure 1-16 and added Example 7 including Figure 1-17. Added further discussion to Clock Buffers and Multiplexers. Updated the STATUS[7:3] description in Table 2-5 and added STATUS[7:3] to Table 2-7. Added description of reset circuit for lower-power devices to RST Input Behavior section. Updated Figure 3-3 and added Figure 3-4. Adding equations Equation 3-2 through Equation 3-6. Revised Equation 3-7 and Equation 3-9 and added Equation 3-8. Updated the description of EXTERNAL compensation in Table 3-5.

Table of Contents

Revision History 3

Preface: About This Guide

Guide Contents 9
Additional Documentation 9
Additional Resources 10

Chapter 1: Clock Resources

Summary 11
Introduction 11
Clock Resources 12
Global Clocking Infrastructure 13
I/O Clocking Infrastructure 20
Spanning a Full Bank with a Single I/O Clock 21
Clock Inputs 22
Clocking Structure Guidelines 26
SDR Data Rate (FD Register in IOB, No IOSERDES2) 27
DDR Data Rate (IDDR2, ODDR2, No IOSERDES2) 27
High-Speed IOSERDES2 Usage for Advanced Serialization 28
Global Clock Input Buffer Primitives 28
Examples of High Speed I/O Clock Network Connections 29
Clock Buffers and Multiplexers 34
Global Clock Buffer Primitives 34
BUFGMUX 35
BUFGMUX_1 36
BUFG 38
BUFGCE and BUFGCE_1 39
Clock Buffers for the High Speed I/O Clock Region 40
BUFIO2 41
BUFIO2_2CLK 45
BUFPLL 48
BUFPLL_MCB 49
BUFIO2FB 50

Chapter 2: Clock Management Technology

Clock Management Summary 53
DCM Summary 54
DCM Introduction 54
Compatibility and Comparison with Other Xilinx FPGA Families 55
DCM Functional Overview 56
Delay-Locked Loop 57
Digital Frequency Synthesizer 57
Phase Shift 58

Status Logic . . . 58
DCM Primitives . . . 58
DCM_SP Primitive . . . 59
DCM_CLKGEN Primitive . . . 64
DCM_SP Design Guidelines . . . 67
Input Clock Frequency Range . . . 67
Output Clock Frequency Range . . . 67
Input Clock and Clock Feedback Variation . . . 68
Cycle-to-Cycle Jitter . . . 68
Period Jitter . . . 68
DLL Feedback Delay Variance . . . 68
Spread Spectrum Clock Reception . . . 69
Optimal DCM Clock and External Feedback Inputs . . . 69
LOCKED Output Behavior . . . 69
Using the LOCKED Signal . . . 70
RST Input Behavior . . . 71
DCM_CLKGEN Design Guidelines . . . 71
Dynamic Frequency Synthesis . . . 72
Spread-Spectrum Clock Generation . . . 75
Spread-Spectrum Generation . . . 76
Fixed Spread Spectrum . . . 76
Soft Spread Spectrum . . . 77
Free-Running Oscillator . . . 78

Chapter 3: Phase-Locked Loops

Introduction . . . 81
Phase Lock Loop (PLL) . . . 84
Aligning PLL using CLK_FEEDBACK and BUFIO2FB . . . 86
General Usage Description . . . 88
PLL Primitives . . . 88
PLL_BASE Primitive . . . 88
PLL_ADV Primitive . . . 89
Clock Network Deskew . . . 89
Frequency Synthesis Only . . . 90
Jitter Filter . . . 90
Limitations . . . 90
VCO Operating Range . . . 91
Minimum and Maximum Input Frequency . . . 91
Duty Cycle Programmability . . . 91
Phase Shift . . . 91
PLL Programming . . . 91
Determine the Input Frequency . . . 91
Determine the M and D Values . . . 92
PLL Ports . . . 92
PLL Attributes . . . 94
PLL Clock Input Signals . . . 95
Counter Control . . . 96
Clock Shifting . . . 97
Detailed VCO and Output Counter Waveforms . . . 97
Missing Input Clock or Feedback Clock . . . 98
PLL Use Models . . . 98

Clock Network Deskew 98
PLL with Internal Feedback 99
Zero Delay Buffer 100
DCM Driving PLL 100
PLL Driving DCM 101
PLL to PLL Connection 102
Application Guidelines 103
PLL Application Example 103

About This Guide

This document describes Spartan®-6 FPGA clocking. Complete and up-to-date documentation of the Spartan-6 family of FPGAs is available on the Xilinx website at http://www.xilinx.com/support/documentation/spartan-6.htm.

Guide Contents

This manual contains the following chapters:

- Chapter 1, Clock Resources
- Chapter 2, Clock Management Technology
- Chapter 3, Phase-Locked Loops

Additional Documentation

The following documents are also available for download at http://www.xilinx.com/support/documentation/spartan-6.htm.

- Spartan-6 Family Overview

  This overview outlines the features and product selection of the Spartan-6 family.

- Spartan-6 FPGA Data Sheet: DC and Switching Characteristics

  This data sheet contains the DC and switching characteristic specifications for the Spartan-6 family.

- Spartan-6 FPGA Packaging and Pinout Specifications

  This specification includes the tables for device/package combinations and maximum I/Os, pin definitions, pinout tables, pinout diagrams, mechanical drawings, and thermal specifications.

- Spartan-6 FPGA Configuration User Guide

  This all-encompassing configuration guide includes chapters on configuration interfaces (serial and parallel), multi-bitstream management, bitstream encryption, boundary-scan and JTAG configuration, and reconfiguration techniques.

- Spartan-6 FPGA SelectIO Resources User Guide

  This guide describes the SelectIO™ resources available in all Spartan-6 devices.

- Spartan-6 FPGA Block RAM Resources User Guide

  This guide describes the Spartan-6 device block RAM capabilities.

- Spartan-6 FPGA Configurable Logic Block User Guide

  This guide describes the capabilities of the configurable logic blocks (CLBs) available in all Spartan-6 devices.

- Spartan-6 FPGA DSP48A1 Slice User Guide

  This guide describes the architecture of the DSP48A1 slice in Spartan-6 FPGAs and provides configuration examples.

- Spartan-6 FPGA GTP Transceiver User Guide

  This guide describes the GTP transceivers available in the Spartan-6 LXT FPGAs.

- Spartan-6 FPGA Memory Controller User Guide

  This guide describes the Spartan-6 FPGA memory controller block, a dedicated, embedded multi-port memory controller that greatly simplifies interfacing Spartan-6 FPGAs to the most popular memory standards.

- Spartan-6 FPGA PCB Design Guide

  This guide provides information on PCB design for Spartan-6 devices, with a focus on strategies for making design decisions at the PCB and interface level.

Additional Resources

To search the Answer Database of silicon, software, and IP questions and answers, or to create a technical support WebCase, see the Xilinx website at:

http://www.xilinx.com/support.

XILINX®

Chapter 1

Clock Resources

Summary

This chapter describes how to take advantage of the Spartan-6 FPGA clock resources, including the dedicated clock inputs, buffers, and routing. The clocking infrastructure provides a series of low-capacitance, low-skew interconnect lines that are well suited to carrying high-frequency signals throughout the FPGA, minimizing clock skew and improving performance, and should be used for all clock signals. Third-party synthesis tools, and Xilinx synthesis and implementation tools, automatically use some of these resources for high fan-out clock signals.

The clock routing can be used in conjunction with the DCMs and PLLs, which are discussed in more detail in Chapter 2, Clock Management Technology and Chapter 3, Phase-Locked Loops.

Introduction

Each Spartan-6 FPGA device offers 16 high-speed, low-skew global clock resources to optimize performance. These resources are used automatically by the Xilinx tools. Even if the clock rate is relatively slow, it is still important to use the global routing resources to eliminate any potential for timing hazards. It is important to understand how to define and take the best advantage of these resources.

Each Spartan-6 FPGA also provides 40 ultra high-speed, low-skew I/O regional clock resources to serve localized I/O serializer/de-serializer (ISERDES and OSERDES) circuits. For more information on ISERDES and OSERDES, go to the UG381, *Spartan-6 FPGA SelectIO Resources User Guide* and XAPP1064, *Source-Synchronous Serialization and Deserialization (up to 1050 Mb/s)*.

Use the ISE® software to check all the design rules and to ensure correct usage of clock resources, SelectIO logic, I/O standard compatibility, and routability. A completed design ensures that all placement and logic restrictions are properly checked.

A design checklist is provided in UG393, *Spartan-6 FPGA PCB Design Guide* to assist with pin planning.

Clock Resources

The Spartan-6 FPGA clock resources consist of four types of connections:

- Global clock input pads (GCLK)
- Global clock multiplexers
- I/O clock buffers
- Clock routing networks

There are two types of clock networks:

- Global clock network driven by global clock multiplexers (BUFGMUX)
- I/O regional clock networks driven by I/O clock buffers (BUFIO2) as well as PLL clock buffers (BUFPLL)

BUFGMUX can multiplex between two global clock sources or be used as a simple BUFG clock buffer. The clock buffer can only drive the global clock routing resources, which can only drive clock inputs. However, clock inputs on the FPGA logic flip-flops can also come from general-purpose routing, although their use should be limited due to higher skew.

BUFPLL and BUFIO2 are used to drive clocks routed only on the I/O regional clock network with much higher performance than the global clock network. This limits the driving destination only to the input serial-to-parallel logic resources (ISERDES) or output parallel-to-serial logic resources (OSERDES) on each bank of the FPGA.

BUFIO2 can drive ILOGIC and OLOGIC for DDR paths. BUFIO2 can also route global clock or GTP clock pins to DCM and PLL clock inputs.

Global Clocking Infrastructure

The detailed Spartan-6 FPGA global clocking infrastructure is shown in Figure 1-1.

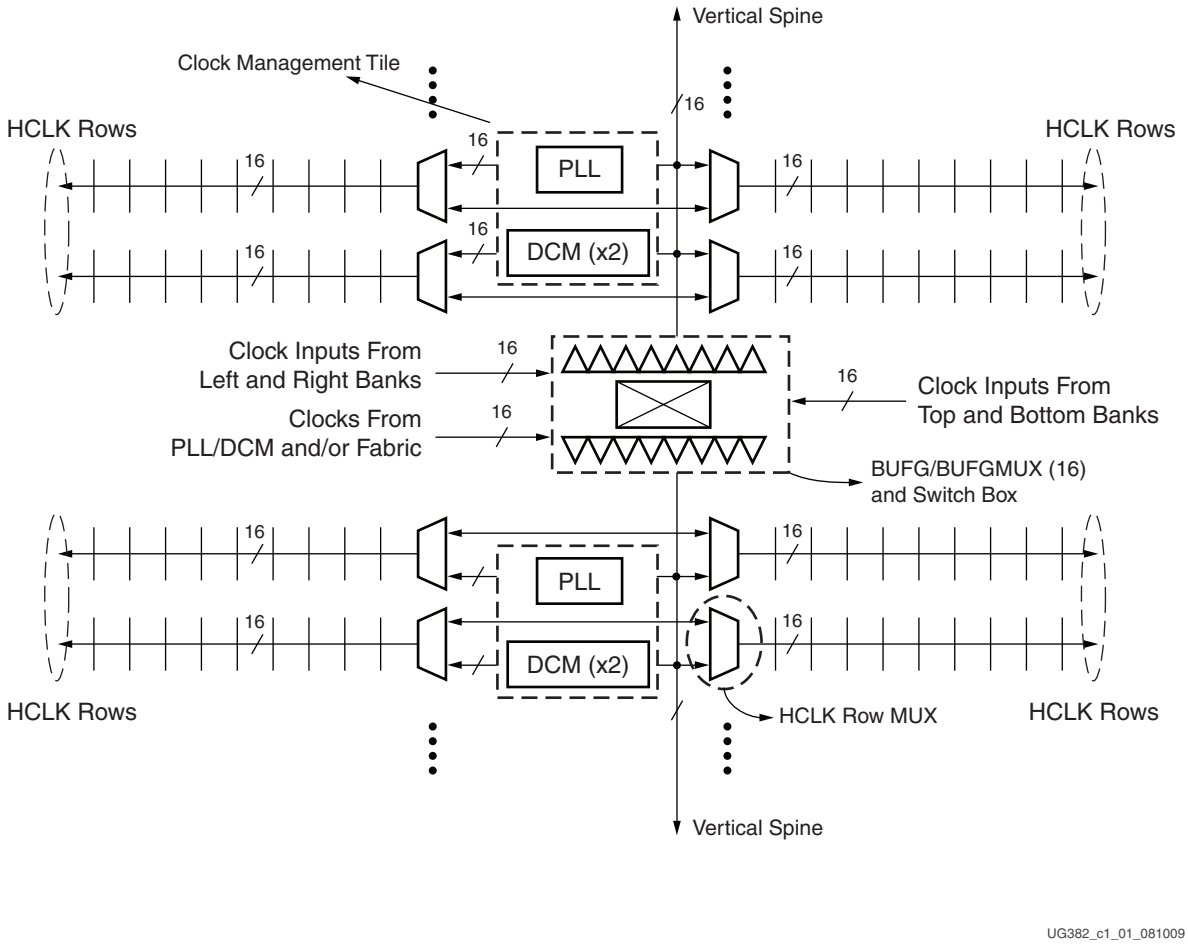


Figure 1-1: **Spartan-6 FPGA Global Clock Structure**

The global clock network in Spartan-6 FPGAs is driven by 16 BUFGMUXes located in the center of the device. The 16 BUFGMUXes can be fed from three different sources; clock inputs from top and bottom banks, clock inputs from left and right banks, and clocks from FPGA logic interconnect and/or PLL/DCM. These three clock sources are multiplexed using a switch box also located in the center of the device.

The 16 BUFGMUXes then drive a vertical spine to travel north and south. Along the way it horizontally spans toward HCLK row clocks used to provide clock access to regional logic primitives. The HCLK row is entered through a dedicated multiplexer switching clocks between the vertical spine and the PLL or DCM outputs. Each HCLK row hosts either one PLL or two DCMs.

Since there are up to 32 GCLK input pins and only 16 global clock buffers in Spartan-6 devices, every global clock buffer can be driven by one of two GCLK pins. When driving a global clock buffer (BUFG or BUFGMUX) directly with a global clock pin (IBUFG or IBUFGDS), the global clock pins from banks 0, 1, and 5 share the same eight global clock buffers as shown in Table 1-1. Similarly, banks 2, 3, and 4 share eight global clock buffers (Table 1-2).

To illustrate the routing conflict caused by the sharing of BUFGMUX inputs, consider a design using GCLK19 and GCLK11. As Table 1-1 shows, both of the global clocks are connected to BUFGMUX_X2Y1 causing a routing error to be generated.

For more routing flexibility, the BUFIO2 can additionally be used to route to a second global clock buffer when using a BUFIO2 (Table 1-1). When using a BUFIO2, a nominal delay through the BUFIO2 will be incurred. Using the BUFIO2 can also impact clock routing to the I/O clock network. Additional routing information is shown in Spanning a Full Bank with a Single I/O Clock, page 21.

When using a differential global clock, the global clock associated with the master side of the differential pair (P) will determine the global clock resource used.

Table 1-1: **Shared Global Clocking Resources for Bank 0 and Bank 1**

BUFGMUX Routing Restrictions		Bank 0	Bank 1
BUFGMUX_X2Y1 (I0) BUFGMUX_X2Y2 (I1)	Direct Routing	GCLK_19	GCLK_11
	Indirect BUFIO2	GCLK_19 <BUFIO2_X2Y28>	GCLK_11 <BUFIO2_X4Y20>
	Indirect BUFIO2	GCLK_15 <BUFIO2_X2Y28>	GCLK_7 <BUFIO2_X4Y20>
BUFGMUX_X2Y2 (I0) BUFGMUX_X2Y1 (I1)	Direct Routing	GCLK_18	GCLK_10
	Indirect BUFIO2	GCLK_18 <BUFIO2_X2Y29>	GCLK_10 <BUFIO2_X4Y21>
	Indirect BUFIO2	GCLK_14 <BUFIO2_X2Y29>	GCLK_6 <BUFIO2_X4Y21>
BUFGMUX_X2Y3 (I0) BUFGMUX_X2Y4 (I1)	Direct Routing	GCLK_17	GCLK_9
	Indirect BUFIO2	GCLK_17 <BUFIO2_X2Y26>	GCLK_9 <BUFIO2_X4Y18>
	Indirect BUFIO2	GCLK_13 <BUFIO2_X2Y26>	GCLK_5 <BUFIO2_X4Y18>
BUFGMUX_X2Y4 (I0) BUFGMUX_X2Y3 (I1)	Direct Routing	GCLK_15	GCLK_7
	Indirect BUFIO2	GCLK_15 <BUFIO2_X4Y28>	GCLK_7 <BUFIO2_X3Y12>
	Indirect BUFIO2	GCLK_19 <BUFIO2_X4Y28>	GCLK_11 <BUFIO2_X3Y12>
BUFGMUX_X3Y5 (I0) BUFGMUX_X3Y6 (I1)	Direct Routing	GCLK_16	GCLK_8
	Indirect BUFIO2	GCLK_16 <BUFIO2_X2Y27>	GCLK_8 <BUFIO2_X4Y19>
	Indirect BUFIO2	GCLK_12 <BUFIO2_X2Y27>	GCLK_4 <BUFIO2_X4Y19>
BUFGMUX_X3Y6 (I0) BUFGMUX_X3Y5 (I1)	Direct Routing	GCLK_14	GCLK_6
	Indirect BUFIO2	GCLK_14 <BUFIO2_X4Y29>	GCLK_6 <BUFIO2_X3Y13>
	Indirect BUFIO2	GCLK_18 <BUFIO2_X4Y29>	GCLK_10 <BUFIO2_X3Y13>
BUFGMUX_X3Y7 (I0) BUFGMUX_X3Y8 (I1)	Direct Routing	GCLK_13	GCLK_5
	Indirect BUFIO2	GCLK_13 <BUFIO2_X4Y26>	GCLK_5 <BUFIO2_X3Y10>
	Indirect BUFIO2	GCLK_17 <BUFIO2_X4Y26>	GCLK_9 <BUFIO2_X3Y10>
BUFGMUX_X3Y8 (I0) BUFGMUX_X3Y7 (I1)	Direct Routing	GCLK_12	GCLK_4
	Indirect BUFIO2	GCLK_12 <BUFIO2_X4Y27>	GCLK_4 <BUFIO2_X3Y11>
	Indirect BUFIO2	GCLK_16 <BUFIO2_X4Y27>	GCLK_8 <BUFIO2_X3Y11>

Table 1-2: **Shared Global Clocking Resources for Bank 2 and Bank 3**

BUFGMUX Routing Restrictions		Bank 2	Bank 3
BUFGMUX_X2Y9 (I0) BUFGMUX_X2Y10 (I1)	Direct Routing	GCLK_3	GCLK_27
	Indirect BUFIO2	GCLK_3 <BUFIO2_X3Y0>	GCLK_27 <BUFIO2_X1Y8>
	Indirect BUFIO2	GCLK_31 <BUFIO2_X3Y0>	GCLK_23 <BUFIO2_X1Y8>
BUFGMUX_X2Y10 (I0) BUFGMUX_X2Y9 (I1)	Direct Routing	GCLK_2	GCLK_26
	Indirect BUFIO2	GCLK_2 <BUFIO2_X3Y1>	GCLK_26 <BUFIO2_X1Y9>
	Indirect BUFIO2	GCLK_30 <BUFIO2_X3Y1>	GCLK_22 <BUFIO2_X1Y9>
BUFGMUX_X2Y11 (I0) BUFGMUX_X2Y12 (I1)	Direct Routing	GCLK_1	GCLK_25
	Indirect BUFIO2	GCLK_1 <BUFIO2_X3Y6>	GCLK_25 <BUFIO2_X1Y14>
	Indirect BUFIO2	GCLK_29 <BUFIO2_X3Y6>	GCLK_21 <BUFIO2_X1Y14>
BUFGMUX_X2Y12 (I0) BUFGMUX_X2Y11 (I1)	Direct Routing	GCLK_31	GCLK_23
	Indirect BUFIO2	GCLK_31 <BUFIO2_X1Y0>	GCLK_23 <BUFIO2_X0Y16>
	Indirect BUFIO2	GCLK_3 <BUFIO2_X1Y0>	GCLK_27 <BUFIO2_X0Y16>
BUFGMUX_X3Y13 (I0) BUFGMUX_X3Y14 (I1)	Direct Routing	GCLK_0	GCLK_24
	Indirect BUFIO2	GCLK_0 <BUFIO2_X3Y7>	GCLK_24 <BUFIO2_X1Y15>
	Indirect BUFIO2	GCLK_28 <BUFIO2_X3Y7>	GCLK_20 <BUFIO2_X1Y15>
BUFGMUX_X3Y14 (I0) BUFGMUX_X3Y13 (I1)	Direct Routing	GCLK_30	GCLK_22
	Indirect BUFIO2	GCLK_30 <BUFIO2_X1Y1>	GCLK_22 <BUFIO2_X0Y17>
	Indirect BUFIO2	GCLK_2 <BUFIO2_X1Y1>	GCLK_26 <BUFIO2_X0Y17>
BUFGMUX_X3Y15 (I0) BUFGMUX_X3Y16 (I1)	Direct Routing	GCLK_29	GCLK_21
	Indirect BUFIO2	GCLK_29 <BUFIO2_X1Y6>	GCLK_21 <BUFIO2_X0Y22>
	Indirect BUFIO2	GCLK_1 <BUFIO2_X1Y6>	GCLK_25 <BUFIO2_X0Y22>
BUFGMUX_X3Y16 (I0) BUFGMUX_X3Y15 (I1)	Direct Routing	GCLK_28	GCLK_20
	Indirect BUFIO2	GCLK_28 <BUFIO2_X1Y7>	GCLK_20 <BUFIO2_X0Y23>
	Indirect BUFIO2	GCLK_0 <BUFIO2_X1Y7>	GCLK_24 <BUFIO2_X0Y23>

A graphical representation of the conflicting BUFGMUX inputs is shown in Figure 1-2 and Figure 1-3.

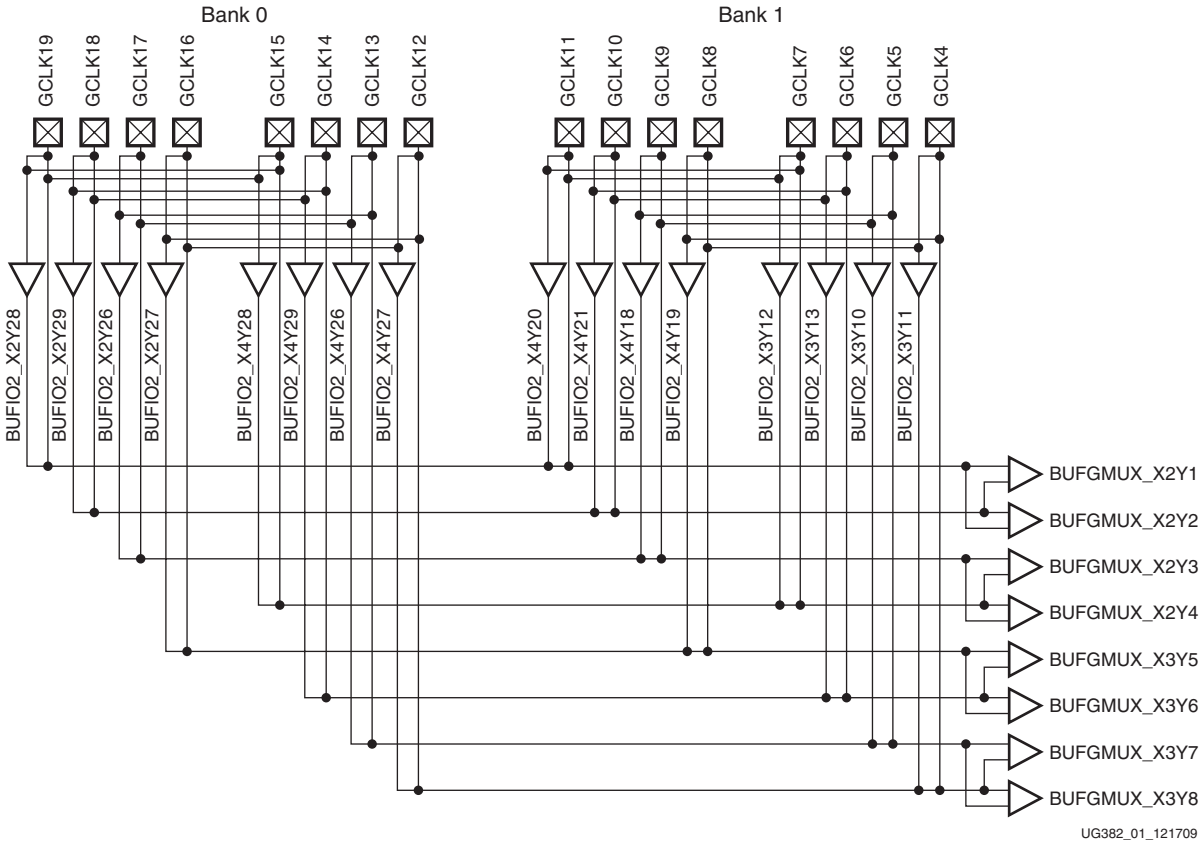


Figure 1-2: **BUFGMUX Connections for Bank 0 and Bank 1**

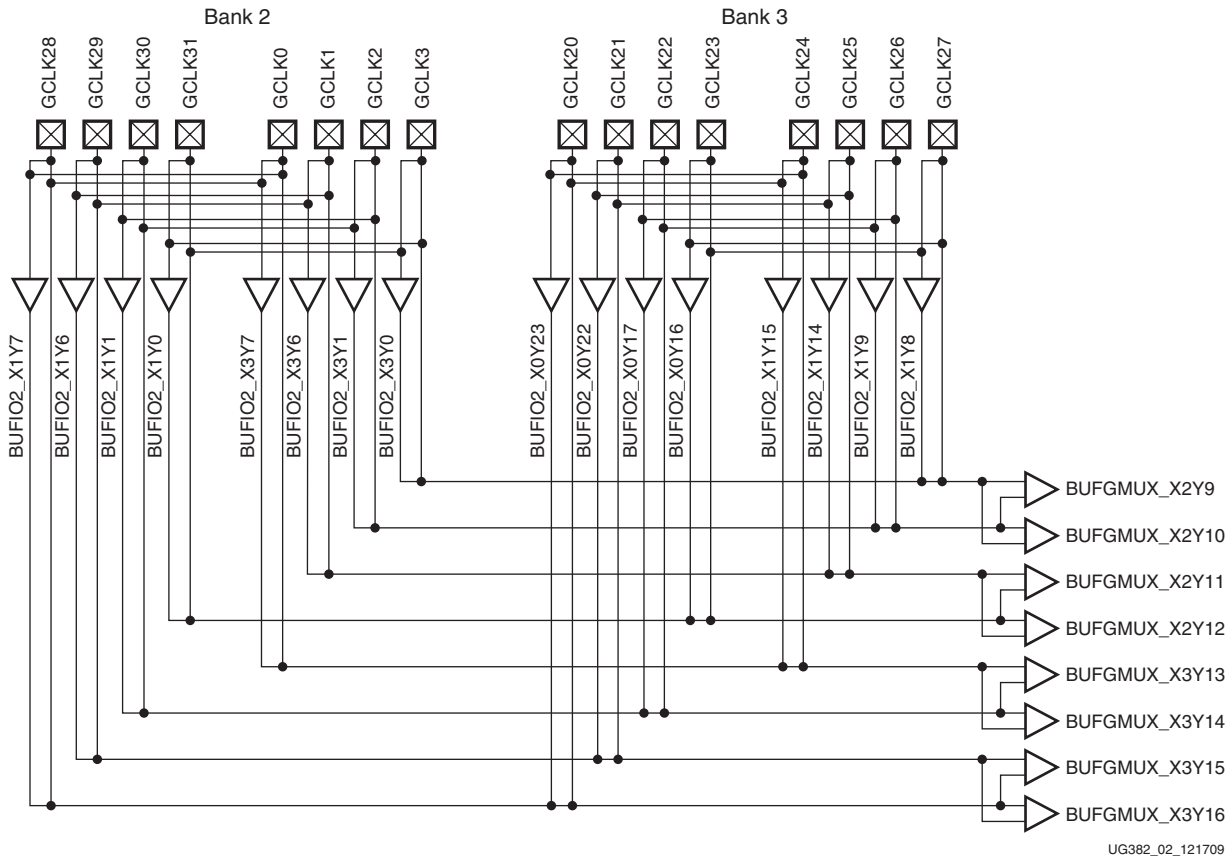


Figure 1-3: **BUFGMUX Connections for Bank 2 and Bank 3**

For designs using GTP transceivers, each GTP reference clock is associated with a BUFIO2. This can affect the global clock pins located in bank 0 or bank 2. For SDR interfaces, Table 1-3 lists the GCLK inputs. For DDR interfaces, a second BUFIO2 can be required to invert the clock using the inverting BUFIO2 placements as shown in Table 1-4.

For a complete listing GTP_DUAL placement please see the placement diagrams in UG386, *Spartan-6 FPGA GTP Transceivers User Guide*.

Table 1-3: **BUFIO2 Input Conflicts for SDR Data Rates (ISERDES2 (SDR), OSERDES2(SDR))**

Bank	BUFIO2	GCLK Inputs		GTP Reference Clock for Example Device (1)	Shared GTPCLKOUT	BUFIO2 Clocking Region
Bank 0	BUFIO2_X2Y26	GCLK17	GCLK13	GTPA1_DUAL_X0Y1	GTPCLKOUT1[0]	TL
	BUFIO2_X2Y27	GCLK16	GCLK12		GTPCLKOUT1[1]	TL
	BUFIO2_X2Y28	GCLK19	GCLK15		GTPCLKOUT0[0]	TL
	BUFIO2_X2Y29	GCLK18	GCLK14		GTPCLKOUT0[1]	TL
	BUFIO2_X4Y26	GCLK13	GCLK17	GTPA1_DUAL_X1Y1	GTPCLKOUT1[0]	TR
	BUFIO2_X4Y27	GCLK12	GCLK16		GTPCLKOUT1[1]	TR
	BUFIO2_X4Y28	GCLK15	GCLK19		GTPCLKOUT0[0]	TR
	BUFIO2_X4Y29	GCLK14	GCLK18		GTPCLKOUT0[1]	TR

Table 1-3: **BUFIO2 Input Conflicts for SDR Data Rates (ISERDES2 (SDR), OSERDES2(SDR)) *(Cont'd)***

Bank	BUFIO2	GCLK Inputs		GTP Reference Clock for Example Device (1)	Shared GTPCLKOUT	BUFIO2 Clocking Region
Bank 2	BUFIO2_X1Y0	GCLK31	GCLK3	GTPA1_DUAL_X0Y0	GTPCLKOUT0[0]	BL
	BUFIO2_X1Y1	GCLK30	GCLK2		GTPCLKOUT0[1]	BL
	BUFIO2_X1Y6	GCLK29	GCLK1		GTPCLKOUT1[0]	BL
	BUFIO2_X1Y7	GCLK28	GCLK0		GTPCLKOUT1[1]	BL
	BUFIO2_X3Y0	GCLK3	GCLK31	GTPA1_DUAL_X1Y0	GTPCLKOUT0[0]	BR
	BUFIO2_X3Y1	GCLK2	GCLK30		GTPCLKOUT0[1]	BR
	BUFIO2_X3Y6	GCLK1	GCLK29		GTPCLKOUT1[0]	BR
	BUFIO2_X3Y7	GCLK0	GCLK28		GTPCLKOUT1[1]	BR

Notes:

1. Example using an LX100T/LX150T in an FG(G)900 package.

Table 1-4: **BUFIO2 Input Conflicts for DDR Data Rates (IDDR2, ODDR2, ISERDES2 (DDR), OSERDES2 (DDR))**

Bank	BUFIO2	GCLK Inputs (Inverting)		GTP Reference Clock for Example Device (1)	Shared GTPCLKOUT	BUFIO2 Clocking Region
Bank 0	BUFIO2_X2Y26 (I_INVERT = TRUE)	GCLK16	GCLK12	GTPA1_DUAL_X0Y1	GTPCLKOUT1[0]	TL
	BUFIO2_X2Y27 (I_INVERT = TRUE)	GCLK17	GCLK13		GTPCLKOUT1[1]	TL
	BUFIO2_X2Y28 (I_INVERT = TRUE)	GCLK18	GCLK14		GTPCLKOUT0[0]	TL
	BUFIO2_X2Y29 (I_INVERT = TRUE)	GCLK19	GCLK15		GTPCLKOUT0[1]	TL
	BUFIO2_X4Y26 (I_INVERT = TRUE)	GCLK12	GCLK16	GTPA1_DUAL_X1Y1	GTPCLKOUT1[0]	TR
	BUFIO2_X4Y27 (I_INVERT = TRUE)	GCLK13	GCLK17		GTPCLKOUT1[1]	TR
	BUFIO2_X4Y28 (I_INVERT = TRUE)	GCLK14	GCLK18		GTPCLKOUT0[0]	TR
	BUFIO2_X4Y29 (I_INVERT = TRUE)	GCLK15	GCLK19		GTPCLKOUT0[1]	TR

Table 1-4: **BUFIO2 Input Conflicts for DDR Data Rates (IDDR2, ODDR2, ISERDES2 (DDR), OSERDES2 (DDR)) *(Cont'd)***

Bank	BUFIO2	GCLK Inputs (Inverting)		GTP Reference Clock for Example Device (1)	Shared GTPCLKOUT	BUFIO2 Clocking Region
Bank 2	BUFIO2_X1Y0 (I_INVERT = TRUE)	GCLK30	GCLK2	GTPA1_DUAL_X0Y0	GTPCLKOUT0[0]	BL
	BUFIO2_X1Y1 (I_INVERT = TRUE)	GCLK31	GCLK3		GTPCLKOUT0[1]	BL
	BUFIO2_X1Y6 (I_INVERT = TRUE)	GCLK28	GCLK0		GTPCLKOUT1[0]	BL
	BUFIO2_X1Y7 (I_INVERT = TRUE)	GCLK29	GCLK1		GTPCLKOUT1[1]	BL
	BUFIO2_X3Y0 (I_INVERT = TRUE)	GCLK2	GCLK30	GTPA1_DUAL_X1Y0	GTPCLKOUT0[0]	BR
	BUFIO2_X3Y1 (I_INVERT = TRUE)	GCLK3	GCLK31		GTPCLKOUT0[1]	BR
	BUFIO2_X3Y6 (I_INVERT = TRUE)	GCLK0	GCLK28		GTPCLKOUT1[0]	BR
	BUFIO2_X3Y7 (I_INVERT = TRUE)	GCLK1	GCLK29		GTPCLKOUT1[1]	BR

Notes:

1. Example using an LX100T/LX150T in an FG(G)900 package.

I/O Clocking Infrastructure

Figure 1-4 illustrates the I/O clocking infrastructure.

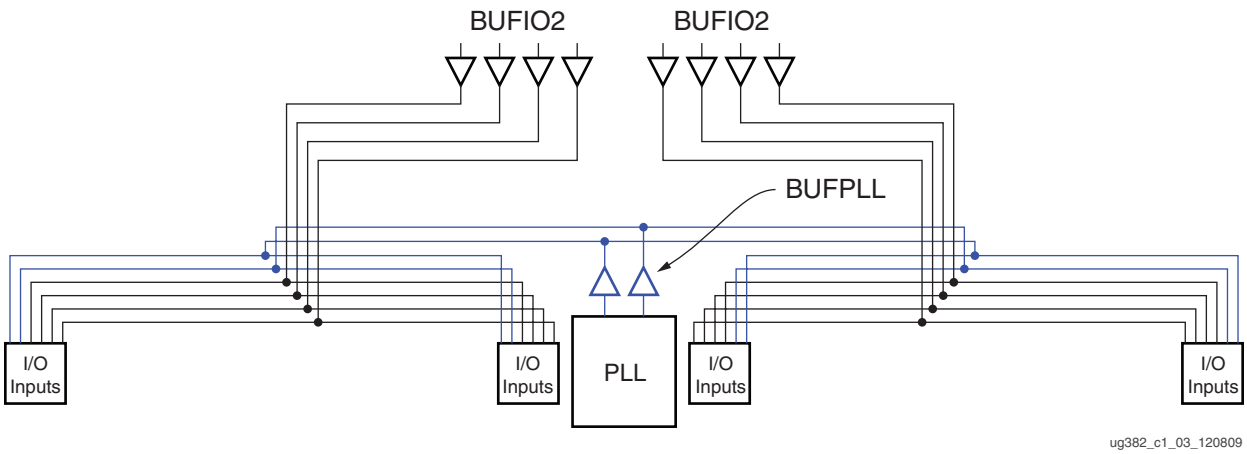


Figure 1-4: **Spartan-6 FPGA I/O Clock Structure in an I/O Bank**

There are four high-speed I/O clocks in every BUFIO2 clocking region driven by four dedicated BUFIO2 buffers. Each bank has two separate BUFIO2 clocking regions for devices with only four banks. In devices with six banks, see the pinout tables in UG385, *Spartan-6 FPGA Packaging and Pinout Specification* for BUFIO2 clocking regions. GCLK pins associated with bank 4 are still powered by V_{CCO_3}. Similarly, GCLK pins associated with bank 5 are powered by V_{CCO_1}.

Spanning a Full Bank with a Single I/O Clock

It is possible to span an entire bank with a single I/O clock input that is connected to the BUFIO2 buffers on either side of the bank. Figure 1-5 illustrates the connection in Bank 0. Two BUFIO2 resources are used, BUFIO2_X2Y28 and BUFIO2_X4Y28. In Figure 1-5, the dashed lines denote I_INVERT paths. Spanning the entire bank by using two BUFIO2 primitives can only be done when the clock input is directly connected to the BUFIO2 primitive. For some applications, an IODELAY2 could be needed to delay the input clock. Because the IODELAY2 can only connect to a single BUFIO2, routing of the delayed GCLK input will be restricted to one BUFIO2 clocking region.

Alternatively, to drive the entire bank when using the IODELAY2 primitive, use the PLL with the BUFPLL primitive.

The I/O clock network can also be driven by a PLL through the BUFPLL buffers. Each PLL has two associated buffers to span an entire I/O bank.

Note: Using IODELAY2 clocking with a full bank is not supported.

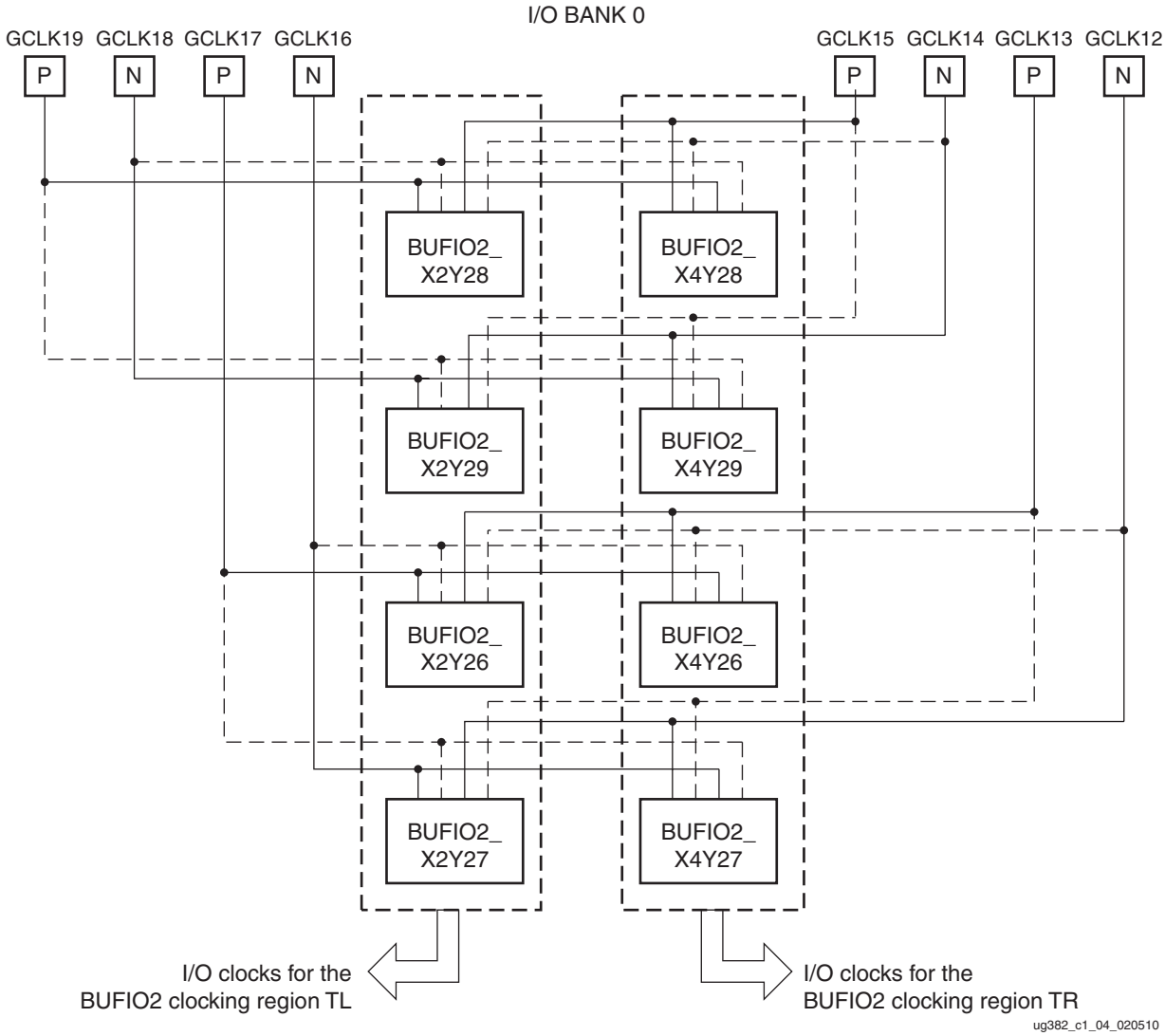


Figure 1-5: **I/O Clock Spanning a Full Bank**

Clock Inputs

Clock pins accept external clock signals and connect directly to BUFGMUX or BUFIO2 primitives. Clock pins can also be used as general-purpose I/Os. In addition to routing a clock from its input pin onto the I/O clock network, the BUFIO2 also provides a dedicated clock path to PLLs/DCMs and BUFGs. Figure 1-6 illustrates the dedicated clock routes.

Note: Using IODELAY2 clocking with a full bank is not supported.

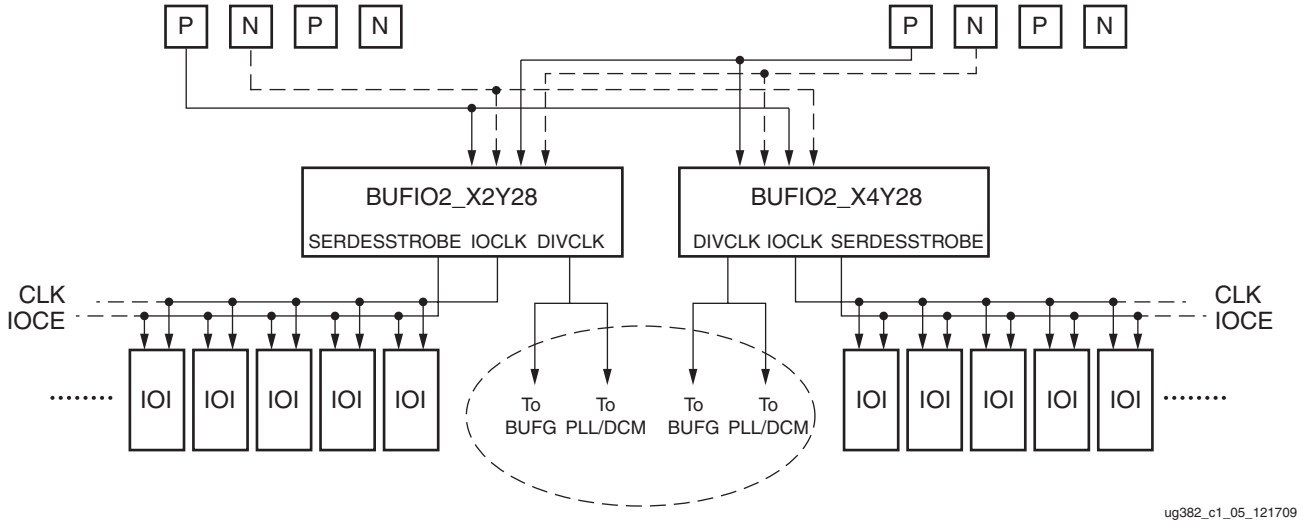


Figure 1-6: **Dedicated Clock Inputs Routed by BUFIO2**

Each Spartan-6 FPGA has:

- Up to 32 global clock inputs located along four edges of the FPGA.
- Eight dedicated clock inputs in the middle of each edge of the device.
- Eight BUFIO2 clocking regions

Table 1-5 lists the global clock pin locations where P is the positive and N is the negative side of the differential pairs.

Table 1-5: **Global Clock Pin Locations**

GCLK	P/N	TQG144	CPG196	CSG225	FGG256	CSG324		CSG484		FGG484		FGG676		FGG900	
						LX	LXT	LX	LXT	LX	LXT	LX	LXT	LX	LXT
GCLK0	N	P55	P8	N7	T8	V10	V10	AB12	AB12	AB13	AB13	AF13	AC14	AK18	AG16
GCLK1	P	P56	N8	M8	P8	U10	U10	AA12	AA12	Y13	Y13	AE13	AB14	AJ18	AF16
GCLK2	N	none	none	R8	N8	T10	T10	Y10	Y10	Y12	U12	AF14	AF15	AK19	AD16
GCLK3	P	none	none	N8	M9	R10	R10	W11	W11	W12	T12	AD14	AE15	AH19	AC16
GCLK4	N	P84	H12	J15	J16	H18	H18	L22	L22	J22	L22	U26	U26	W30	W30
GCLK5	P	P85	H11	J14	J14	H17	H17	L20	L20	J20	L20	U25	U25	W29	W29
GCLK6	N	P87	H14	H15	K11	L16	L16	K20	K20	L19	N19	W24	W24	AB30	AB30
GCLK7	P	P88	H13	H13	K12	L15	L15	L19	L19	M20	P20	V23	V23	AB28	AB28
GCLK8	N	P92	F14	G15	K14	K16	K16	M19	M19	H22	K22	P22	R26	W28	W28
GCLK9	P	P93	F13	G14	J13	K15	K15	M18	M18	H21	K21	P21	R25	W27	W27
GCLK10	N	P94	G14	L12	J12	L13	L13	K17	L17	K19	M19	M21	U24	V27	V27
GCLK11	P	P95	G13	K12	J11	L12	L12	L17	M17	K20	M20	N20	U23	V26	V26
GCLK12	N	P123	A8	A9	C10	A10	E12	C12	F12	A12	F16	A15	A14	A18	D16
GCLK13	P	P124	B8	B9	E10	C10	F12	D11	G12	B12	E16	C15	B14	C18	E16
GCLK14	N	P126	C8	A8	E8	C11	G11	A12	G11	C12	F15	C14	A12	A16	A16
GCLK15	P	P127	D8	C8	E7	D11	G9	B12	H11	D11	F14	D14	B12	C16	C16
GCLK16	N	P131	A7	A7	A10	A9	E8	A11	F11	A11	G11	A14	A13	A15	A15
GCLK17	P	P132	B7	B7	B10	B9	G8	C11	F10	C11	H12	B14	C13	B15	B15
GCLK18	N	P133	A6	D8	A9	C9	F7	A10	G10	A10	F10	A13	D13	C15	G15
GCLK19	P	P134	B6	E7	C9	D9	E6	B10	H10	B10	G9	C13	E13	D15	H15
GCLK20	N	P14	F1	G1	H3	H3	H3	G1	G1	J4	L4	R1	R1	V3	V3
GCLK21	P	P15	F2	G2	H4	H4	H4	G3	G3	K3	M3	R2	R2	V4	V4
GCLK22	N	P16	H1	J3	H5	K5	K5	P3	P3	K4	M4	P8	R6	W4	W4
GCLK23	P	P17	H2	K4	J6	L5	L5	N4	N4	K5	M5	N8	R7	W5	W5
GCLK24	N	P21	G1	H1	J4	K3	K3	H1	H1	L4	N4	W3	W3	AB1	AB1
GCLK25	P	P22	G2	H3	K3	K4	K4	H2	H2	M3	P3	V4	V4	AB2	AB2
GCLK26	N	P23	J1	J1	F1	H1	H1	J1	J1	J1	L1	T1	T1	AA1	AA1
GCLK27	P	P24	J2	J2	F2	H2	H2	J3	J3	J3	L3	T3	T3	AA3	AA3
GCLK28	N	N/A	N/A	R7	T7	V9	V9	AB10	AB10	AB11	AB11	AF12	AF14	AK17	AK17
GCLK29	P	N/A	N/A	P7	R7	T9	T9	AA10	AA10	Y11	Y11	AD12	AD14	AH17	AJ17
GCLK30	N	P50	P7	L8	M7	T8	T8	AB11	AB11	AB12	AB12	AD13	AF13	AK16	AK16
GCLK31	P	P51	N7	K8	P7	R8	R8	Y11	Y11	AA12	AA12	AC13	AE13	AJ16	AH16

Figure 1-7 illustrates a GCLK pin layout for the four bank Spartan-6 devices which include XC6SLX4, XC6SLX9, XC6SLX16, XC6SLX25, XC6SLX25T, XC6SLX45, XC6SLX45T; and the XC6SLX75/75T, XC6SLX100/100T, and XC6SLX150/150T in the FG(G)484 and CSG484 packages.

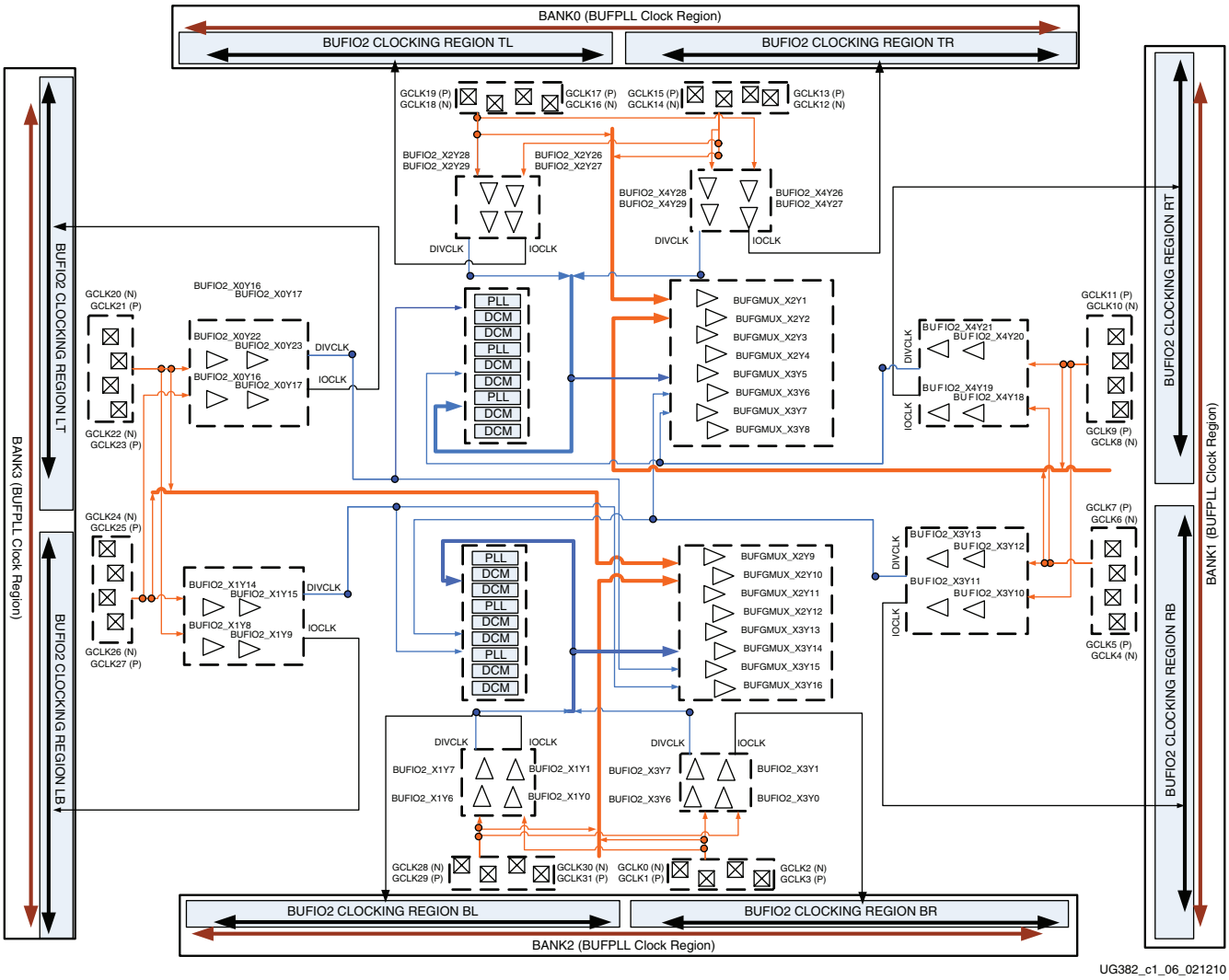


Figure 1-7: **Spartan-6 FPGA Clock Pin Layout—Devices with Four Banks**

Figure 1-8 shows the GCLK pin layout for the larger devices with the additional bank 4 and bank 5. The devices include the XC6SLX75, XC6SLX75T in the FG(G)676 package, and the XC6SLX100, XC6SLX100T, XC6SLX150, and XC6SLX150T in the FG(G)676 and FG(G)900 packages. GCLK20 through GCLK23 are powered from V_{CCO} bank 3 while the IOCLKs connect to BUFIO2 clocking region LT. Similarly, GCLK8 through GCLK11 are powered from V_{CCO} bank 1 while the IOCLKs connect to BUFIO2 clocking region RT.

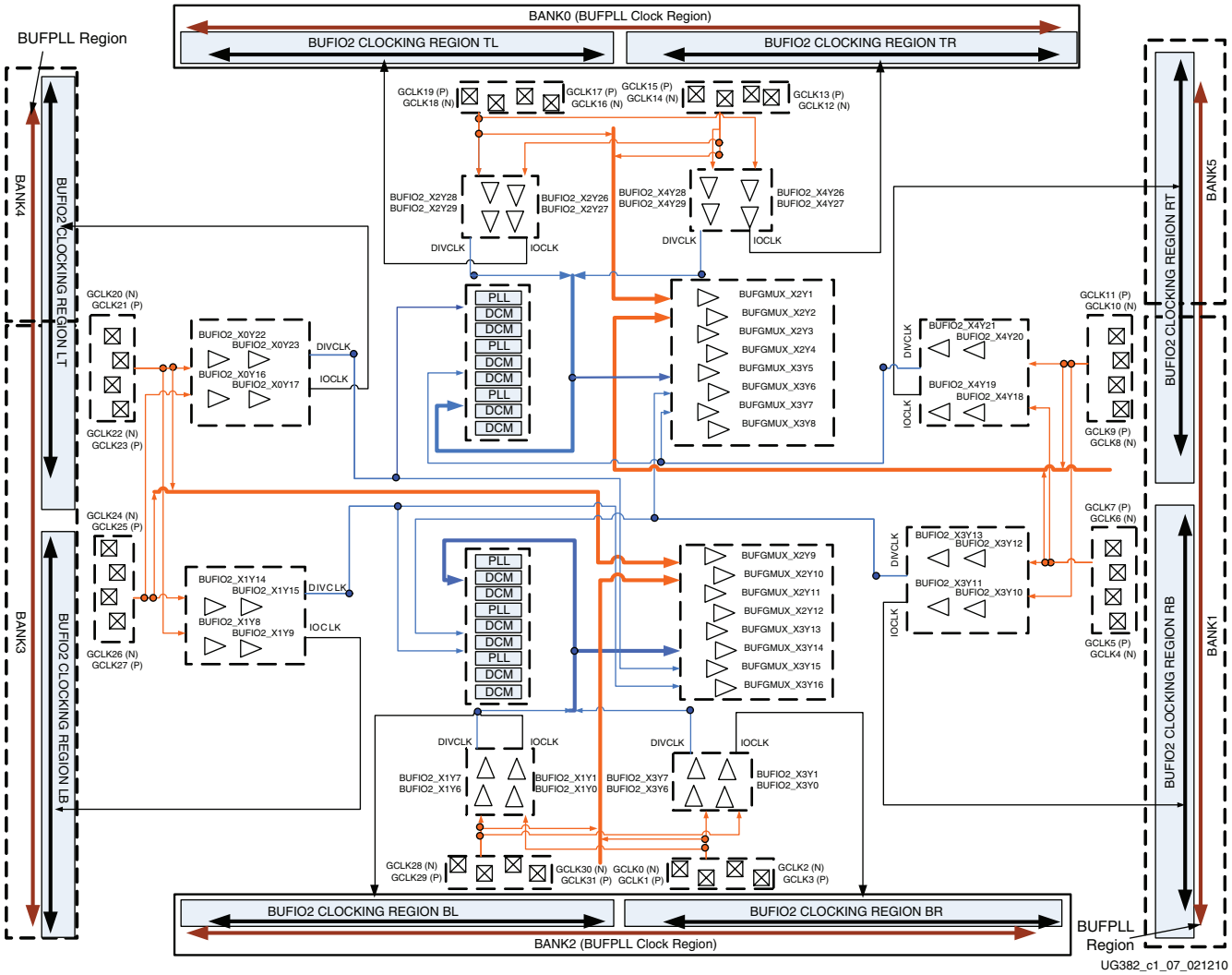


Figure 1-8: **Spartan-6 FPGA Clock Pin Layout—Devices with Additional Bank 4 and Bank 5**

Global clock inputs are always powered by the same V_{CCO} bank for both four bank and six bank devices. As a result, for devices that contain six banks, GCLK[8:11] is powered by V_{CCO1}, which can affect designs using the GCLK pins for logic. The IOLOGIC2 will still be driven by BUFIO2 locations associated with Bank 5. Similarly, GCLK[20:23] is powered by the V_{CCO} bank V_{CCO3}. When using GCLK[20:23] as IOLOGIC2, the IOCLK is driven by the BUFIO2 associated with bank 4. See Table 1-6.

Table 1-6: **GCLK V_{CCO} Bank Support Versus IOLOGIC2**

GCLK	V_{CCO} (Six Banks)	BUFIO2 (IOLOGIC2)	BUFIO2 Routing to BUFGMUX
GCLK[0:3]	2	X3Y[0,1,6,7]	X1Y[0,1,6,7] X3Y[0,1,6,7]
GCLK[4:7]	1	X3Y[10,11,12,13]	X3Y[10,11,12,13] X4Y[18,19,20,21]
GCLK[8:11]	1	X4Y[18,19,20,21]	X3Y[10,11,12,13] X4Y[18,19,20,21]
GCLK[12:15]	0	X4Y[26,27,28,29]	X4Y[26,27,28,29] X2Y[26,27,28,29]
GCLK[16:19]	0	X2Y[26,27,28,29]	X4Y[26,27,28,29] X2Y[26,27,28,29]
GCLK[20:23]	3(1)	X0Y[16,17,22,23]	X0Y[16,17,22,23] X1Y[14,15,18,19]
GCLK[24:27]	3	X1Y[14,15,18,19]	X0Y[16,17,22,23] X1Y[14,15,18,19]
GCLK[28:31]	2	X1Y[0,1,6,7]	X1Y[0,1,6,7] X3Y[0,1,6,7]

The restrictions for the BUFIO2 and V_{CCO} banks does not affect the valid BUFIO2 locations when routing a global clock pin to a DCM or PLL. For valid BUFIO2 locations for a global clock pin, see Table 1-1.

BUFIO2 located in the top half of the device (BUFIO2 clocking regions TL, TR, LT, and RT) are limited to routing to the DCM/PLL in the top half of the device. Similarly, BUFIO2 buffers connected to the bottom half of the device (BUFIO2 clocking regions BL, BR, LB, and RB) are connected to the DCM/PLL in the bottom half of the device. See Figure 1-7 and Figure 1-8.

GCLK input pins are used to drive clock buffers. A differential clock input requires two global clock inputs. The P and N inputs follow the same configuration as the standard inputs on the clock input pins. The clock inputs that are paired together are consecutive pins in clock number, an even clock number, and the next higher odd value. For example, GCLK0 and GCLK1 are a differential pair as are GCLK20 and GCLK21.

In a Spartan-6 FPGA, two clock inputs are available for each global clock buffer, allowing up to 16 differential global clock inputs.

All clock input pins can be represented in a design by the IBUFG primitive. In general, an IBUFG is inferred by the synthesis tool on any top-level clock port. An IBUFG can be instantiated when more control is necessary by connecting the I port directly to the top-level port and the O port to a DCM, BUFG, or general logic. Most synthesis tools infer the BUFG automatically when connecting an IBUFG to the clock resources of the FPGA.

Clocking Structure Guidelines

The advanced features of the Spartan-6 FPGA SelectIO logic can require different clocking structures to support a range of different SelectIO solutions. This section outlines the

recommended clocking solutions for optimal performance. A list of possible clocking structures is provided in High-Speed IOSERDES2 Usage for Advanced Serialization.

SDR Data Rate (FD Register in IOB, No IOSERDES2)

Two SelectIO options for registering data into the device.

- Figure 1-9 uses a BUFIO2 (IOCLK) to drive the I/O flip-flop with BUFG (BUFIO2-DIVCLK) to drive FPGA logic registers. Works with or without IODELAY2.
- Figure 1-10 uses a BUFG (GCLK) to drive both FPGA logic and I/O. Works with or without IODELAY2.

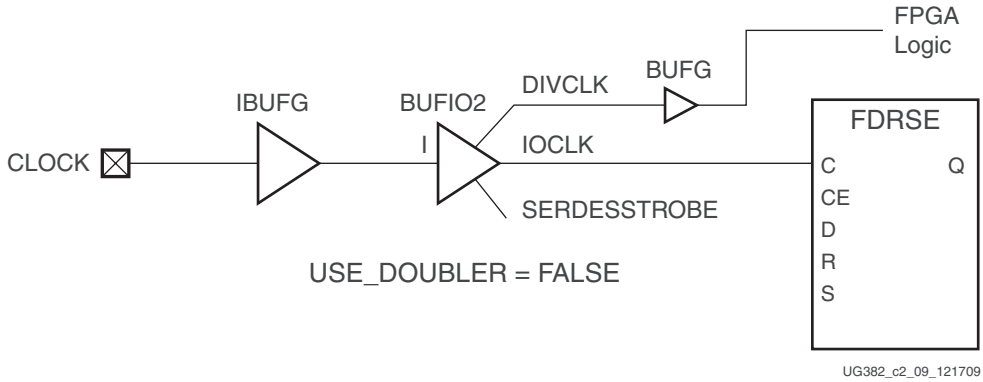


Figure 1-9: **I/O Flip-Flop Clocking using BUFIO2**

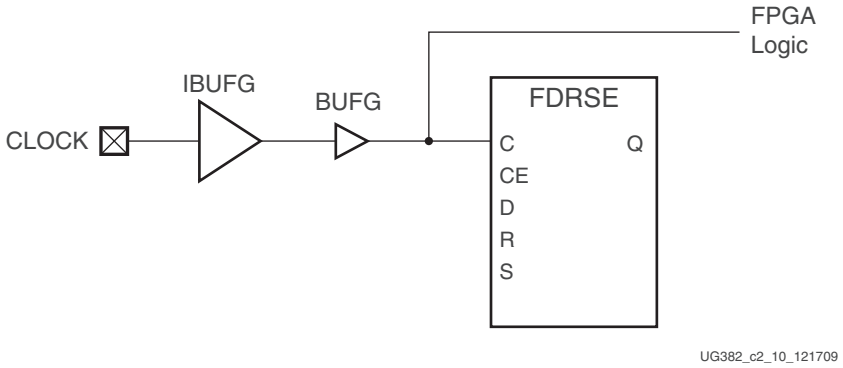


Figure 1-10: **I/O Flip-Flop Clocking using BUFG**

DDR Data Rate (IDDR2, ODDR2, No IOSERDES2)

The following options can be used for clocking IDDR2 and ODDR2 primitives.

- When performance is not critical, use a single DCM output to drive both clock (C0) and the inverted clock (C1) using local inversion. Works with or without IODELAY2.
- For the highest performance, use two DCM outputs with separate BUFGs with 180° phase difference. Works with or without IODELAY2. See Figure 1-15.
- If not using a DCM, then the GCLK input should directly drive two BUFIO2s. Use two BUFIO2s with the first BUFIO2 (USE_DOUBLER) for C0 and an inverted clock using BUFIO2 (I_INVERT = TRUE) for C1 connected to the same GCLK. FPGA logic is driven by BUFG (C0 BUFIO2-DIVCLK). See Figure 1-12.

- Using an IODELAY2 requires the IBUFGDS_DIFF_OUT. (See Figure 1-29, page 46)
- A single-ended input with IODELAY2 is not supported.

- For bidirectional interfaces, input and output logic must both use the same data rate (IDDR2 and ODDR2). Mixing SDR and DDR bidirectional I/Os are not permitted.

High-Speed IOSERDES2 Usage for Advanced Serialization

IOSERDES2 (SDR)

IOSERDES2 (SDR) requires one BUFIO2. BUFIO2 (USE_DOUBLER = FALSE and I_INVERT = FALSE) with IOCE driven by BUFIO2-SERDESSTROBE and CLKDIV driven by BUFG (BUFIO2-DIVCLK). FPGA logic driven by BUFG (BUFIO2 - DIVCLK). Works with or without IODELAY2. See Figure 1-11.

IOSERDES2 (DDR)

IOSERDES2 (DDR) requires two BUFIO2s. Use first BUFIO2 (USE_DOUBLER = TRUE) with IOCE driven by BUFIO2 (SERDESSTROBE) and CLKDIV driven by BUFG (BUFIO2-DIVCLK). Second BUFIO2 uses (I_INVERT = TRUE, USE_DOUBLER = FALSE) to drive C1 clock input. See Figure 1-12.

- Using an IODELAY2 requires the IBUFGDS_DIFF_OUT. (See Figure 1-25, page 41).
- Single-ended input with IODELAY2 is not supported in this case.

IOSERDES2 with PLL

Only SDR is supported. The GCLK inputs drive the inferred BUFIO2's DIVCLK output, which drives the PLL clock input. The PLL uses two clock outputs to drive the BUFPLL's PLLIN input and the BUFPLL's GCLK input from the BUFG output. Connect the BUFPLL's LOCKED input to the PLL's LOCKED output. Works with or without IODELAY2. See Figure 1-13.

For bidirectional interfaces, input and output logic must set DATA_RATE identically for input logic and output logic. Mixing SDR and DDR bidirectional I/Os is not permitted.

Global Clock Input Buffer Primitives

The IBUFG and IBUFGDS primitives in Table 1-7 are different configurations of the clock input buffer. These two primitives work in conjunction with the Spartan-6 FPGA I/O resource by setting the IOSTANDARD attribute to the desired standard. Refer to *Spartan-6 FPGA SelectIO Resources User Guide* for a complete list of possible I/O standards.

Table 1-7: **Clock Buffer Primitives**

Primitive	Input	Output	Description
IBUFG	I	O	Input clock buffer for single-ended I/O
IBUFGDS	I, IB	O	Input clock buffer for differential I/O

Examples of High Speed I/O Clock Network Connections

The examples in this section illustrate how the global clock buffers, I/O clock buffers, and I/O tile can be used together for high-speed interfaces.

The example in Figure 1-11 shows the simplest implementation where an input clock is used to clock the ISERDES2. The BUFIO2 provides the FPGA logic clock as well as the strobe signals used by ISERDES2. Serial data is clocked using IOCLK on the I/O clock network. Parallel data is clocked out in the FPGA clock domain using the DIVCLK output and the synchronous SERDESSTROBE signal.

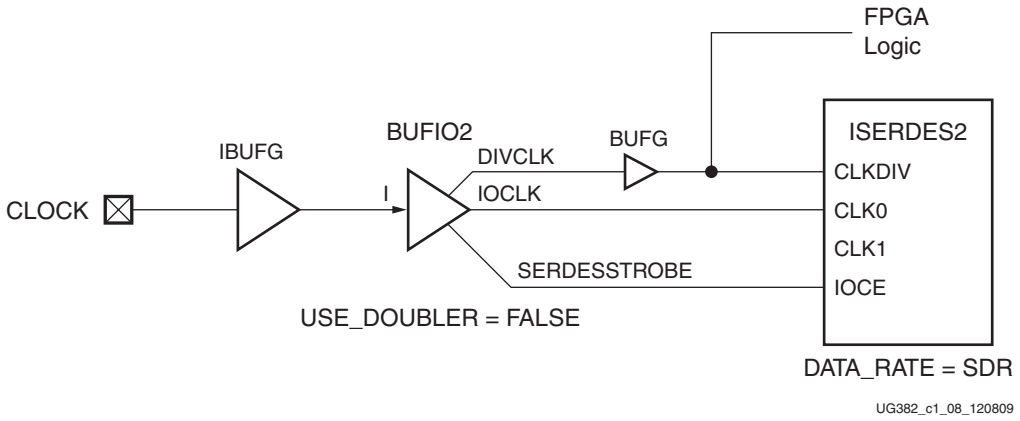


Figure 1-11: **Example 1: BUFIO2 Driving ISERDES2, DATA_RATE = SDR**

In DDR applications where serialized data is clocked in on both the rising and falling edges of the input clock, a second inverted clock is required to drive CLK1 as shown Figure 1-12. Because data is clocked in on both edges of the IOCLK, DIVCLK is divided by a DIVIDE/2 by setting USE_DOUBLER = TRUE.

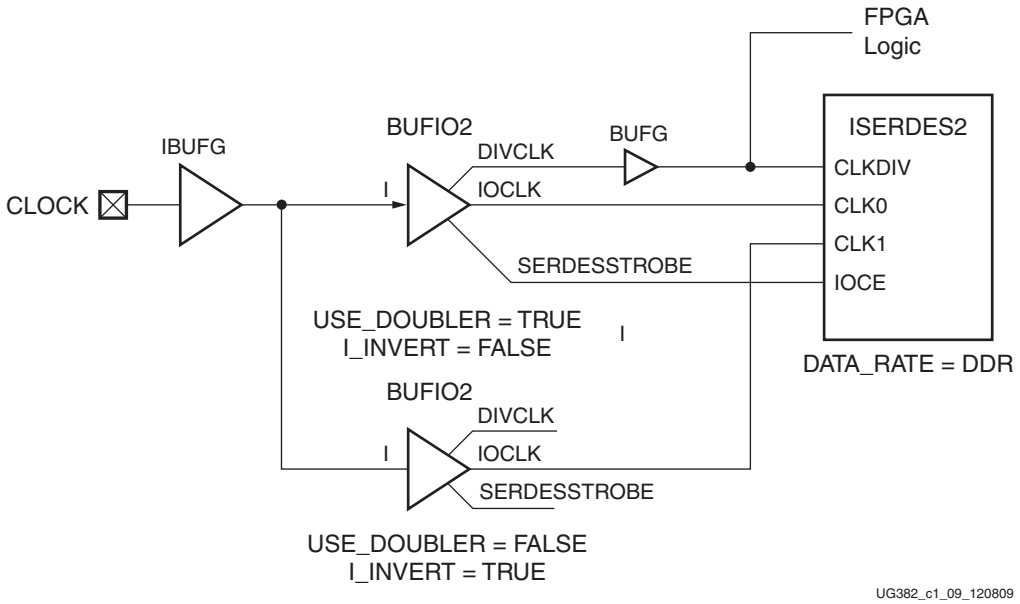


Figure 1-12: **Example 2: BUFIO2 Driving ISERDES2, DATA_RATE = DDR**

In applications where the input clock is run at the frequency of the parallel data and not the serial data, such as the pixel clock for video applications, the input clock must be multiplied up to create a high-speed I/O clock. Figure 1-13 shows a PLL providing the high-speed I/O clock required for the ISERDES.

GCLK clock inputs are automatically routed to the PLL and DCM clock inputs using a BUFIO2. This BUFIO2 routing path allows the input path to be deskewed using the BUFIO2FB (if needed).

The PLL drives the I/O clock network with the CLKOUT0 output. BUFIO2FB is balanced to deskew the input routing delays associated with the primary BUFIO2. The FPGA clock domain is driven by a separate PLL clock output using a BUFG.

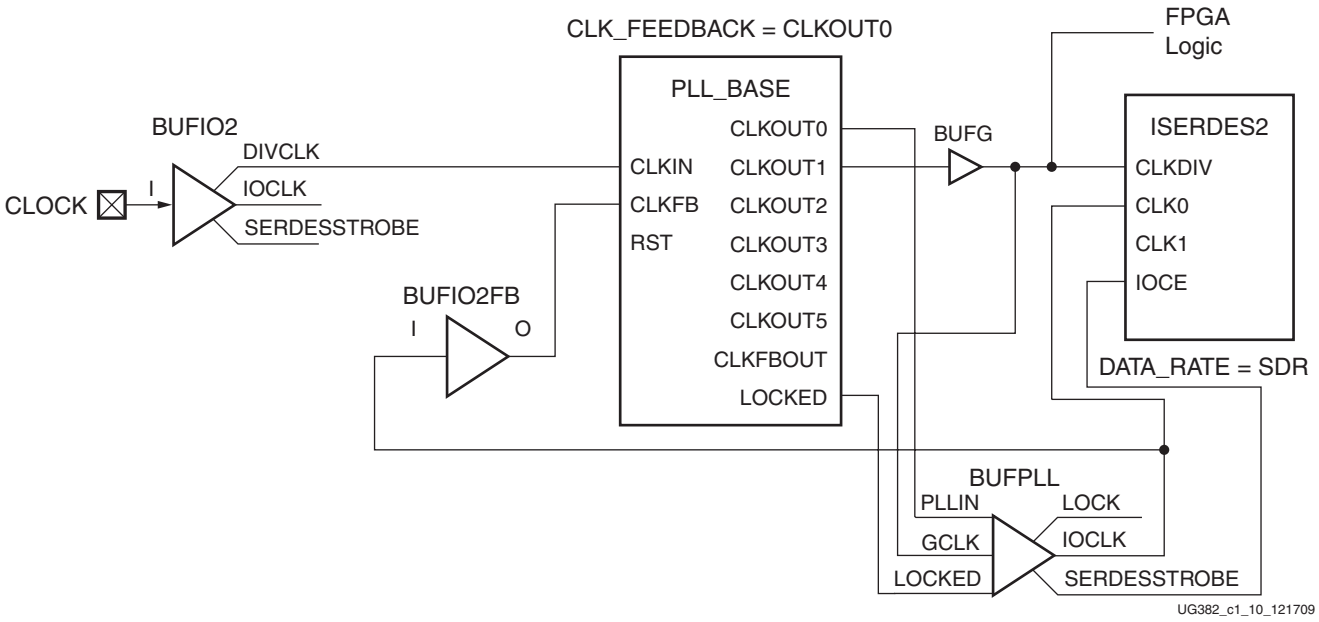


Figure 1-13: **Example 3: Basic PLL ISERDES2 (SDR)**

Designs with high-speed source synchronous outputs do not require exact timing delays from the GCLK input to the I/O clock domain. When timing alignment is not required, the PLL can use a dedicated feedback from CLKFBOUT to CLKFBIN without the use of any clock buffers (Figure 1-14).

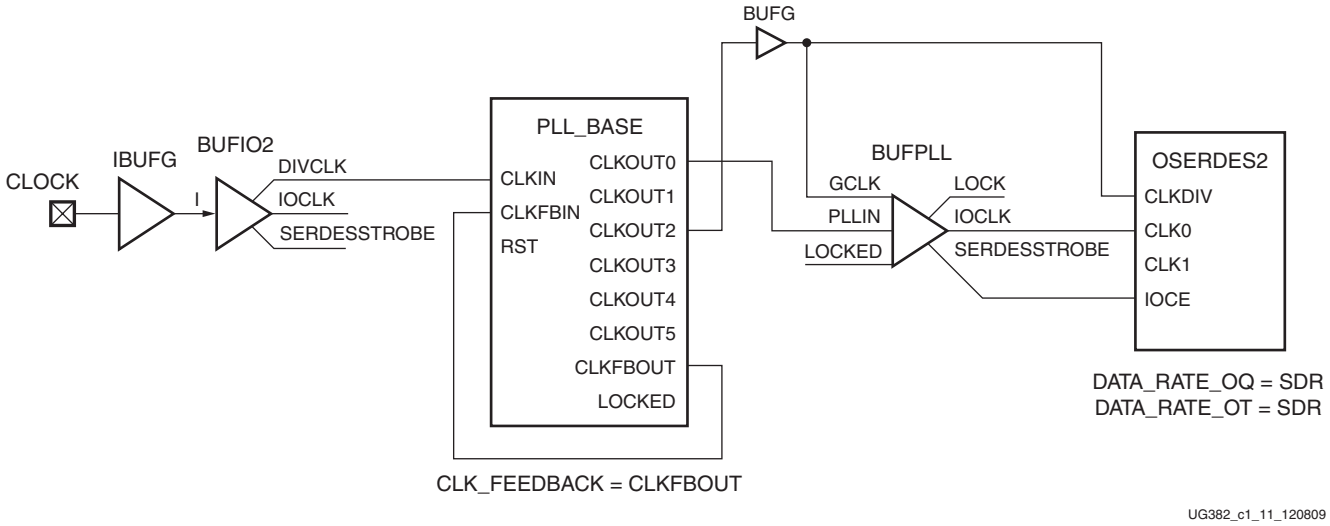


Figure 1-14: **Example 4: Basic PLL OSERDES2 (SDR)**

In designs where DCM_SP performance is adequate, DCM_SP can be used to drive IOLOGIC (IDDR2) using up to three BUFG clock buffers. To match the input routing delays, either CLK0 or CLK2X must be used to drive the BUFIO2FB as shown in Figure 1-15.

To maintain the best duty-cycle performance using the DCM, use separate DCM clock outputs to drive C0 and C1. Each DCM output drives a separate global buffer. While possible using the BUFG to invert one phase locally within the I/O tile, it is not recommended as locally inverting one of the clocks inserts duty-cycle distortion.

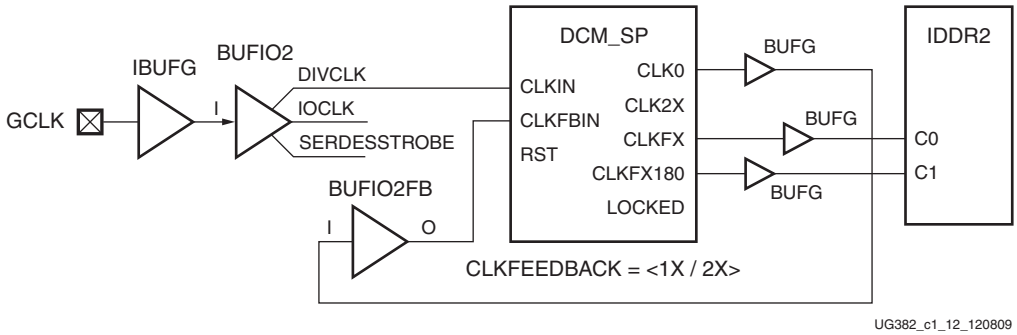


Figure 1-15: **Example 5: DCM Deskewed to the Inputs**

When using GTP transceivers, GTP reference clocks contain dedicated routing connections to BUFIO2 that can be used to connect to the Clock Management Tiles (CMT).

Example 6 in Figure 1-16 shows a single lane PCI Express design using the PLL_BASE and a feedback path routed through the GTP_DUAL using the BUFIO2FB. See UG386, *Spartan-6 FPGA GTP Transceivers User Guide* for more information.

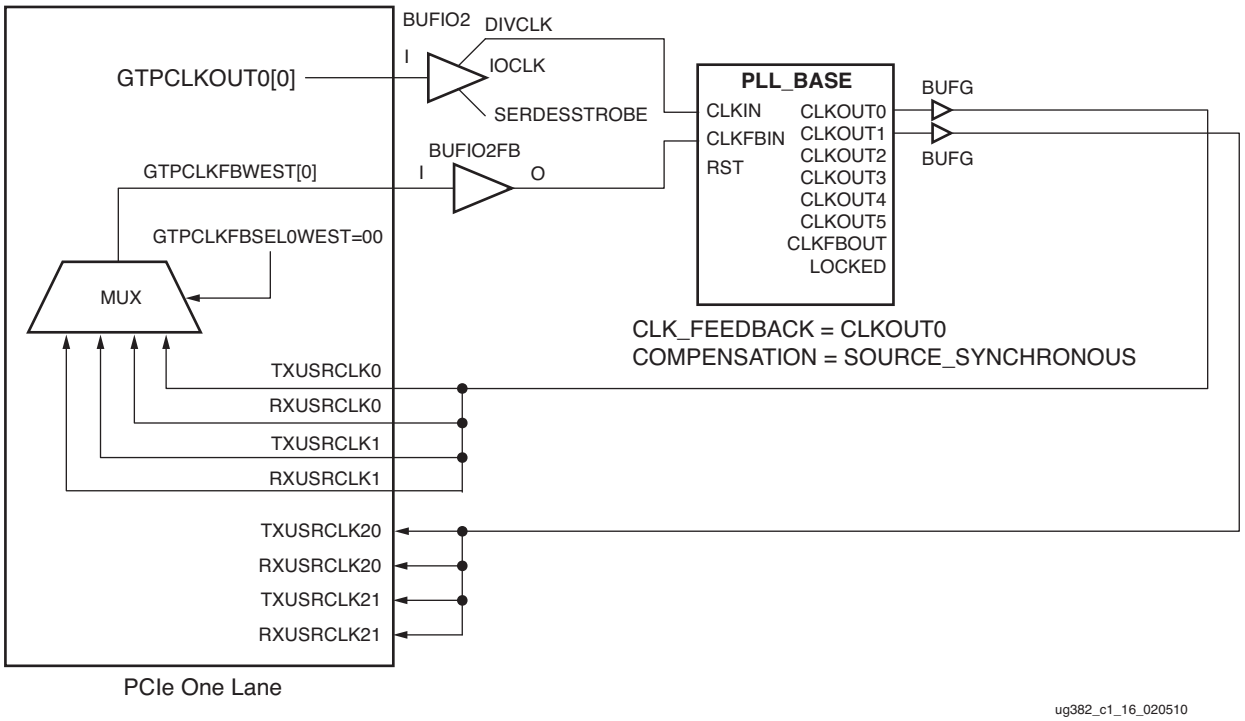


Figure 1-16: **Example 6: Single Lane Clocking for PCI Express**

Example 7 in Figure 1-17 shows a single lane PCI Express design where the input frequency and feedback frequency are different. Because the input frequency and the feedback frequency do not match, additional analysis of the PLL settings is required. In this example, GTPCLKOUT0[0] is a 100 MHz clock. To create a reference clock frequency that meets both the GTP_DUAL and PLL requirements, a 250 MHz reference clock is selected by setting TXDATAWIDTH0[0] = 2.

To allow for more flexibility in matching the Phase-Frequency Detector (PFD) frequencies, the PLL is setup to use CLK_FEEDBACK = CLKOUT0. The PFD operates at 50 MHz and, using the given settings, the VCO is 500 MHz.

Additional instructions for selecting PLL settings are described in Chapter 3, Phase-Locked Loops. See UG386, *Spartan-6 FPGA GTP Transceivers User Guide* for more information.

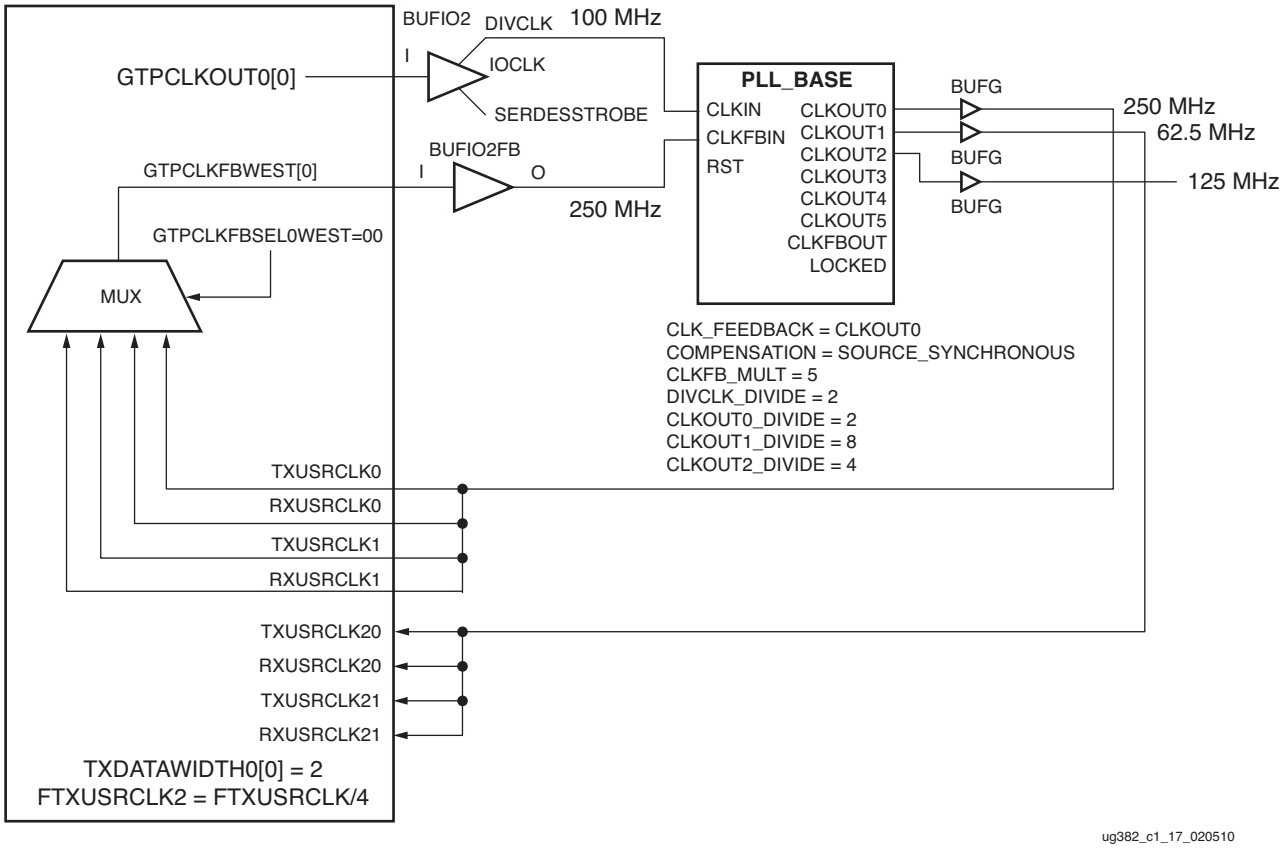


Figure 1-17: **Example 7: Single Lane Clocking Example for PCI Express with 100 MHz Clock**

Clock Buffers and Multiplexers

The clock buffers and multiplexers either drive clock input signals directly onto a clock line (BUFG or BUFPLL) or optionally provide a multiplexer to switch between two unrelated, possibly asynchronous clock signals (BUFGMUX).

Clock buffers are designed to drive clock signals.

- When used to reset/set a slice, the clock buffer must be located in one of the following locations: BUFGMUX_X2Y9, BUFGMUX_X2Y10, BUFGMUX_X2Y11, BUFGMUX_X2Y12, BUFGMUX_X3Y13, BUFGMUX_X3Y14, BUFGMUX_X3Y15, or BUFGMUX_X3Y16.
- When used as a reset/set for a block RAM, a combinatorial input for a slice, clock enable, or as a BUFGMUX input, the clock buffer must be located in one of the following locations: BUFGMUX_X2Y1, BUFGMUX_X2Y2, BUFGMUX_X2Y3, BUFGMUX_X2Y4, BUFGMUX_X3Y5, BUFGMUX_X3Y6, BUFGMUX_X3Y7, BUFGMUX_X3Y8.

Global Clock Buffer Primitives

The primitives in Table 1-8 are different configurations of the global clock buffers.

Table 1-8: **Global Clock Buffer Primitives**

Primitive	Input	Output	Control
BUFGMUX	I0, I1	O	S
BUFGMUX_1	I0, I1	O	S
BUFG	I	O	–
BUFGCE	I	O	CE
BUFGCE_1	I	O	CE

BUFGMUX

Each BUFGMUX primitive, shown in Figure 1-18, is a 2-to-1 multiplexer. S, the select line, chooses from the two inputs, I0 or I1 to drive the BUFGMUX output signal, O, as described in Table 1-9. As specified in the *Spartan-6 FPGA Data Sheet*, the S input has a setup time requirement. It also has programmable polarity.

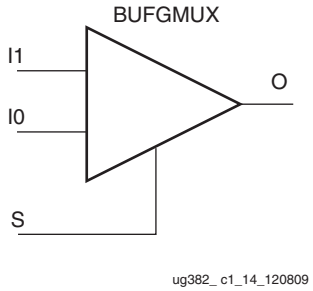


Figure 1-18: **BUFGMUX Primitive**

Table 1-9: **BUFGMUX Primitive**

S Input	O Output
0	I0 Input
1	I1 Input

Table 1-10: **BUFGMUX Attribute**

Attribute Name	Description	Possible Values	Default Value
CLK_SEL_TYPE	Specifies synchronous or asynchronous	SYNC, ASYNC	SYNC

The BUFGMUX multiplexes two clock signals while eliminating any timing hazards by switching from one clock source to a completely asynchronous clock source without glitches. The primitive guarantees that when the select line S is toggled to choose the other clock source, the output remains in the inactive state until the next active clock edge on either input. The output can be either High or Low when disabled (when toggling between clock inputs). The default is Low. A cross-coupled register pair ensures the BUFGMUX output does not inadvertently generate a clock edge.

When the S input changes, the BUFGMUX does not drive the new input to the output until the previous clock input is Low and the new clock input has a High-to-Low transition (Table 1-11). By not toggling on the first Low-to-High transition of the input, the output clock pulse is never shorter than the shortest input clock pulse.

The S input selects clock input I0 when Low and I1 when High, but also has built-in programmable polarity, equivalent to swapping I0 and I1. Programmable polarity on the clock signal is available at each flip-flop, which can be rising-edge or falling-edge triggered, avoiding having to generate and propagate two separate clock signals.

Table 1-11: **BUFGMUX Functionality**

Inputs			Outputs
I0	**I1**	**S**	**O**
I0	X	0	I0
X	I1	1	I1
X	X	↑	0
X	X	↓	0

When only one clock input is needed, a BUFG primitive should be chosen since a second clock input and select lines would not be used.

The BUFGMUX is initialized with I0 selected at power-up and after the assertion of the Global Set/Reset (GSR). Simulation also starts with S = 0 at time 0. If S = 1 at time 0, the output is unknown until the next falling edge of I1.

The select line can change at almost any time, independent of the clock states or transitions. The only exception is a short setup time prior to a Low-to-High transition on the selected clock input, which can result in an undefined runt pulse output.

BUFGMUX_1

BUFGMUX and BUFGMUX_1 are distinguished by which state the output assumes when it switches between clocks in response to a change in its select input. BUFGMUX assumes output state 0 and BUFGMUX_1 assumes output state 1 (Table 1-12).

Table 1-12: **BUFGMUX_1 Functionality**

Inputs			Outputs
I0	**I1**	**S**	**O**
I0	X	0	I0
X	I1	1	I1
X	X	↑	1
X	X	↓	1

Figure 1-19 illustrates the timing diagram for BUFGMUX_1.

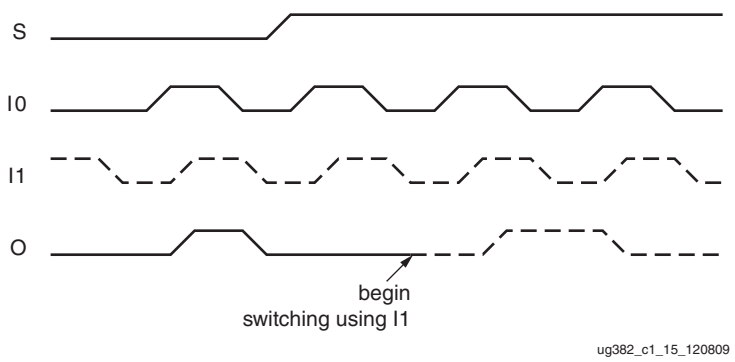


Figure 1-19: **BUFGMUX Timing Diagram**

In Figure 1-19:

- The current clock is I0.
- S is activated High.
- If I0 is currently High, the multiplexer waits for I0 to deassert Low.
- Once I0 is Low, the multiplexer output stays Low until I1 transitions High to Low.
- When I1 transitions from High to Low, the output switches to I1.
- No glitches or short pulses can appear on the output.

BUFGMUX_1 is rising edge sensitive and held at High prior to input switch. Figure 1-20 illustrates the timing diagram for BUFGMUX_1.

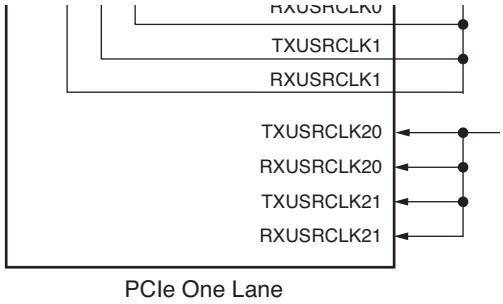


Figure 1-20: **BUFGMUX_1 Timing Diagram**

In Figure 1-20:

- The current clock is I0.
- S is activated High.
- If I0 is currently Low, the multiplexer waits for I0 to be asserted High.
- Once I0 is High, the multiplexer output stays High until I1 transitions Low to High.
- When I1 transitions from Low to High, the output switches to I1.
- No glitches or short pulses can appear on the output.

BUFG

The BUFGMUX is the physical clock buffer in the device, but it can be used as a simple single-input clock buffer. The BUFG clock buffer primitive (see Figure 1-21) drives a single clock signal onto the clock network and is essentially the same as a BUFGMUX, without the clock select mechanism. BUFG is the generic primitive for clock buffers across multiple Virtex and Spartan architectures.

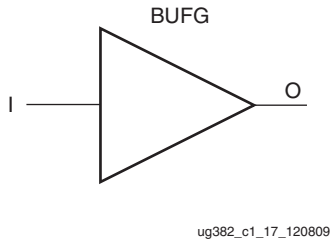


Figure 1-21: **BUFG Primitive**

The BUFG is built from the BUFGMUX as shown in Figure 1-22.

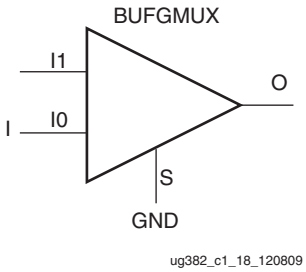


Figure 1-22: **BUFG Built from a BUFGMUX**

BUFGCE and BUFGCE_1

The BUFGCE primitive creates an enabled clock buffer using the BUFGMUX select mechanism (see Figure 1-23). BUFGCE is a global clock buffer with a single gated input. Its O output is 0 when clock enable (CE) is Low (inactive). When clock enable (CE) is High, the I input is transferred to the O output. The BUFGCE truth table is shown in Table 1-13.

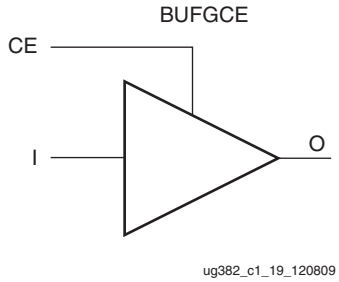


Figure 1-23: **BUFGCE Primitive**

Table 1-13: **BUFGCE Truth Table**

S Input		O Output
I	**CE**	**O**
X	0	0
X	1	I

The BUFGCE is built from the BUFGMUX by multiplexing a fixed value for one input. The default value is Low when disabled. The BUFGCE_1 primitive is similar with V_{CC} connected to I1, making the output High when disabled. It also uses the BUFGMUX_1 primitive to provide glitchless operation during the transition between inputs.

Figure 1-24 shows the equivalent functionality, although the library element truly is a primitive. The CE inversion is built into the BUFGMUX functionality. The 0 source can be fed from any convenient unused LUT.

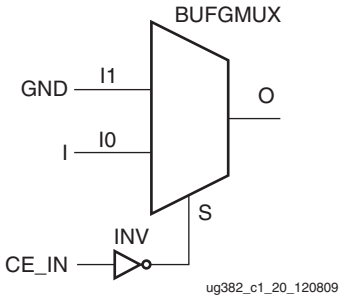


Figure 1-24: **Equivalent Functionality of BUFGCE**

Clock Buffers for the High Speed I/O Clock Region

To improve the performance of the I/O tile, Spartan-6 FPGAs contain a dedicated I/O clock network for the connections where performance is most critical. I/O clock buffers Table 1-14 work with the IODELAY2, IDDR2, ODDR2, ISERDES2, and OSERDES2 logic in the I/O tile by connecting to both the I/O clock network and the FPGA logic. The I/O clock buffer outputs restricted to the I/O clock network are listed in Table 1-15.

Table 1-14: **I/O Clock Buffers**

Primitive	Input	Output	Control
BUFIO2	I	IOCLK, DIVCLK, SERDESSTROBE	
BUFIO2_2CLK	I, IB	DIVCLK, IOCLK, SERDESSTROBE	
BUFPLL	GCLK, PLLIN, LOCKED	IOCLK, SERDESSTROBE, LOCK	
BUFPLL_MCB	PLLIN0, PLLIN1	IOCLK0, IOCLK1, SERDESSTROBE0, SERDESSTROBE1	
BUFIO2_2FB	I	O	

Table 1-15 lists ports that can be used on the I/O clock network.

Table 1-15: **I/O Clock Network Signals**

Primitive	I/O Clock Network Inputs	I/O Clock Network Outputs	Resource
BUFIO2		IOCLK(1), SERDESSTROBE(1)	I/O Clock Buffer
BUFIO2_2CLK		IOCLK(1), SERDESSTROBE(1)	I/O Clock Buffer
BUFPLL		IOCLK(1), SERDESSTROBE(1)	I/O Clock Buffer
BUFPLL_MCB		IOCLK0(1), IOCLK1(1), SERDESSTROBE0(1), SERDESSTROBE1(1)	I/O Clock Buffer
BUFIO2_2FB	I		I/O Clock Buffer
ILOGIC2	C0, C1		I/O Tile Logic
OLOGIC2	C0, C1		I/O Tile Logic
ISERDES2	CLK0, CLK1, IOCE		I/O Tile Logic
OSERDES2	CLK0, CLK1, IOCE		I/O Tile Logic
IODELAY2	IOCLK0, IOCLK1	DATAOUT	I/O Tile Logic
GTP_DUAL		CLKOUT0[1:0], CLKOUT1[1:0]	GTP_DUAL Tile

Notes:

1. Outputs only to the I/O clock network. Does not connect to FPGA logic.

BUFIO2

The BUFIO2 takes a GCLK clock input and generates two clock outputs and a strobe pulse as illustrated in Figure 1-25.

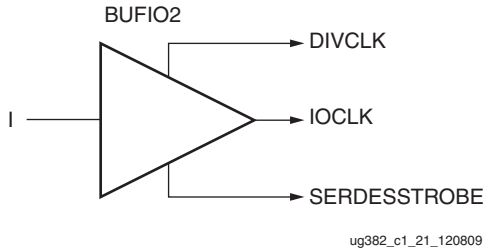


Figure 1-25: **BUFIO2 Primitive**

Table 1-16 lists the BUFIO2 ports. The IOCLK output is a buffered version of the input clock (I). The period and duty-cycle of the DIVCLK output is dependent on the attribute setting listed in Table 1-17.

Table 1-16: **BUFIO2 Port List and Definitions**

Port Name	Type	Definition
I	Input	Clock input. Can optionally be connected to the IODELAY2 (DATAOUT) or the GTP_DUAL tile (GTPCLKOUT0[1:0], GTPCLKOUT1[1:0]).
IOCLK	Output	I/O clock network output. Connects to IODDR2 (C0 or C1), IOSERDES2 (CLK0 or CLK1), or IODELAY2 (IOCLK0, IOCLK1).
DIVCLK	Output	Divided clock output. Connects to BUFG, PLL_BASE (CLKIN), DCM_SP (CLKIN), and DCM_CLKGEN (CLKIN).
SERDESSTROBE	Output	I/O clock network output used to drive IOSERDES2 (IOCE).

Table 1-17: **BUFIO2 Attributes**

Attribute Name	Description	Possible Values	Default Value
DIVIDE	Sets the DIVCLK and SERDESSTROBE divider divide-by values. FDIVCLK = FIN / DIVIDE <USE_DOUBLER = FALSE> FDIVCLK = (2 * FIN) / DIVIDE <USE_DOUBLER = TRUE>	1, 2, 3, 4, 5, 6, 7, 8	1
DIVIDE_BYPASS	When FALSE, DIVCLK outputs source from divider. When TRUE, DIVCLK outputs source from input I, bypassing the divider.	TRUE, FALSE	TRUE

Table 1-17: **BUFIO2 Attributes *(Cont'd)***

Attribute Name	Description	Possible Values	Default Value
I_INVERT	When set to TRUE, BUFIO2 placement is restricted to the I_INVERT locations of BUFIO2 (see Figure 1-5). IOCLK output is shifted by 180°. Primarily used for IODDR2 or IOSERDES2 (DATA_RATE = DDR).	TRUE, FALSE	FALSE
USE_DOUBLER	Used for ISERDES2/OSERDES2 with DATA_RATE = DDR. When set to TRUE, doubles the DIVCLK and SERDESSTROBE frequencies. FDIVCLK = (2 * FIN) / DIVIDE	TRUE, FALSE	FALSE

As listed in Table 1-17, when the DIVIDE_BYPASS is set to TRUE, the DIVCLK output is a buffered version of the input clock and the SERDESSTROBE output is driven to 1. When the DIVIDE_BYPASS is set to FALSE then the DIVCLK and SERDESSTROBE outputs will be the input clock divided by the setting of the divide attribute except when using USE_DOUBLER.

For applications where the I/O clock network is driven by a DDR clock, the USE_DOUBLER must be set to TRUE. Setting USE_DOUBLER = TRUE provides the required DIVCLK and SERDESSTROBE outputs when connected to IOSERDES2 with DATA_RATE = DDR (Figure 1-26). An additional BUFIO2 is required to create the 180° phase shift (see Figure 1-27).

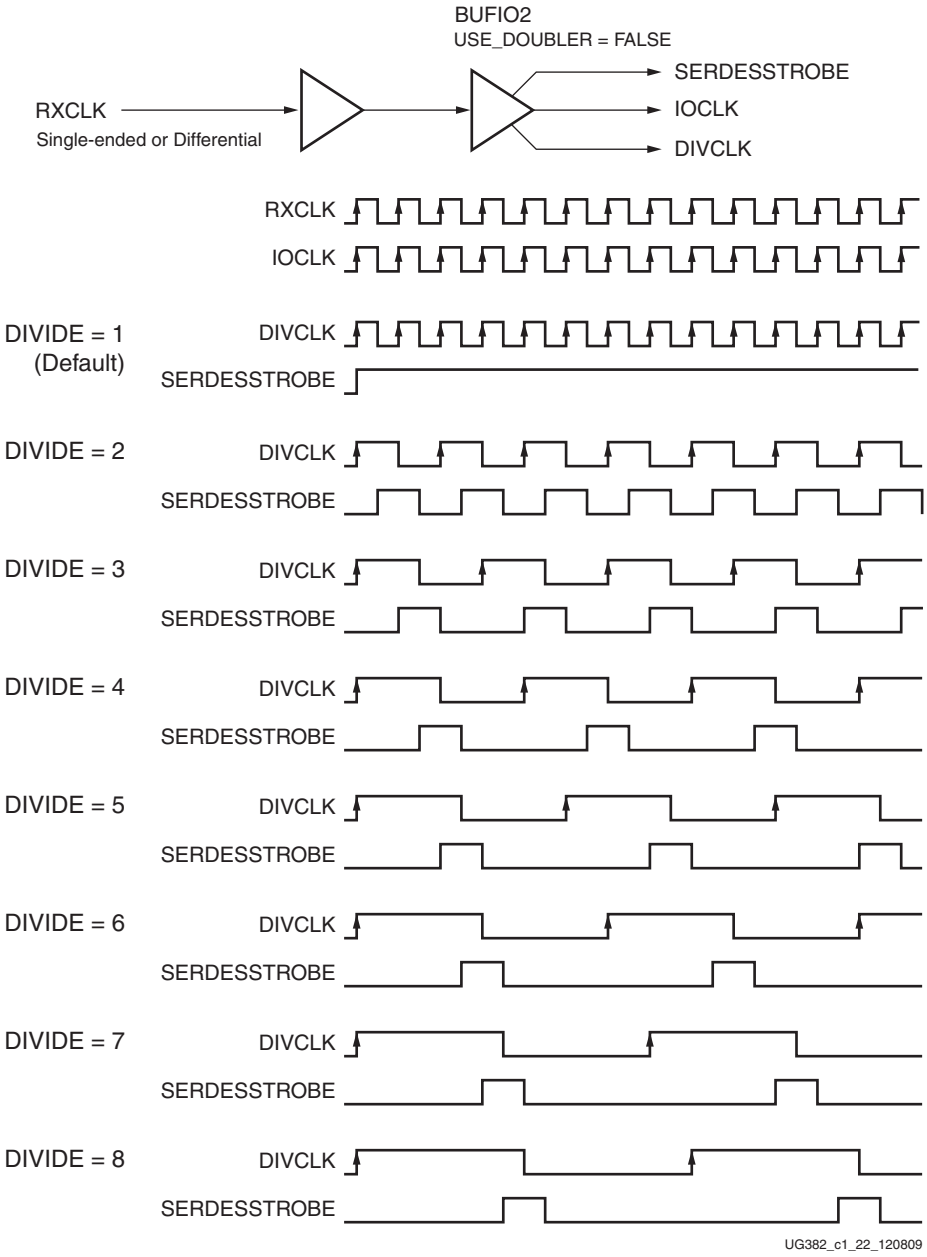


Figure 1-26: **BUFIO2 Single Data Rate Clock**

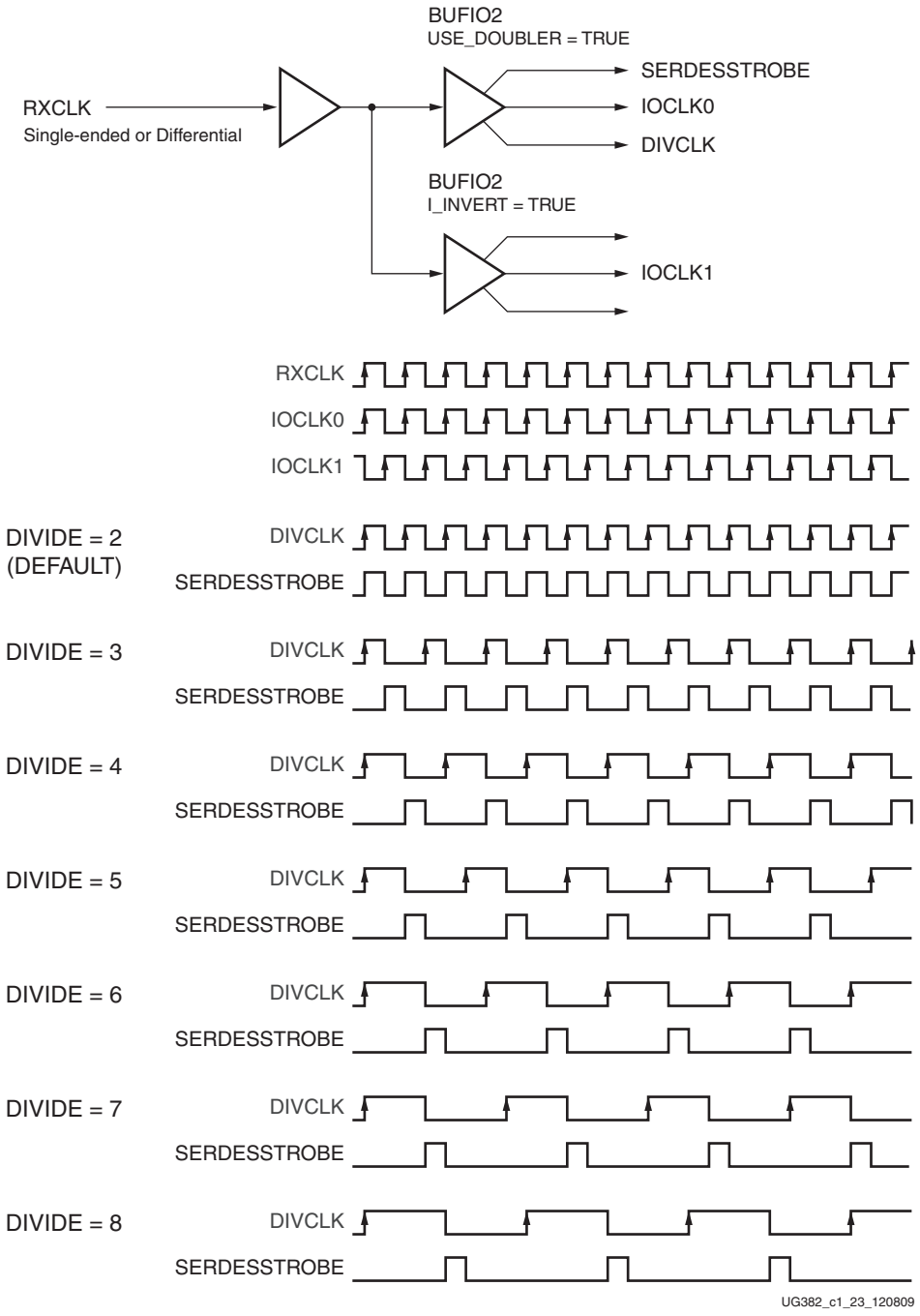


Figure 1-27: **BUFIO2 DDR Clock**

Each BUFIO2 is limited to routing to a single clock for every I/O interface tile. Consequently, when using DDR clocks, a second clock is required with 180° phase shift (Figure 1-27). An example of using two BUFIO2 clock buffers to create the 180° phase shift is shown in Figure 1-12, page 29.

For optimal performance when using a PLL or a DCM, use a BUFIO2. Each GCLK is associated with two BUFIO2 (see Table 1-1 for a complete listing).

A detailed discussion on how to use the strobe and clock outputs is available at Examples of High Speed I/O Clock Network Connections, page 29.

BUFIO2_2CLK

The BUFIO2_2CLK (Figure 1-28) has almost the same functionality as the BUFIO2 (USE_DOUBLER = TRUE) except it takes two single-ended clocks or a differential pair (output from IBUFDS_DIFF_OUT). Table 1-18 lists the BUFIO2_2CLK ports. Table 1-19 lists the attributes.

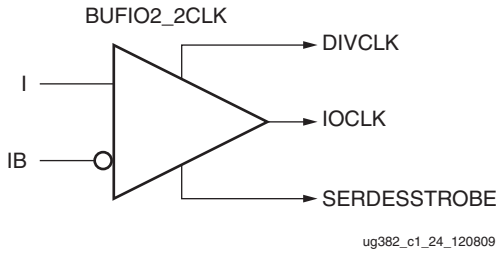


Figure 1-28: **BUFIO2_2CLK Primitive**

Table 1-18: **BUFIO2_2CLK Port List and Definitions**

Port Name	Type	Definition
I	Input	GCLK clock input.
IB	Input	Inverted GCLK clock input.
IOCLK	Output	I/O clock network output. Connects to IODDR2 (C0 or C1), IOSERDES2 (CLK0 or CLK1) or IODELAY2 (IOCLK0, IOCLK1).
DIVCLK	Output	Divided clock output. Connects to BUFG, PLL_BASE (CLKIN), DCM (CLKIN), and DCM_CLKGEN (CLKIN).
SERDESSTROBE	Output	I/O clock network output used to drive IOSERDES2 (IOCE).

Table 1-19: **BUFIO2_2CLK Attributes**

Attribute Name	Description	Possible Values	Default Value
DIVIDE	Data rate setting used for setting DIVCLK and SERDESSTROBE divider divide-by value. FDIVCLK = (2 * FIN) / DIVIDE	2, 3, 4, 5, 6, 7, 8	2
DIVIDE_BYPASS	When FALSE, DIVCLK outputs source from divider. When TRUE, DIVCLK outputs source from input I, bypassing the divider.	TRUE, FALSE	TRUE

As shown Figure 1-29, BUFIO2_2CLK can be connected to a differential GCLK input.

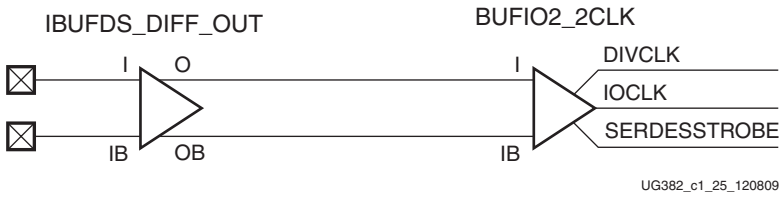


Figure 1-29: **BUFIO2_2CLK Driven by Differential GCLK Clock Input**

Figure 1-30 shows the timing waveforms when combined with a second BUFIO2 when used for ISERDES2 (DATA_PATH = DDR) or OSERDES2 (DATA_PATH_OQ = DDR).

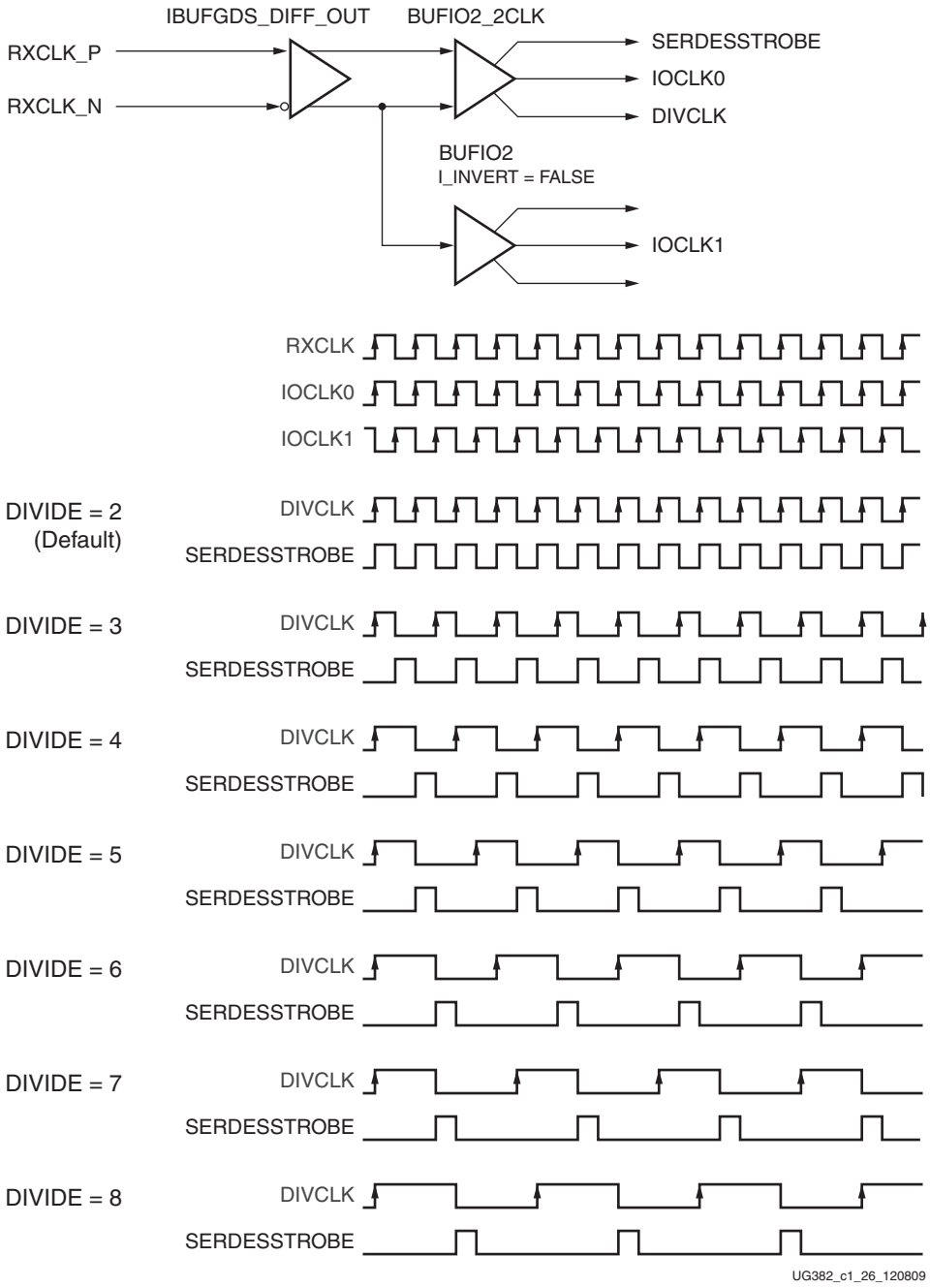


Figure 1-30: **BUFIO2_2CLK DDR Clock**

BUFPLL

The BUFPLL (Figure 1-31) is intended for high speed I/O routing to generate clocks and strobe pulses for the ISERDES2 (SDR) and OSERDES2 (SDR) primitives. The BUFPLL_MCB contains two BUFPLLs within the same bank. As a result, the BUFPLL_MCB and BUFPLL cannot be used at the same time.

The BUFPLL also aligns a LOCK output of the PLL with the GCLK, SERDES strobe, and PLL clocks. The IOCLK output is a buffered version of the input clock. The LOCK output serves the exact same function as the PLL LOCKED signal except it does not go HIGH until the PLL has locked and the BUFPLL has aligned the SERDESSTROBE signal correctly. Table 1-20 lists the BUFPLL ports, Table 1-21 lists the attribute.

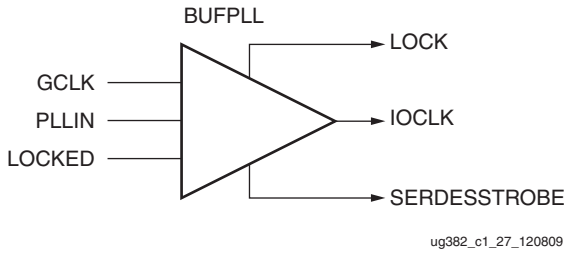


Figure 1-31: **BUFPLL Primitive**

Table 1-20: **BUFPLL Port List and Definitions**

Port Name	Type	Definition
PLLIN	Input	Clock input from PLL (CLKOUT0, CLKOUT1). Banks 1, 3, 4, and 5 can also drive BUFG (O).
GCLK	Input	Clock input from BUFG or GCLK. The GCLK frequency must match the expected SERDESSTROBE frequency. $F_{GCLK} = F_{PLLIN}/DIVIDE$
LOCKED	Input	LOCKED signal from PLL.
IOCLK	Output	I/O clock network output. Connects to IOSERDES2 (CLK0), BUFIO2FB (I), or IODELAY2 (IOCLK0, IOCLK1).
SERDESSTROBE	Output	I/O clock network output used to drive IOSERDES2 (IOCE).
LOCK	Output	Synchronized LOCK output.

Table 1-21: **BUFPLL Attributes**

Attribute Name	Description	Possible Values	Default Value
DIVIDE	Sets the PLLIN divider divide-by value for SERDESSTROBE	1, 2, 3, 4, 5, 6, 7, 8	1
ENABLE_SYNC	When set, synchronizes SERDESSTROBE to GCLK input. Only clear if BUFPLL is driven by BUFG	TRUE, FALSE	TRUE

See Examples of High Speed I/O Clock Network Connections.

BUFPLL_MCB

The BUFPLL_MCB primitive is dedicated to supporting the integrated memory controller blocks available in Spartan-6 FPGAs. The BUFPLL_MCB contains two BUFPLLs within the same bank. As a result, the BUFPLL_MCB and BUFPLL cannot be used at the same time.

Table 1-22 lists all the BUFPLL_MCB port names and Table 1-23 lists all the attributes. The BUFPLL_MCB primitive contains two buffers that operate independently when the LOCK_SRC attribute is set to INDEPENDENT. This circuitry synchronizes the SERDESSTROBE0 and SERDESSTROBE1. The synchronization is enabled by setting the LOCK_SRC to LOCK_TO_0 or LOCK_TO_1. When LOCK_SRC is set to LOCK_TO_1, the SERDESSTROBE0 follows the SERDESSTROBE1 by one clock cycle. Similarly, when LOCK_SRC is set to LOCK_TO_0, the SERDESSTROBE1 follows the SERDESSTROBE0 by one clock cycle. A detailed use case discussion is available in the UG388, *Spartan-6 FPGA Memory Controller User Guide*.

Table 1-22: **BUFPLL_MCB Port List and Definitions**

Port Name	Type	Definition
PLLIN0	Input	Clock input from PLL (CLKOUT0 or CLKOUT1). Banks 1, 3, 4, and 5 can be driven by BUFG (O).
PLLIN1	Input	Clock input from PLL (CLKOUT0 or CLKOUT1). Banks 1, 3, 4, and 5 can be driven by BUFG (O).
IOCLK0	Output	I/O clock network output. Connects to IOSERDES2 (CLK0) or BUFIO2FB (I).
IOCLK1	Output	I/O clock network output. Connects to IOSERDES2 (CLK0) or BUFIO2FB (I).
SERDESSTROBE0	Output	I/O clock network output used to drive IOSERDES2 (IOCE).
SERDESSTROBE1	Output	I/O clock network output used to drive IOSERDES2 (IOCE).

Table 1-23: **BUFPLL_MCB Attributes**

Attribute Name	Description	Possible Values	Default Value
LOCK_SRC	Sets whether PLLIN0 and PLLIN1 are independent or locked. If locked, the signal it is locked to PLLIN0 or PLLIN1.	INDEPENDENT, LOCK_TO_0, LOCK_TO_1	LOCK_TO_0
DIVIDE	Sets the PLLIN0 and PLLIN1 divider divide-by value for SERDESSTROBE0 and SERDESSTROBE1.	1, 2, 3, 4, 5, 6, 7, 8	2
ENABLE_SYNC	When set, synchronizes SERDESSTROBE to GCLK input. Only clear if BUFPLL is driven by BUFG	TRUE, FALSE	TRUE

BUFIO2FB

The BUFIO2FB is a simple buffer that uses an attribute to determine the output delay. It has only one input and one output (Figure 1-32). Table 1-24 lists the BUFIO2FB ports. As listed in Table 1-25, when the DIVIDE_BYPASS is set to TRUE then the delays are equivalent to the BUFIO2 bypass delays, when set to FALSE the delays will be similar to the DIVCLK output of a BUFIO2, keeping the outputs of the BUFIO2 and BUFIO2FB phase aligned.

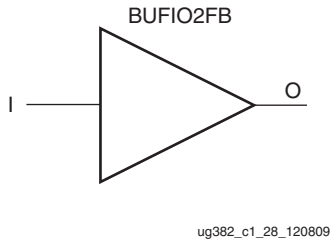


Figure 1-32: **BUFIO2FB Primitive**

Table 1-24: **BUFIO2FB Port List and Definitions**

Port Name	Type	Definition
I	Input	Feedback clock input. Can be driven by BUFIO2 (IOCLK), BUFPLL (IOCLK), IODELAY2 (DATAOUT), GTPCLKFBWEST, GTPCLKFBEAST, or BUFG (O).
O	Output	Output feedback clock

Table 1-25: **BUFIO2FB Attributes**

Attribute Name	Description	Possible Values	Default Value
DIVIDE_BYPASS	When FALSE, DIVCLK outputs source from divider. The CLKDIV_DIVIDE must be set to 1. When TRUE, DIVCLK outputs source from input I, bypassing the divider.	TRUE, FALSE	TRUE

The BUFIO2FB buffer provides a way to match clock routing delay between a CMT (PLL or DCM) reference input CLKIN and feedback CLKFB as shown in Figure 1-33. The ISE Design Suite automatically inserts BUFIO2FB and BUFIO2 buffers when the CMT feedback path is used.

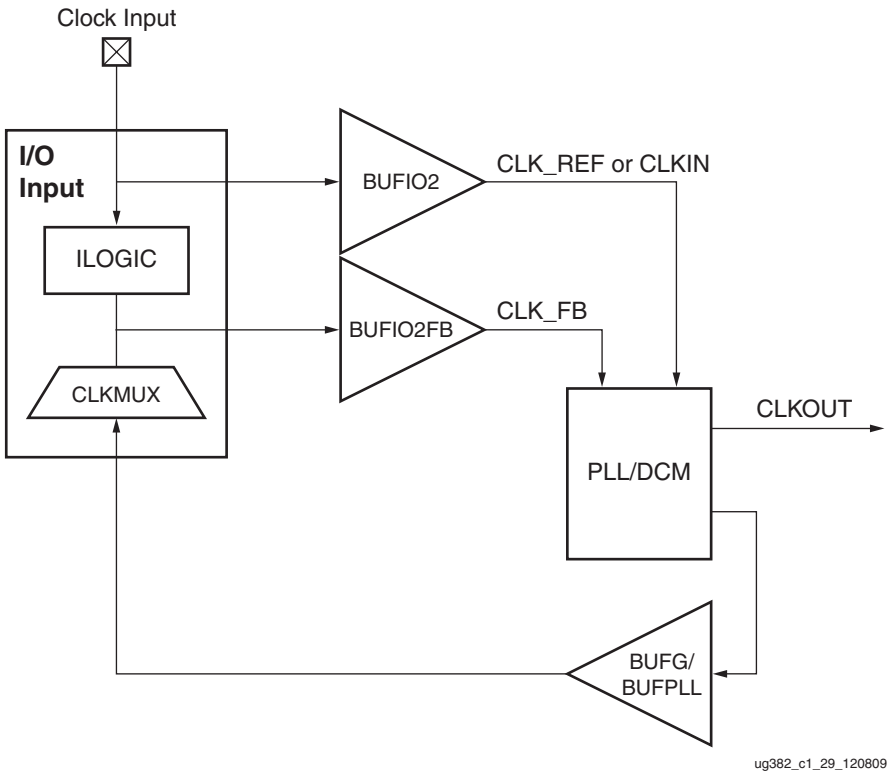


Figure 1-33: **BUFIO2FB Buffer Matches Clock Routing Delay**

Chapter 2

Clock Management Technology

Clock Management Summary

The Spartan-6 FPGA Clock Management Tiles (CMTs) provide very flexible, high-performance clocking. The Spartan-6 FPGA CMT blocks (Figure 2-1) are located in the center column along the vertical global clock tree. Each CMT block contains two DCMs and one PLL.

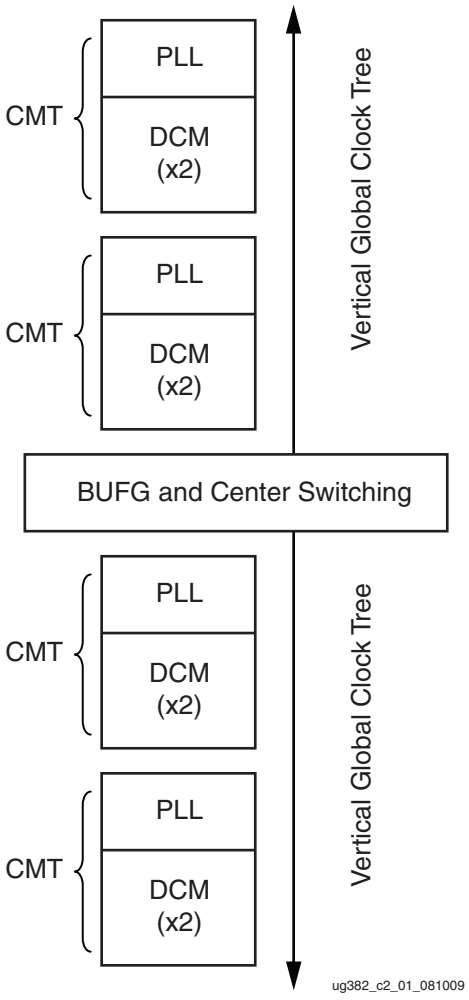


Figure 2-1: **Spartan-6 FPGA CMT Location**

Table 2-1 summarizes the availability of CMTs, DCMs, and PLLs in each Spartan-6 device.

Table 2-1: **Available CMT, DCM, and PLL Resources**

Device	Number of CMTs	Number of DCMs	Number of PLLs
XC6SLX4	2	4	2
XC6SLX9	2	4	2
XC6SLX16	2	4	2
XC6SLX25	2	4	2
XC6SLX25T	2	4	2
XC6SLX45	4	8	4
XC6SLX45T	4	8	4
XC6SLX75	6	12	6
XC6SLX75T	6	12	6
XC6SLX100	6	12	6
XC6SLX100T	6	12	6
XC6SLX150	6	12	6
XC6SLX150T	6	12	6

To minimize clock skew, use global clock buffers for the clock outputs from the CMT. When clock buffers are limited, CMT clock outputs can optionally be used without a global clock buffer, but all logic is required to be placed within a clock region. Each of these clock regions is 16 CLBs tall, contains up to four 18 Kb block RAMs, and up to four DSP48A1 slices.

DCM Summary

Digital Clock Managers (DCMs) provide advanced clocking capabilities to Spartan-6 FPGA applications. Primarily, DCMs eliminate clock skew, thereby improving system performance. Similarly, a DCM optionally phase shifts the clock output to delay the incoming clock by a fraction of the clock period. DCMs optionally multiply or divide the incoming clock frequency to synthesize a new clock frequency. The DCMs integrate directly with the global low-skew clock distribution network.

DCM Introduction

DCMs integrate advanced clocking capabilities directly into the global clock distribution network. Consequently, DCMs solve a variety of common clocking issues, especially in high-performance, high-frequency applications:

- Eliminate clock skew, either within the device or to external components, to improve overall system performance and to eliminate clock distribution delays.
- Phase shift a clock signal, either by a fixed fraction of a clock period or by incremental amounts.
- Multiply or divide an incoming clock frequency or synthesize a completely new frequency by a mixture of static or dynamic clock multiplication and division.

- Condition a clock, ensuring a clean output clock with a 50% duty cycle.
- Mirror, forward, or rebuffer a clock signal, often to deskew and convert the incoming clock signal to a different I/O standard. For example, forwarding and converting an incoming LVTTL clock to LVDS.
- Clock input jitter filtering
- Free-running oscillator
- Spread-spectrum clock generation

Table 2-2: **DCM Features and Capabilities**

Feature	Description	DCM Signals
DCMs per device	Four to 12 DCMs, depending on device size. See Table 2-1.	All
Clock input sources	GCLK input, BUFG output, cascaded DCM or PLL output (within the same CMT)	CLKIN
Frequency synthesizer output	Multiply CLKIN by the fraction (M/D) where M = {2..256}, D = {1..256} when using the DCM_CLKGEN primitive	CLKFX, CLKFX180
Clock divider output	Divide CLKIN by 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 13, 14, 15, or 16	CLKDV
Clock doubler output	Multiply CLKIN frequency by 2	CLK2X, CLK2X180
Clock conditioning, duty-cycle correction	Always provided on most outputs.	All
Quadrant phase-shift outputs	0° (no phase shift), 90° (¼ period), 180° (½ period), 270° (¾ period)	CLK0, CLK90, CLK180, CLK270
Half-period phase-shift outputs	Output pairs with 0º and 180º phase shift, ideal for DDR applications	CLK0, CLK180, CLK2X, CLK2X180, CLKFX, CLKFX180
Variable phase-shifting	Allows DCM clock outputs to adjust phase shift during operation	PSEN, PSINCDEC, PSCLK, PSDONE
General purpose DCM operation indicators	Number of DCM clock outputs connected to general-purpose interconnect	STATUS, LOCKED

Compatibility and Comparison with Other Xilinx FPGA Families

The Spartan-6 FPGA includes a very similar DCM design to the Spartan-3E and Extended Spartan-3A family. There are, however, important DCM design differences between the Spartan-6 family and Virtex-5 FPGAs.

Similar to the Spartan-3E and Extended Spartan-3A families, the Spartan-6 FPGA DCMs automatically determine their operating range and are not limited to either a Low or High operating frequency range. Spartan-6 FPGAs implement variable-phase shift operations differently. Spartan-6 FPGAs now include the DCM_CLKGEN primitive to support more advanced features such as jitter reduction, dynamic programming of frequency multiplication, dynamic programming of frequency division, and generation of spread-spectrum clocks. Table 2-3 compares various DCM functions in Xilinx FPGAs.

Table 2-3: **DCM Differences between Xilinx FPGAs**

Function	Virtex-5 FPGAs(1)	Spartan-3E and Extended Spartan-3A FPGAs	Spartan-6 FPGAs
Design primitive	DCM_BASE DCM_ADV	DCM_SP	DCM_SP DCM_CLKGEN
Distinct DLL operating frequency ranges	Two: Low and High	One	One
Distinct DFS operating frequency ranges	Two: Low and High	One	One
Variable phase-shift increment or decrement unit	$^1/_{256}$th of CLKIN period (degrees)	DCM_DELAY_STEP between 15 to 35 ps (time)	DCM_DELAY_STEP See the Spartan-6 FPGA data sheet
DCM V_{CCAUX} voltage supply	2.5V	2.5V or 3.3V	2.5V or 3.3V
Jitter reduction with expense of phase alignment	No	No	Yes
Dynamic programming of frequency multiplication and division	No	No	Yes
Generation of spread-spectrum clocks	No	No	Yes

Notes:

1. When converting legacy designs using the Virtex-5 FPGA primitives DCM_ADV or DCM_BASE, use the Spartan-6 FPGA DCM_SP or DCM_CLKGEN primitives instead.

DCM Functional Overview

The DCM consists of four distinct functions that can operate independently or in tandem. Figure 2-2 shows a simplified block diagram of a DCM.

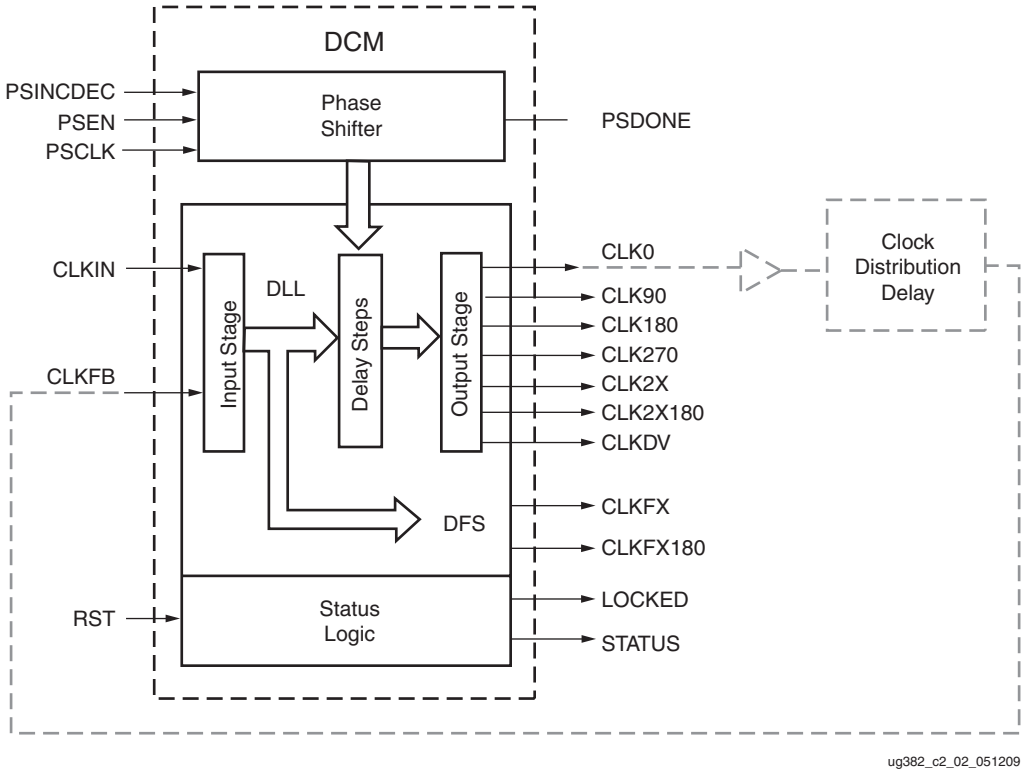


Figure 2-2: **DCM Functional Block Diagram**

Delay-Locked Loop

The Delay-Locked Loop (DLL) provides an on-chip digital deskew circuit that effectively generates clock output signals with a net zero delay. The deskew circuit compensates for the delay on the clock routing network by monitoring an output clock, from either the CLK0 or the CLK2X outputs. The DLL effectively eliminates delay from the external clock input port to the individual clock loads within the device. The well-buffered global network minimizes the clock skew on the network caused by loading differences.

To accurately deskew the input routing, the BUIO2FB buffer must be used as shown in Figure 1-33, page 51. The BUFIO2FB is matched to the primary BUFIO2 buffer limiting the deskewing to a single DCM.

The input signals to the DLL unit are CLKIN and CLKFB. The output signals from the DLL are CLK0, CLK90, CLK180, CLK270, CLK2X, CLK2X180, and CLKDV.

The DLL unit generates the outputs for the clock doubler (CLK2X, CLK2X180), the clock divider (CLKDV) and the quadrant phase-shift functions.

Digital Frequency Synthesizer

The Digital Frequency Synthesizer (DFS) provides a wide and flexible range of output frequencies based on the ratio of two user-defined integers, a multiplier (CLKFX_MULTIPLY) and a divisor (CLKFX_DIVIDE). The output frequency is derived from the input clock (CLKIN) by simultaneous frequency division and multiplication. The DFS feature can be used in conjunction with or separately from the DLL feature of the

DCM. If the DLL is not used, then there is no phase relationship between CLKIN and the DFS outputs.

The DFS unit generates the frequency synthesizer (CLKFX and CLKFX180) outputs.

Phase Shift

The Phase Shift (PS) controls the phase relations of the DCM clock outputs to the CLKIN input. PS can be used in either fixed phase-shift or variable phase shift modes.

The phase of all nine DCM clock output signals are shifted by a fixed fraction of the input clock period when using the fixed phase shift. The fixed phase-shift value is set at design time and loaded into the DCM during FPGA configuration. If the DLL is not used, then the DFS output clocks will not be deskewed since the DLL is required to provide the deskew feedback clock.

The PS also provides a digital interface for the FPGA application to dynamically advance or retard the current shift value, called variable phase shift. The Spartan-6 FPGA variable phase shift changes by one DCM_DELAY_STEP with a fixed range as defined in the Spartan-6 FPGA data sheet.

The PS input signals are PSINCDEC, PSEN, and PSCLK. The output signals are PSDONE and STATUS[0].

Status Logic

The status logic indicates the current state of the DCM via the LOCKED and STATUS[0] output signals. The LOCKED output signal indicates whether the DCM outputs are in phase with the CLKIN input. The STATUS output signals indicate the state of the DLL and PS operations.

The RST input signal resets the DCM logic and returns it to its post-configuration state. Likewise, a reset forces the DCM to reacquire and lock to the CLKIN input.

DCM Primitives

The DCM design primitives (Figure 2-3), DCM_SP and DCM_CLKGEN, represent all the features within the DCM. STATUS[7:0} is used for simulation when using DCM_CLKGEN for the lower-power Spartan-6 devices.

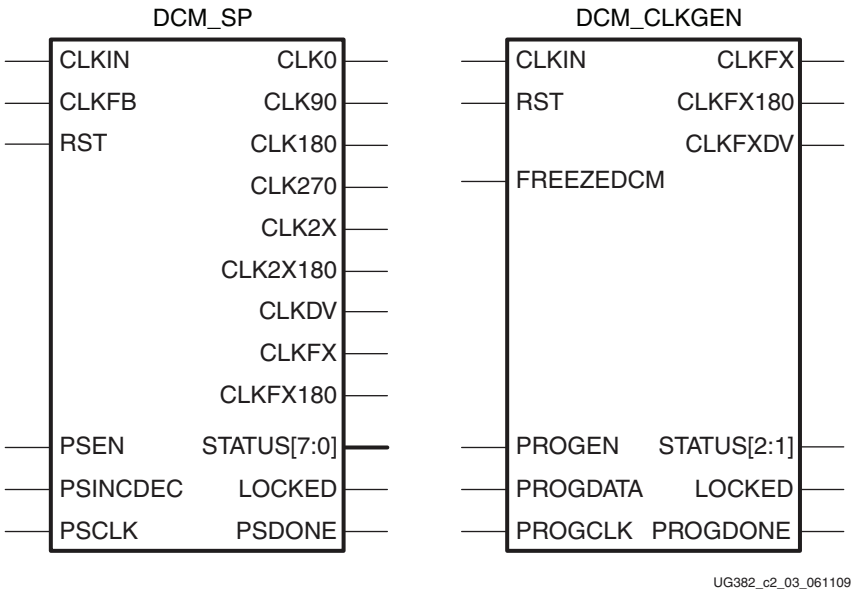


Figure 2-3: **DCM Primitives**

Each DCM connection port, attributes, properties, and constraints are summarized in this section.

DCM_SP Primitive

The DCM_SP primitive accesses traditional DCM features to provide clock deskew, frequency synthesis, and fixed and variable phase shifting.

Each port description includes the signal direction and notes the DCM functions that require (R) a connection. Table 2-4 provides the abbreviated name for each function unit used in Table 2-5. Table 2-5 lists the DCM_SP ports.

Table 2-4: **Functional Unit Abbreviations for Table 2-5**

Abbreviation	DCM Function
DLL	Delay-locked Loop
PS	Phase shift
DFS	Digital frequency synthesizer

Table 2-5: **DCM_SP Ports**

Port	Direction	Description	DLL	PS	DFS
CLKIN	Clock Input	Clock input to DCM. Always required. The CLKIN frequency and jitter must fall within the limits specified in the data sheet.	R	R	R
CLKFB	Input	Clock feedback input to DCM. The feedback input is required unless the DFS outputs, CLKFX or CLKFX180, are used stand-alone. The source of the CLKFB input must be the CLK0 or CLK2X output from the DCM and the CLK_FEEDBACK must be set to 1X or 2X accordingly. When set to NONE, CLKFB is unused. Ideally, the feedback point includes the delay added by the clock distribution network, either internally or externally.	R	R	Optional
RST	Input	Asynchronous reset input. Resets the DCM logic to its post-configuration state. Causes DCM to reacquire and relock to the CLKIN input. Invertible within DCM block. Non-inverted behavior shown below. 0: No effect 1: Reset DCM block. Hold RST pulse High for at least three valid CLKIN cycles	R	R	R
PSEN	Input	Variable phase-shift enable. Can be inverted within a DCM block. Non-inverted behavior shown below. 0: Disable variable phase shift. Ignore inputs to phase shifter 1: Enable variable phase shift operations on next rising PSCLK clock edge		R	
PSINCDEC	Input	Increment/decrement variable phase shift. Can be inverted within a DCM block. Non-inverted behavior shown below. 0: Decrement phase shift value on next enabled, rising PSCLK clock edge 1: Increment phase shift value on next enabled, rising PSCLK clock edge		R	
PSCLK	Clock Input	Clock input to variable phase shifter, clocked on rising edge. When using a global clock buffer, only the upper eight BUFGMUXs can drive PSCLK: BUFGMUX_X2Y1, BUFGMUX_X2Y2, BUFGMUX_X2Y3, BUFGMUX_X2Y4, BUFGMUX_X3Y5, BUFGMUX_X3Y6, BUFGMUX_X3Y7, and BUFGMUX_X3Y8.		R	
CLK0	Clock Output	Same frequency as CLKIN, 0° phase shift (i.e., not phase shifted). Always conditioned to a 50% duty cycle on Spartan-6 FPGAs. CLK_FEEDBACK must be set to 1X or 2X to deskew CLK0. When CLK_FEEDBACK is set to NONE, no phase relationship with CLKIN is present.	R		
CLK90	Clock Output	Same frequency as CLKIN, 90° phase shift (quarter period). Always conditioned to a 50% duty cycle on Spartan-6 FPGAs.	R		
CLK180	Clock Output	Same frequency as CLKIN, 180° phase shift (half period). Always conditioned to a 50% duty cycle on Spartan-6 FPGAs.	R		

Table 2-5: **DCM_SP Ports *(Cont'd)***

Port	Direction	Description	DLL	PS	DFS
CLK270	Clock Output	Same frequency as CLKIN, 270° phase shift (three-quarters period). Always conditioned to a 50% duty cycle on Spartan-6 FPGAs.	R		
CLK2X	Clock Output	Double-frequency clock output, 0° phase shift. When available, the CLK2X output always has a 50% duty cycle. Either CLK0 or CLK2X is required as a feedback source for DLL functions. Clock Doubler (CLK2X, CLK2X180) output.	R		
CLK2X180	Clock Output	Double-frequency clock output, 180° phase shift. When available, the CLK2X180 output always has a 50% duty cycle. Clock doubler (CLK2X, CLK2X180) output.	R		
CLKDV	Clock Output	Divided clock output, controlled by the CLKDV_DIVIDE attribute. The CLKDV output has a 50% duty cycle unless the CLKDV_DIVIDE attribute is a non-integer value. $F_{CLKDV} = \frac{F_{CLKIN}}{CLKDV_DIVIDE}$	R		
CLKFX	Clock Output	Synthesized clock output, controlled by the CLKFX_MULTIPLY and CLKFX_DIVIDE attributes. Always has a 50% duty cycle. If the CLKFX or CLKFX180 clock outputs are used standalone, then no clock feedback is required. $F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$			R
CLKFX180	Clock Output	Synthesized clock output CLKFX, 180° phase shift (appears to be an inverted version of CLKFX). Always has a 50% duty cycle. If only CLKFX or CLKFX180 clock outputs are used on the DCM, then no feedback loop is required.			R
STATUS[0]	Output	Variable phase shift overflow. Control output for variable fine phase shifting. The variable phase shifter has reached a minimum or maximum limit value. The limit value is either ±255 or a lesser value if the phase shift has reached the end of the delay line. 0: The phase shift has not yet reached its limit value 1: The phase shift has reached its limited value		R	
STATUS[1]	Output	CLKIN Input Stopped Indicator. Available only when the CLKFB feedback input is connected. Held in reset until the LOCKED output is asserted. Requires at least one CLKIN cycle to become active. Never asserted if CLKIN never toggles. 0: CLKIN input is toggling 1: CLKIN input is not toggling even though the locked output can still be High.		R	
STATUS[2]	Output	CLKFX or CLKFX180 output stopped indicator. 0: CLKFX and CLKFX180 outputs are toggling 1: CLKFX and CLKFX180 outputs are not toggling, even though the LOCKED output can still be High.			R

Table 2-5: **DCM_SP Ports *(Cont'd)***

Port	Direction	Description	DLL	PS	DFS
STATUS[7:3]	Output	Reserved. Used for simulating reset circuitry in lower-power Spartan-6 devices.			
LOCKED	Output	All DCM features have locked onto the CLKIN frequency. Clock outputs are now valid, assuming CLKIN is within specified limits. 0: DCM is attempting to lock onto CLKIN frequency. DCM clock outputs are not valid 1: DCM is locked onto CLKIN frequency. DCM clock outputs are valid. 1-to-0: DCM lost lock. Reset DCM.	R	R	R
PSDONE	Output	Variable phase shift operation complete. 0: No phase shift operation is active or phase shift operation is in progress. 1: Requested phase shift operation is complete. Output High for one PSCLK cycle. Next variable phase shift operation can commence.		R	

Table 2-6 lists the DCM_SP attributes. All attributes are set at design time and programmed during configuration. Most, except for the dynamic fine phase shift function, cannot be changed by the FPGA application at run-time. Use **<ATTRIBUTE>=<SETTING>** as appropriate in the design entry tool to set an attribute.

Table 2-6: **DCM_SP Attributes**

Attribute	Allowed Settings and Description
DLL_FREQUENCY_MODE	This is a legacy attribute. The DCM is always in the automatic frequency search mode. Setting High or Low makes no effect.
DFS_FREQUENCY_MODE	This is a legacy attribute. The DCM is always in the automatic frequency search mode. Setting High or Low makes no effect.
CLKIN_PERIOD	Specifies in ns the period of the clock used to drive the CLKIN pin of the DCM. Setting a Spartan-6 FPGA CLKIN_PERIOD helps reduce DFS jitter and results in a faster locking time.
CLK_FEEDBACK	Defines the frequency of the feedback clock. 1X: Default. CLK0 feedback. Same frequency as CLKIN 2X: CLK2X feedback. Double the frequency of CLKIN NONE: No feedback. DCM and DLL outputs run without a fixed phase.
CLKDV_DIVIDE	Defines the frequency of the CLKDV output. Allowable values for CLKDV_DIVIDE include 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 13, 14, 15, 16. The locking time is longer, and there is more output jitter when CLKDV_DIVIDE is a non-integer value. $F_{CLKDV} = \frac{F_{CLKIN}}{CLKDV_DIVIDE}$

Table 2-6: **DCM_SP Attributes *(Cont'd)***

Attribute	Allowed Settings and Description
CLKFX_MULTIPLY	Defines the multiplication factor for the frequency of the CLKFX and CLKFX180 outputs. Used in conjunction with the CLKFX_DIVIDE attribute. Allowable values for CLKFX_MULTIPLY include integers ranging from 2 to 32. Default value is 4. $F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$
CLKFX_DIVIDE	Defines the division factor for the frequency of the CLKFX and CLKFX180 outputs. Used in conjunction with the CLKFX_MULTIPLY attribute. Allowable values for CLKFX_DIVIDE include integers ranging from 1 to 32. Default value is 1. $F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$
PHASE_SHIFT	The PHASE_SHIFT attribute is applicable only if the CLKOUT_PHASE_SHIFT attribute is set to FIXED or VARIABLE. Defines the rising-edge skew between CLKIN and all the DCM clock outputs at configuration and consequently phase shifts the DCM clock outputs. The skew or phase shift value is specified as an integer that represents a fraction of the clock period as expressed in the equations in "Fine Phase Shifting". The integer value must range from –255 to 255. The default is 0. Actual allowable values depend on input clock frequency. The actual range is less when T_{CLKIN} > FINE_SHIFT_RANGE. The FINE_SHIFT_RANGE specification represents the total delay of all taps in the delay line.
CLKOUT_PHASE_SHIFT	Sets the phase shift mode. Together with the PHASE_SHIFT constraint, implements the DPS feature of the DCM. Affects all DCM clock outputs from both the DLL and DFS units. NONE: Default. CLKIN and CLKFB are in phase (no skew) and phase relationship cannot be changed. Equivalent to FIXED setting with a PHASE_SHIFT value of 0. FIXED: Phase relationship is set at configuration by the PHASE_SHIFT attribute value and cannot be changed by the application VARIABLE: Phase relationship is set at configuration by the PHASE_SHIFT attribute value but can be changed by the application using the Variable Phase Shift controls, PSEN, PSCLK, PSINCDEC, and PSDONE.
DESKEW_ADJUST	Controls the clock delay alignment between the FPGA clock input pin and the DCM output clocks. SYSTEM_SYNCHRONOUS: Default. All devices clocked by a common, system-wide clock source. SOURCE_SYNCHRONOUS: Clock is provided by the data source, i.e., source-synchronous applications. Do not use this setting to phase shift DCM clock outputs. Instead, use the CLK and PHASE_SHIFT constraints to achieve accurate phase shifting.

Table 2-6: **DCM_SP Attributes *(Cont'd)***

Attribute	Allowed Settings and Description
STARTUP_WAIT	Controls whether the FPGA configuration signal DONE waits for the DCM to assert its LOCKED signal before going High. FALSE: Default. DONE is asserted at the end of configuration without waiting for the DCM to assert LOCKED. TRUE: The DONE signal does not transition High until the LOCKED signal transitions High on the associated DCM. STARTUP_WAIT does not prevent LOCKED from transitioning High. The FPGA startup sequence must also be modified to insert a LCK (lock) cycle before the postponed cycle. The DONE cycle or the GWE cycle are typical choices. When more than one DCM is configured, the FPGA waits until all DCMs are LOCKED.
CLKIN_DIVIDE_BY_2	Optionally divides in half the CLKIN before entering the DCM block. In some applications, CLKIN_DIVIDE_BY_2 reduces the input clock frequency to acceptable limits. FALSE: Default. CLKIN input directly feeds the DCM. TRUE: Divides CLKIN frequency in half and provides roughly a 50% duty cycle clock before entering the DCM. Helps high frequency clocks meet the DCM input clock frequency or duty cycle requirements. Divides the clock frequency in half when determining operating frequency modes and calculating phase shift limits.
LOC	Specifies the physical location of the DCM.

DCM_CLKGEN Primitive

The DCM_CLKGEN primitive provides access to more advanced DFS features. These features are:

- Lower output jitter on CLKFX and CLKFX180
- Improved jitter tolerance on CLKIN
- Dynamic programming of M and D values, overwrites the CLKFX_MULTIPLY and CLKFX_DIVIDE attributes
- Wider range of the M and D values than the fixed CLKFX_MULTIPLY and CLKFX_DIVIDE attributes
- CLKFXDV provides an additional divided version of the CLKFX output
- Free running oscillator in the event of lost input clock
- Spread-spectrum clock generation

Table 2-7 lists the DCM_CLKGEN ports. Each port lists has a brief description and the signal direction.

Table 2-7: **DCM_CLKGEN Ports**

Port	Direction	Description
CLKIN	Clock Input	Clock input to DCM. Always required. The CLKIN frequency and jitter must fall within the limits specified in the data sheet. In the case of free-running oscillator mode, running clock needs to be connected until DCM is locked and DCM is frozen, then clock can be removed. In the other modes, a free running clock needs to be provided and remains.
RST	Input	Asynchronous reset input. Resets the DCM logic to its post-configuration state. Causes DCM to reacquire and relock to the CLKIN input. Invertible within DCM block. Non-inverted behavior shown below. 0: No effect 1: Reset DCM block. Hold RST pulse High for at least three valid CLKIN cycles
FREEZEDCM	Input	Prevents tap adjustment drift in the event of a lost CLKIN input. The DCM is then configured into a free-run mode.
CLKFX	Clock Output	Synthesized clock output, controlled by the CLKFX_MULTIPLY and CLKFX_DIVIDE attributes. Can be either statically set or dynamically programmed through a dedicated 4-wire SPI port (PROGDATA, PROGCLK, PROGDONE, and PROGEN). Always has a 50% duty cycle. $F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$
CLKFX180	Clock Output	Synthesized clock output CLKFX, 180° phase shift (appears to be an inverted version of CLKFX). Always has a 50% duty cycle.
LOCKED	Output	Synchronous output indicates whether the DCM is ready for operation. 0: DCM clock outputs are not valid 1: DCM is ready for operation 1-to-0: DCM lost LOCK. Reset DCM.
STATUS[1]	Output	STATUS[1] port is unused for CLKGEN.
STATUS[2]	Output	CLKFX or CLKFX180 output stopped indicator. 0: CLKFX and CLKFX180 outputs are toggling 1: CLKFX and CLKFX180 outputs are not toggling, even though the LOCKED output can still be High.
STATUS[7:3]	Output	Reserved. Used for simulating reset circuitry in lower-power Spartan-6 devices.
CLKFXDV	Clock Output	Divided CLKFX output clock. Divide value derived from CLKFXDV_DIVIDE attribute. There is no phase alignment between CLKFX and CLKFXDV. $F_{CLKFXDV} = \frac{F_{CLKFX}}{CLKFXDV_DIVIDE}$
PROGDONE	Output	Indication of M and D programming completeness. 0: No programming operation of M and D is active or the programming is in progress. 1: Requested programming is complete. Output High for one PROGCLK cycle. Next PROGCLK operation can commence.
PROGDATA	Input	Serial data input to supply information for the programming of M and/or D values of the DCM. This input must be applied synchronous to the PROGCLK input.

Table 2-7: **DCM_CLKGEN Ports *(Cont'd)***

Port	Direction	Description
PROGEN	Input	Indication of whether the programming of M and D values is enabled or not. 0: Programming of CLKFX_MULTIPLY and CLKFX_DIVIDE is disabled. 1: Programming of CLKFX_MULTIPLY and CLKFX_DIVIDE is enabled.
PROGCLK	Input	Clock input for the programming of M and D values. When using a global clock buffer, only the upper eight BUFGMUXs can drive PROGCLK: BUFGMUX_X2Y1, BUFGMUX_X2Y2, BUFGMUX_X2Y3, BUFGMUX_X2Y4, BUFGMUX_X3Y5, BUFGMUX_X3Y6, BUFGMUX_X3Y7, and BUFGMUX_X3Y8.

Table 2-8 lists the DCM_CLKGEN attributes. All attributes can be set at design time and programmed during configuration. Use **<ATTRIBUTE>=<SETTING>** as appropriate in the design entry tool to set an attribute. The CLKFX_MULTIPLY and CLKFX_DIVIDE are allowed to be changed by the FPGA application at run-time.

Table 2-8: **DCM_CLKGEN Attributes**

Attribute	Allowed Settings and Description
CLKFX_MULTIPLY	Defines the multiplication factor for the frequency of the CLKFX and CLKFX180 outputs. Used in conjunction with the CLKFX_DIVIDE attribute. Allowable values for CLKFX_MULTIPLY include integers ranging from 2 to 256. Default value is 4. $$F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$$
CLKFX_DIVIDE	Defines the division factor for the frequency of the CLKFX and CLKFX180 outputs. Used in conjunction with the CLKFX_MULTIPLY attribute. Allowable values for CLKFX_DIVIDE include integers ranging from 1 to 256. Default value is 1. $$F_{CLKFX} = F_{CLKIN}\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$$ For proper locking with input frequencies below 52 MHz, $$CLKFX_DIVIDE < \frac{F_{CLKIN}}{0.500\,MHz}$$
CLKFXDV_DIVIDE	Defines the division factor for the frequency of the CLKFXDV output. Allowable values are 2, 4, 8, 16, 32. Default value is 2. $$F_{CLKFXDV} = \frac{F_{CLKFX}}{CLKFXDV_DIVIDE}$$
CLKFX_MD_MAX	When dynamic programming of M and D values is engaged, this attribute specifies the maximum ratio of the M and D. CLKFX_MD_MAX is mainly used for static timing analysis. Default value is: $$\frac{CLKFX_MULTIPLY}{CLKFX_DIVIDE}$$
DFS_BANDWIDTH	Reserved.

Table 2-8: **DCM_CLKGEN Attributes *(Cont'd)***

Attribute	Allowed Settings and Description
PROG_MD_BANDWIDTH	Reserved.
SPREAD_SPECTRUM	CENTER_LOW_SPREAD, CENTER_HIGH_SPREAD, VIDEO_LINK_M0(1), VIDEO_LINK_M1(1), VIDEO_LINK_M2(1)
STARTUP_WAIT	Controls whether the FPGA configuration signal DONE waits for the DCM to assert its LOCKED signal before transitioning High. FALSE: Default. DONE is asserted at the end of configuration without waiting for the DCM to assert LOCKED. TRUE: The DONE signal does not transition High until the LOCKED signal transitions High on the associated DCM. STARTUP_WAIT does not prevent LOCKED from transitioning High. The FPGA startup sequence must also be modified to insert a LCK (lock) cycle before the postponed cycle. The DONE cycle or GWE cycle are typical choices. When more than one DCM is configured, the FPGA waits until all DCMs are LOCKED.
CLKIN_PERIOD	Specifies the CLKIN period in order to optimize the CLKFX/CLKFX180 outputs. This in turn will result in a faster locking time. Any real number is acceptable. Default value is 0.
CLKFX_MD_MAX	When dynamic programming of M and D values is engaged or when SPREAD_SPECTRUM is used, this attribute specifies the maximum ratio of the M and D. CLKFX_MD_MAX is mainly used for static timing analysis. Floating point value. Default value is CLKFX_MULTIPLY/CLKFX_DIVIDE.

Notes:

1. Soft modes of spread spectrum requires an external state machine for correct operation. PROGCLK and PROGDATA must be connected to an external state machine to create a spread-spectrum clock source.

DCM_SP Design Guidelines

Input Clock Frequency Range

The DCM clock input frequency depends on whether the DLL, the DFS, or both are utilized in the application.

The Spartan-6 FPGA data sheet specifies the clock input, CLKIN, and the frequency range for both the DFS and the DLL. The DFS, when used stand-alone, has a wider frequency range than the DLL. If the application uses both the DLL and DFS, then the more restrictive DLL requirements apply. Table 2-9 outlines the input clock frequency range specification names used in the Spartan-6 FPGA data sheet.

Table 2-9: **Input Clock Frequency Range**

Function	Minimum Frequency	Maximum Frequency
DFS	CLKIN_FREQ_FX_MIN	CLKIN_FREQ_FX_MAX
DLL	CLKIN_FREQ_DLL_MIN	CLKIN_FREQ_DLL_MAX

Output Clock Frequency Range

The DCM output clocks also have a specified frequency range.

Input Clock and Clock Feedback Variation

The DCM expects a stable, monotonic clock input. However, for maximum flexibility, the DCM tolerates a certain amount of clock jitter on the CLKIN input and a reasonable amount of frequency variation on both the CLKIN input and the CLKFB clock feedback input.

There are two types of jitter tolerance on the CLKIN input.

- Cycle-to-cycle jitter
- Period jitter

Cycle-to-Cycle Jitter

Cycle-to-cycle jitter indicates how much the CLKIN input period is allowed to change from one cycle to the next. Table 2-10 outlines the maximum allowable cycle-to-cycle change specification names used in the Spartan-6 FPGA data sheet.

Table 2-10: **Maximum Allowable Cycle-to-Cycle Jitter**

Function	All Frequency Ranges
DFS	CLKIN_CYC_JITT_FX
DLL	CLKIN_CYC_JITT_DLL

Period Jitter

The other applicable type of jitter is called period jitter. Period jitter indicates the maximum variation in the clock period over millions of clock cycles. Cycle-to-cycle jitter shows the change from one clock cycle to the next while period jitter indicates the maximum range of change over time. Table 2-11 outlines maximum allowable period jitter specification names used in the Spartan-6 FPGA data sheet.

Table 2-11: **Maximum Allowable Period Jitter**

Function	Frequency Range	
	≤ 150 MHz	≥ 150 MHz
DFS	CLKIN_PER_JITT_FX_LF	CLKIN_PER_JITT_FX_HF
DLL	CLKIN_PER_JITT_DLL_LF	CLKIN_PER_JITT_DLL_HF

DLL Feedback Delay Variance

Another source of stability for the DCM is the clock feedback path used by the DLL. The feedback path delay variance must also be within the limit shown in Table 2-12. This limit only applies to an external feedback path as any on-chip variance is minimal when connected to a global clock line.

Table 2-12: **External Feedback Path Delay Variation**

Specification	Description
CLKFB_DELAY_VAR_EXT	Maximum allowable variation in off-chip CLKFB feedback path

Spread Spectrum Clock Reception

The DCMs accept typical spread-spectrum clocks. The DLL portion of the DCM tracks the frequency changes created by a typical spread-spectrum clock, to drive the global clocks to the FPGA internal logic. The spread spectrum clock must meet the DLL input requirements as specified in the device data sheet. See the Input Clock Jitter Tolerance and Delay Path Variation specifications in the Recommended Operating Conditions for the DLL, CLKIN_CYC_JITT_DLL, and CLKIN_PER_JITT_DLL.

The DFS can track a typical spread-spectrum input as long as it meets the input clock specifications.

Optimal DCM Clock and External Feedback Inputs

Each DCM has multiple optimal inputs for an incoming clock signal or external feedback signal.

LOCKED Output Behavior

The LOCKED output of the DCM indicates when all the enabled DCM functions have locked to the CLKIN input.

Figure 2-4 shows the behavior of the LOCKED output. The LOCKED output is Low immediately after the FPGA finishes its configuration process and is Low whenever the RST input is asserted.

After configuration, the RST input should be asserted until the CLKIN input stabilizes (highly recommended). Once the RST input is released, the DCM locks to the stabilized CLKIN input frequency. The DLL uses both the CLKIN input and the CLKFB feedback input to determine when locking is complete, that is, when the rising edges of CLKIN and CLKFB are phase-aligned. The DFS synthesizes an output clock and locks when a valid frequency is present on the output.

The Spartan-6 FPGA data sheet provides worst-case locking times. In general, the DLL unit outputs lock faster with increasing clock frequency. The DFS lock time depends on many factors including the frequency of operation and the frequency multiply and divide factors. Smaller multiply and divide factors result in faster lock times.

To assure that the system clock is established before the FPGA completes its configuration process, the DCM can optionally delay the completion of the configuration process until after the DCM locks. The STARTUP_WAIT attribute activates this feature.

Until LOCKED is High, the stability of the DCM clock outputs is questionable. The DCM output clocks are not valid until LOCKED is High. Before that time, the DCM clock outputs can exhibit glitches, spikes, or other spurious behavior.

After the DCM has been initially locked, the LOCKED signal can stay High when CLKIN stops. The LOCKED signal can also stay High when CLKIN varies considerably.

In a Spartan-6 FPGA, when using two adjacent DCMs, consider the outputs valid once both DCMs are LOCKED. They also share the same reset signal.

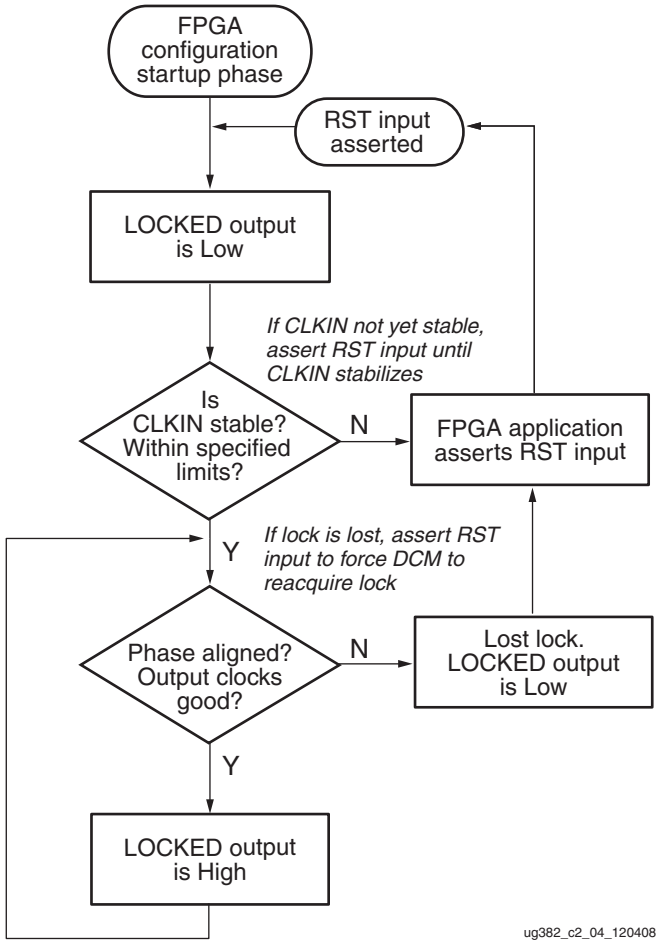


Figure 2-4: **Functional Behavior of LOCKED Output**

Once the DCM loses LOCKED, it does not automatically attempt to reacquire LOCKED. When the DCM loses LOCKED (High transitions Low), the FPGA application must take the appropriate action. For example, once LOCKED is lost, resetting the DCM through the RST input forces the DCM to reacquire LOCKED.

Using the LOCKED Signal

To operate properly, the DCM requires a stable, monotonic clock input. Once locked, the DCM tolerates clock period variations up to the value specified in the Spartan-6 FPGA data sheet. However, it is possible for the clock to stray outside the limits, for the LOCKED output to stay High, and for the DCM outputs to be invalid, for instance when the CLKIN stops toggling. It is a good design practice to monitor both LOCKED and the STATUS signals. Monitoring STATUS[1] is recommended to indicate when the CLKIN has stopped (moved outside the acceptable CLKIN tolerances). STATUS[1] transitions High after one missed CLKIN cycle. STATUS[1] is not a sticky bit; it transitions Low once the CLKIN has returned. Monitor both the LOCKED and STATUS[1] bits for the most robust indicator of the status of the DCM output clock.

Similarly, the STATUS[2] bit indicates that the DFS output CLKFX is stopped. If LOCKED = 0 and STATUS[2] = 1, then the DCM should be reset. If the FPGA application

also resets the DCM, then OR the reset signal from the FPGA application with the monitored output signals.

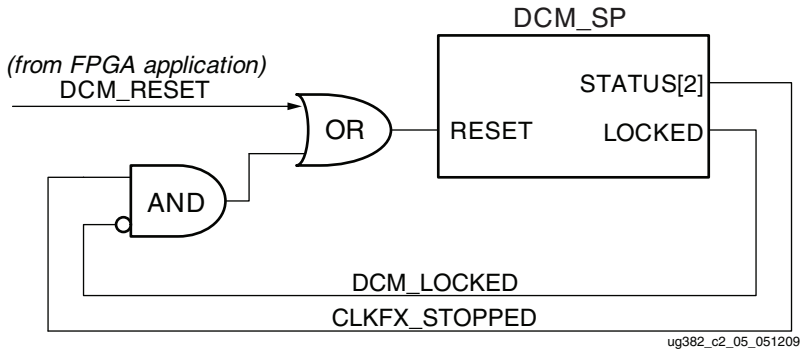


Figure 2-5: **Spartan-6 FPGA DCM DFS Lock Logic**

RST Input Behavior

The asynchronous RST input forces the DCM to its post-configuration state. Use the RST pin when changing the input clock frequency beyond the allowable range. The active-High RST pin either must connect to a dynamic signal or must be tied to ground. The RST input must be asserted for three valid CLKIN cycles or longer.

If the input clock frequency is not yet stable after configuration, assert RST until the clock stabilizes. When using external feedback, hold the DCM in reset immediately after configuration.

If the DCM loses lock, for instance, the LOCKED output was High then transitioned Low, the FPGA application must assert RST to force the DCM to reacquire the input clock frequency. If the DCM LOCKED output is High, then the LOCKED signal deactivates within four source clock cycles when RST is asserted. Asserting RST forces the DCM to reacquire lock.

Asserting RST also resets the DCM's delay tap position to zero. Due to the tap position changes, glitches can occur on the DCM clock output pins. Similarly, the duty cycle on the clock outputs can be affected when RST is asserted.

Asserting RST also resets the present variable phase shift value back to the value specified by the PHASE_SHIFT attribute.

For lower-power Spartan-6 designs, a small reset circuit is automatically inserted into designs. The additional logic is required to ensure proper operation when using DCM_SP or DCM_CLKGEN with V_{CCINT} = 1.0V. Because of the additional circuitry, some signal names will change.

DCM_CLKGEN Design Guidelines

Although the DCM_SP already provides the comprehensive capability to manage and generate various clocking functions, the Spartan-6 FPGA includes a new primitive (DCM_CLKGEN) to respond to increasing application demands to access more advanced clock synthesis features that are not available in a traditional DCM and PLL. Using this new primitive broadens the FPGA application range, especially in the consumer space:

- Some consumer electronics designs provide CLKINs with noise and jitter that traditional DCMs and PLLs can not tolerate.

- Some applications have a CLKIN coming from unsteady or disappearing cable signals. In this case, the DCM output is still expected to continue running.
- Flat-Panel LCD TVs require decent EMI reduction without access to expensive external metal shielding.
- To be compliant with various video timing formats for different screen display modes, a video pixel clock generator requires the ability to perform frequency adjustments during normal operation.
- Complex power management schemes need a way to dynamically scale the clock frequency to tailor power consumption needs.

The following section is a detailed discussion on these new DCM_CLKGEN features.

Dynamic Frequency Synthesis

In contrast to the static clock frequency synthesis described in the Spartan-6 FPGA DCM_SP sections, the DCM_CLKGEN primitive allows the DFS to dynamically synthesize a clock frequency. The M and D values can be programmed to overwrite the corresponding static attributes CLKFX_MULTIPLY and CLKFX_DIVIDE using a dedicated Serial Peripheral Interface (SPI) bus with a programming port using four pins; PROGDATA, PROGEN, PROGCLK, and PROGDONE. The SPI port is always configured as a slave device. The SPI master can be constructed using FPGA logic. Appropriate usage of both the PROGEN and PROGDONE pins allows multiple DCM slaves to be controlled by a single master. Figure 2-6 illustrates the master-slave relationship and their connections.

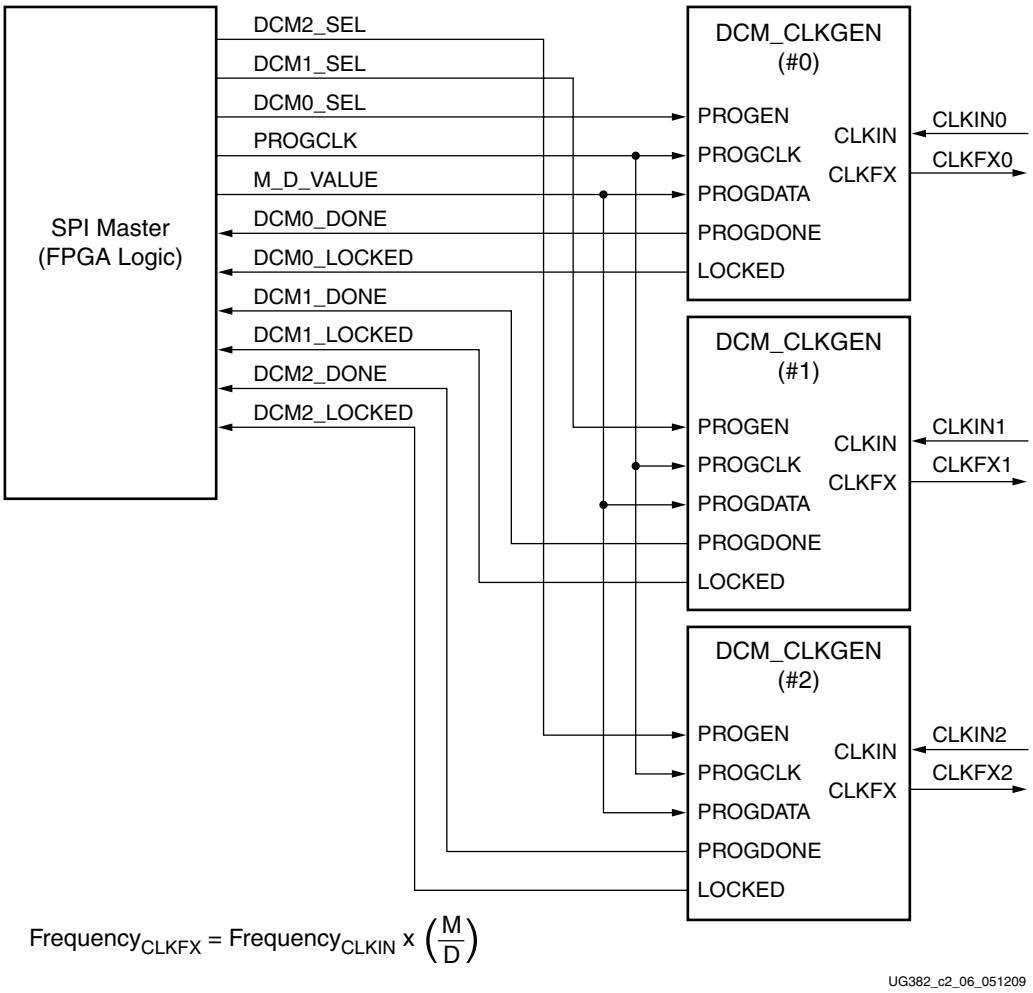


Figure 2-6: **DCM_CLKGEN M and D Programming Interface**

An ordered M/D programming sequence can be described as:

- A 2-bit LoadD command `10`, followed by 8-bit (D-1), with the LSB first. This consumes exactly 10 cycles when the PROGEN pin must remain a logic High.
- A 2-bit LoadM command `11`, followed by 8-bit (M-1), with the LSB first. This consumes exactly 10 cycles when the PROGEN pin must remain a logic High.
- A 1-bit GO command `0`. The PROGEN pin must remain a logic High for exactly one cycle.
- The SPI master monitors the PROGDONE pin and waits for it to be asserted to a logic High.
- When the DCM asserts the LOCKED signal High, a new and valid clock frequency should be present on the CLKFX pin.

Figure 2-7 illustrates an example where the M is programmed as 14 and the D as 3. There is a minimal gap requirement between any two commands. The gap between the LoadD and LoadM is at least two cycles. The gap between the LoadM and GO is at least one cycle.

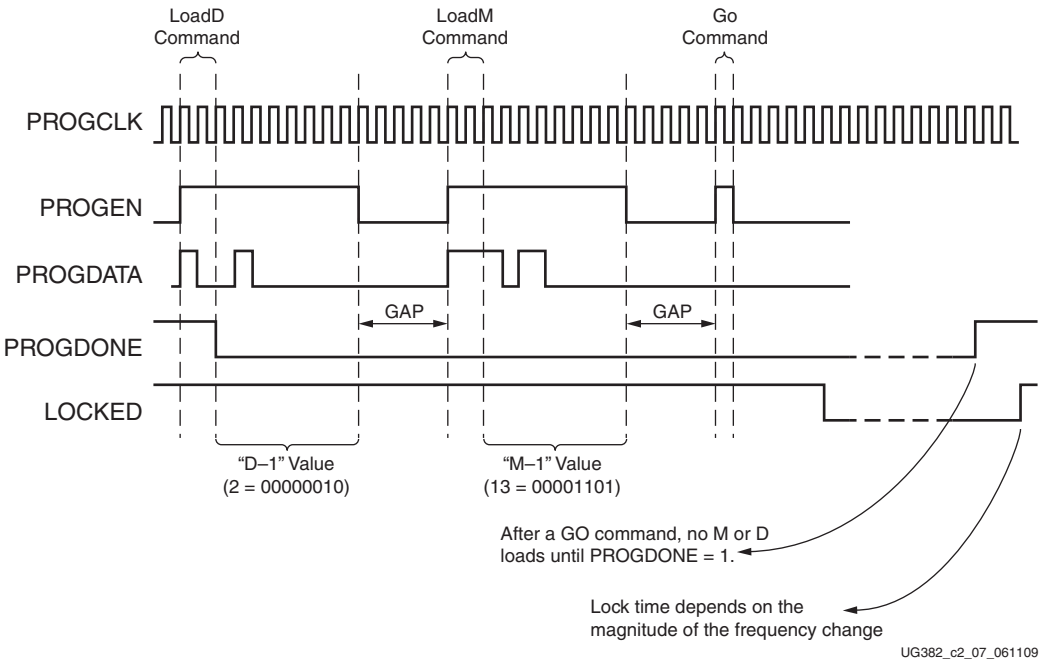


Figure 2-7: **DCM_CLKGEN M and D Configuration Timing Waveform**

When using DCM_CLKGEN with dynamic frequency synthesis where the output is driving a PLL, the VCO range of the PLL must also be considered. DCM_CLKGEN supports a wide range of output frequencies. All frequencies should be checked to make sure the resultant VCO frequency associated with the PLL setup will not violate the VCO range of the PLL (Frequency Synthesis Only in Chapter 3).

Spread-Spectrum Clock Generation

Spread-spectrum clock generation (SSCG) is widely used by manufacturers of electronic devices to reduce the spectral density of the electromagnetic interference (EMI) generated by these devices. Manufacturer13s must ensure that levels of electromagnetic energy emitted do not interfere with the operation of other nearby electronic devices. For example, the clarity of a phone call should not degrade when the phone is next to a video display. In the same way, the display should not be affected when the phone is used.

Electromagnetic Compatibility (EMC) regulations are used to control the noise or EMI that causes these disturbances. Typical solutions for meeting EMC requirements involve adding expensive shielding, ferrite beads, or chokes. These solutions can adversely impact the cost of the final product by complicating PCB routing and forcing longer product development cycles.

SSCG spreads the electromagnetic energy over a large frequency band to effectively reduce the electrical and magnetic field strengths measured within a narrow window of frequencies. The peak electromagnetic energy at any one frequency is reduced by modulating the SSCG output.

The SSCG commonly defines the following parameters:

- Frequency deviation, that is the percentage of the input frequency
- Modulation frequency
- Spread type: up/down/center
- Modulation profile, for example, the shape of the triangle

A typical spread spectrum clock can be defined as: 75 MHz (input frequency), ±2.0% center spread, and 75 KHz triangular modulation. Figure 2-8 illustrates these parameter definitions for center and down spread types.

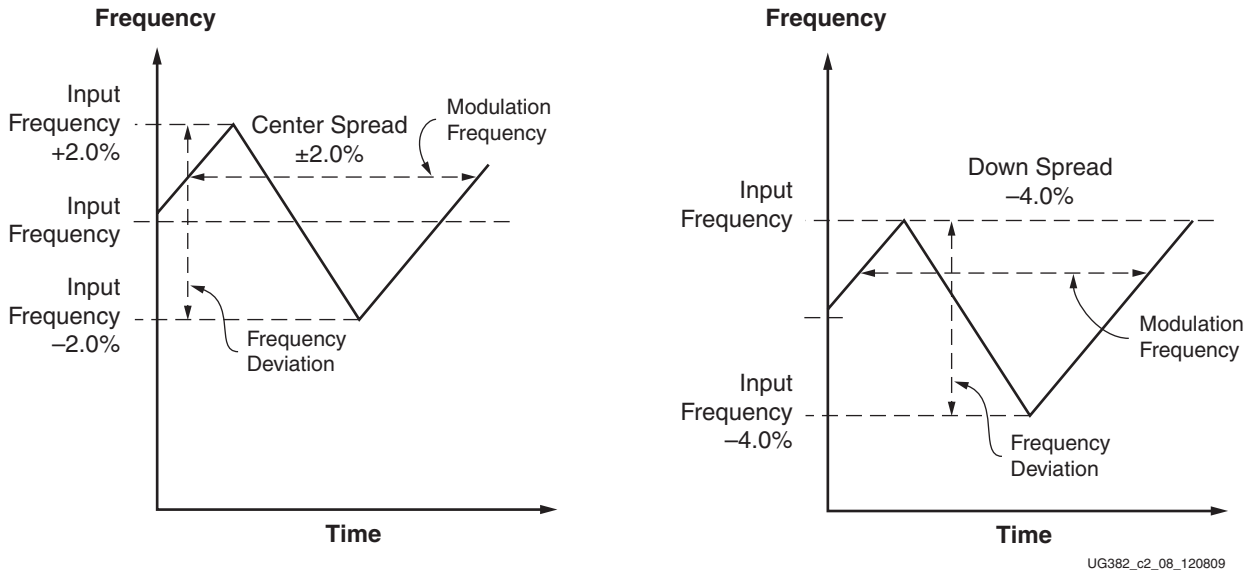


Figure 2-8: **Two Types of Spread Spectrum Clocks with Common Parameters Defined**

Spread-Spectrum Generation

Spartan-6 FPGAs can generate a spread-spectrum clock source from a standard fixed-frequency oscillator. To generate a spread-spectrum clock source from a fixed-frequency clock source, the DCM_CLKGEN can either use a fixed spread-spectrum solution, providing the simplest implementation, or a soft spread-spectrum solution which adds more flexibility but requires additional logic to continually reprogram DCM_CLKGEN. See Table 2-13.

Table 2-13: **DCM_CLKGEN Spread-Spectrum Modes**

Spread Spectrum Values	Fixed Spread-Spectrum Modes	Soft Spread-Spectrum Modes
SPREAD_SPECTRUM values	CENTER_LOW_SPREAD CENTER_HIGH_SPREAD	VIDEO_LINK_M0, VIDEO_LINK_M1, VIDEO_LINK_M2
Additional logic	None	SOFT_SS
Modulation profile	Triangular	Triangular
Spread direction	Center	Down
Spread range	Fixed	See Figure
F_{MOD}	F_{IN}/1024	See Figure
CLKFX_MULTIPLY	2–32	7
CLKFX_DIVIDE	1–4	2, 4
DCM_CLKGEN programming ports	N/A	PROGCLK, PROGEN, PROGDATA, PROGDONE

Fixed Spread Spectrum

The simplest way to implement spread spectrum uses a fixed mode (Figure 2-9) of the DCM_CLKGEN primitive.

```
SPREAD_SPECTRUM = < CENTER_LOW_SPREAD,CENTER_HIGH_SPREAD>
```

Using this fixed mode, the DCM_CLKGEN automatically creates a spread spectrum clock. The modulation frequency is based on the input frequency. Where:

Modulation Frequency = input frequency/1024.

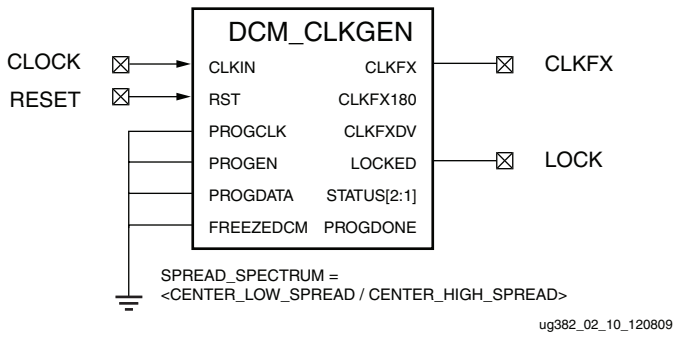


Figure 2-9: **Fixed Spread Spectrum**

Soft Spread Spectrum

For applications requiring downspread modulation, the DCM_CLKGEN can use one of three spread-spectrum modes to control the rate that the DCM_CLKGEN switches between different programming values. A small counter-based state machine can control DCM_CLKGEN to provide a triangular, spread-spectrum clock source (see Figure 2-10). Because DCM_CLKGEN requires an external state machine for the soft spread spectrum, failure to connect PROGCLK and PROGDATA to logic will result in a DRC error.

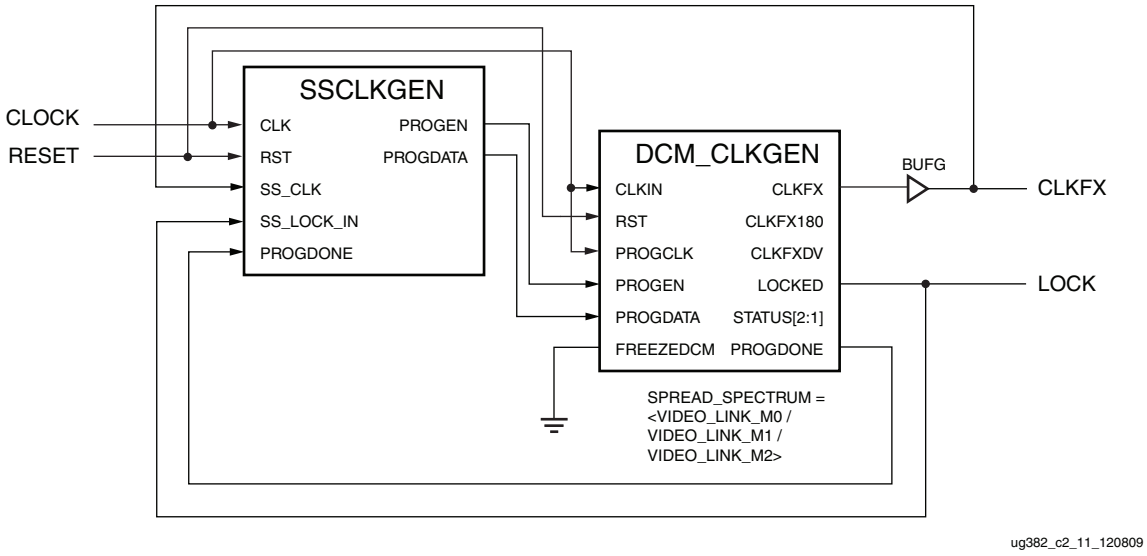


Figure 2-10: **Soft Spread Spectrum**

Typical video link applications need 7:1 serialization. When using IOSERDES2, clock generation requires using both a DCM_CLKGEN and PLL. DCM_CLKGEN generates the spread-spectrum clock source typically with M = 7 and D = 2. To access high-speed I/O clock networks, the PLL multiplies the clock for up to the full clock frequency required for SDR clocking using the BUFPLL as shown in Figure 2-11.

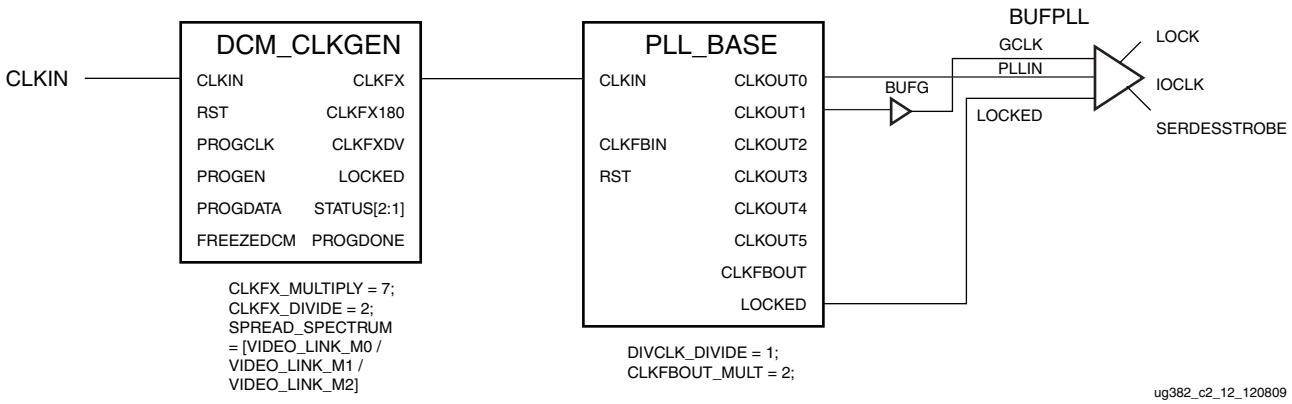


Figure 2-11: **VIDEO_LINK Setup for Downspread Spread Spectrum 20-107 MHz (when $F_{IN} \times 3.5 <$ CLKOUT_FREQ_FX)**

VIDEO_LINK_M0, VIDEO_LINK_M1, and VIDEO_LINK_M2 are selected to cover typical pixel clock frequencies. VIDEO_LINK_M0 has the fastest modulation frequency response to help compensate for the higher periods associated with 20 MHz pixel clocks. Actual modulation frequency depends on the SSCLKGEN setup. VIDEO_LINK_M1 is slower and VIDEO_LINK_M2 is the slowest.

Pixel clock frequencies of CLKFX_MULITPLY = 7, CLKFX_DIVIDE = 2 are used when the maximum CLKOUT_FREQ_FX is maintained. For higher pixel clock frequencies, DCM_CLKGEN must be changed to CLKFX_MULTIPLY = 7 and CLKFX_DIVIDE = 4 to compensated for the PLL addition. See Figure 2-12. This slows down the modulation frequency requiring VIDEO_LINK_M1.

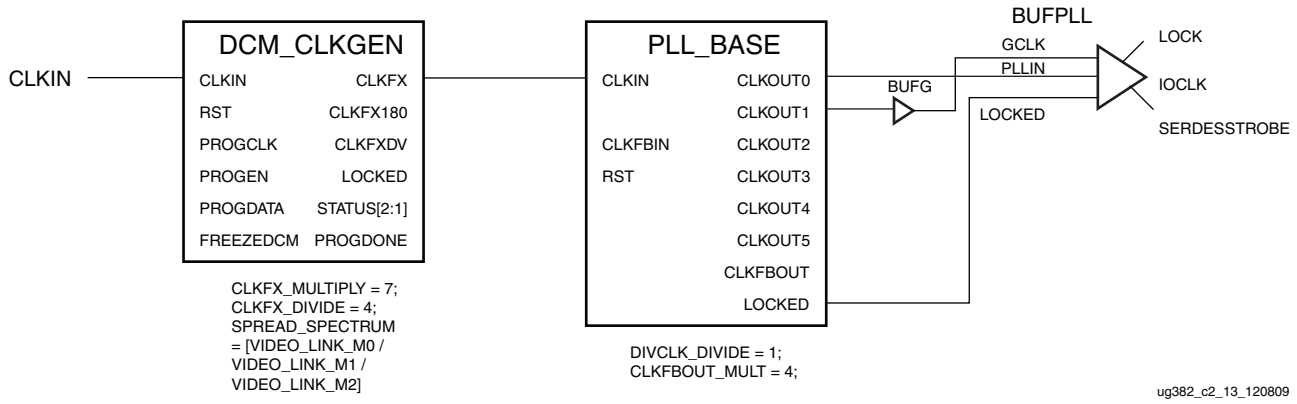


Figure 2-12: **VIDEO_LINK Setup for Downspread Spread Spectrum (when F_{IN} > 107 MHz)**

Free-Running Oscillator

The DCM_CLKGEN can be used to generate a clock source by tieing the LOCKED output pin to the FREEZEDCM input pin. The DCM requires a kick-start in this mode; instead of an always running clock, any oscillating signal can be used until the DCM has LOCKED. Figure 2-13 illustrates an example.

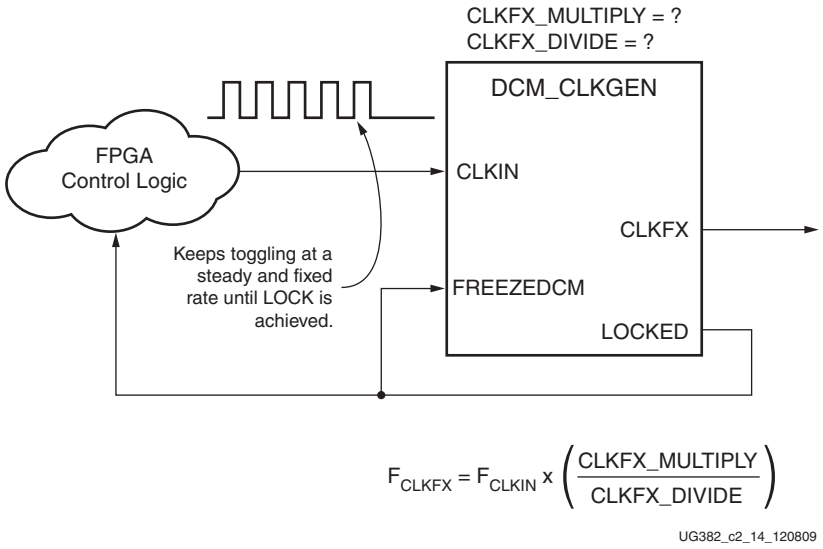


Figure 2-13: **Setup of a Free-Running Oscillator**

For a deterministic frequency output on the CLKFX pin, the CLKIN must keep toggling at a steady rate until the DCM has achieved LOCKED. After that, the CLKIN no longer needs to be present and can be removed.

The DCM_CLKGEN will continue to run at the same frequency. If temperature or voltage levels fluctuate, the frequency can vary. Adjust timing constraints to reflect the highest frequency within the frequency drift. When a new clock input is applied, RESET must be asserted.

XILINX®

Chapter 3

Phase-Locked Loops

Introduction

The clock management tile (CMT) in Spartan-6 FPGAs includes two DCMs and one PLL. There are dedicated routes within a CMT to couple together various components. Each block within the tile can be treated separately, however, there exists a dedicated routing between blocks creating restrictions on certain connections. Using these dedicated routes frees up global resources for other design elements. Additionally, the use of local routes within the CMT provides an improved clock path because the route is handled locally, reducing chances for noise coupling.

The CMT diagram (Figure 3-1) shows a high-level view of the connection between the various clock input sources and the DCM-to-PLL and PLL-to-DCM dedicated routing. The six (total) PLL output clocks are MUXed into a single clock signal for use as a reference clock to the DCMs. Two output clocks from the PLL can drive the DCMs. These two clocks are 100% independent. PLL output clock 0 could drive DCM1 while PLL output clock 1 could drive DCM2. Each DCM output can be MUXed into a single clock signal for use as a reference clock to the PLL. Only one DCM can be used as the reference clock to the PLL at any given time. A DCM can not be inserted in the feedback path of the PLL. Both the PLLs or DCMs of a CMT can be used separately as stand-alone functions. The outputs from the PLL are not spread spectrum.

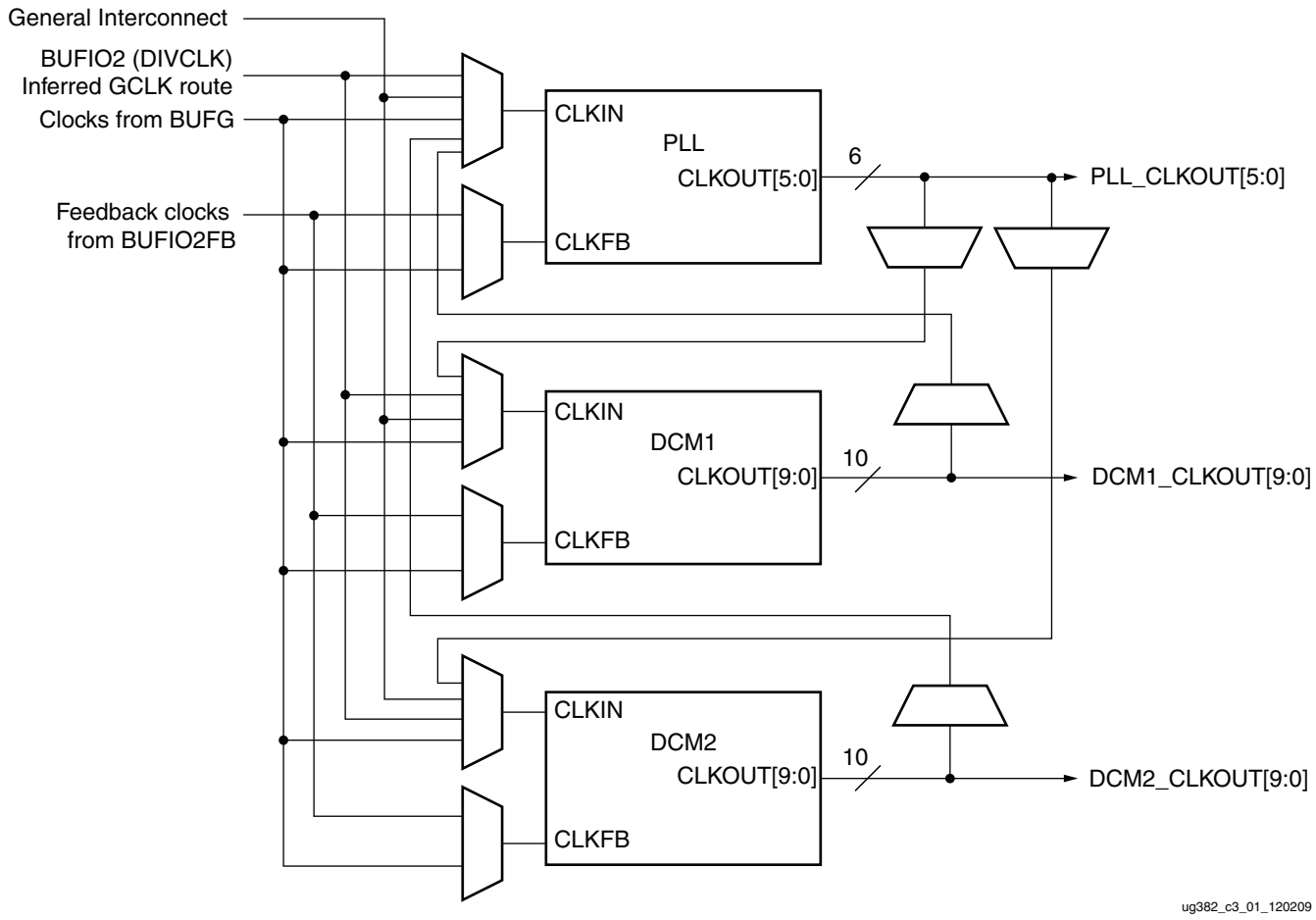


Figure 3-1: **Block Diagram of the Spartan-6 FPGA CMT**

To support the high-performance SDR clock rates associated with the PLL, each BUFPLL is directly routed to a restricted number of PLL locations. Table 3-1 lists the PLL locations that can be connected to each BUFPLL.

Table 3-1: **PLLs with Direct Connections to BUFPLL**

BUFPLL Location	Bank	Valid PLL Locations by Device Type		
		LX4, LX9, LX16, LX25/LX25T	LX45/LX45T	LX75/LX75T LX100/LX100T LX150/LX150T
BUFPLL_X1Y5 BUFPLL_X1Y4 BUFPLL_MCB_X1Y9	0	PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y5 PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y0
BUFPLL_X0Y2 BUFPLL_X0Y3 BUFPLL_MCB_X0Y5	1 (5)	PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y5 PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y0
BUFPLL_X1Y0 BUFPLL_X1Y1 BUFPLL_MCB_X1Y5	2	PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y5 PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y0
BUFPLL_X2Y2 BUFPLL_X2Y3 BUFPLL_MCB_X2Y5	3 (4)	PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y1 PLL_ADV_X0Y0	PLL_ADV_X0Y5 PLL_ADV_X0Y3 PLL_ADV_X0Y2 PLL_ADV_X0Y0

Phase Lock Loop (PLL)

Spartan-6 devices contain up to six CMT tiles. The main purpose of PLLs is to serve as a frequency synthesizer for a wide range of frequencies, and to serve as a jitter filter for either external or internal clocks in conjunction with the DCMs of the CMT.

The PLL block diagram shown in Figure 3-2 provides a general overview of the PLL components.

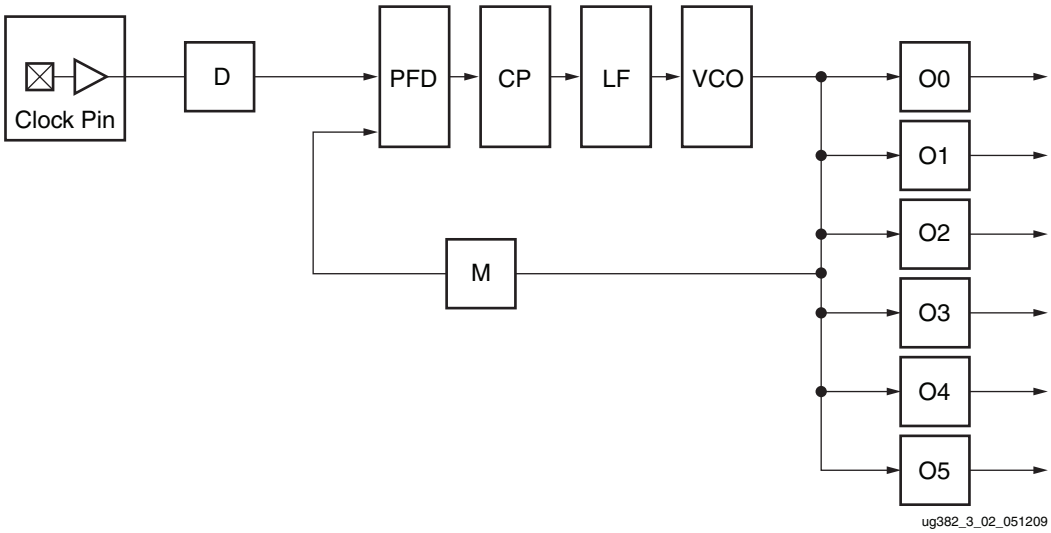


Figure 3-2: **Block Diagram of the Spartan-6 FPGA PLL**

Input MUXes select the reference and feedback clocks from either the IBUFG, BUFG, IBUF, PLL outputs, or one of the DCMs. Each clock input has a programmable counter D. The Phase-Frequency Detector (PFD) compares both phase and frequency of the input (reference) clock and the feedback clock. Only the rising edges are considered because as long as a minimum High/Low pulse is maintained, the duty cycle is not important. The PFD is used to generate a signal proportional to the phase and frequency between the two clocks. This signal drives the Charge Pump (CP) and Loop Filter (LF) to generate a reference voltage to the Voltage Controlled Oscillator (VCO). The PFD produces an up or down signal to the charge pump and loop filter to determine whether the VCO should operate at a higher or lower frequency. When VCO operates at too high of a frequency, the PFD activates a down signal, causing the control voltage to be reduced decreasing the VCO operating frequency. When the VCO operates at too low of a frequency, an up signal will increase voltage. The VCO produces eight output phases. Each output phase can be selected as the reference clock to the output counters. See Figure 3-3 and Figure 3-4. Each counter can be independently programmed for a given customer design. A special counter, M, is also provided. This counter controls the feedback clock of the PLL allowing a wide range of frequency synthesis.

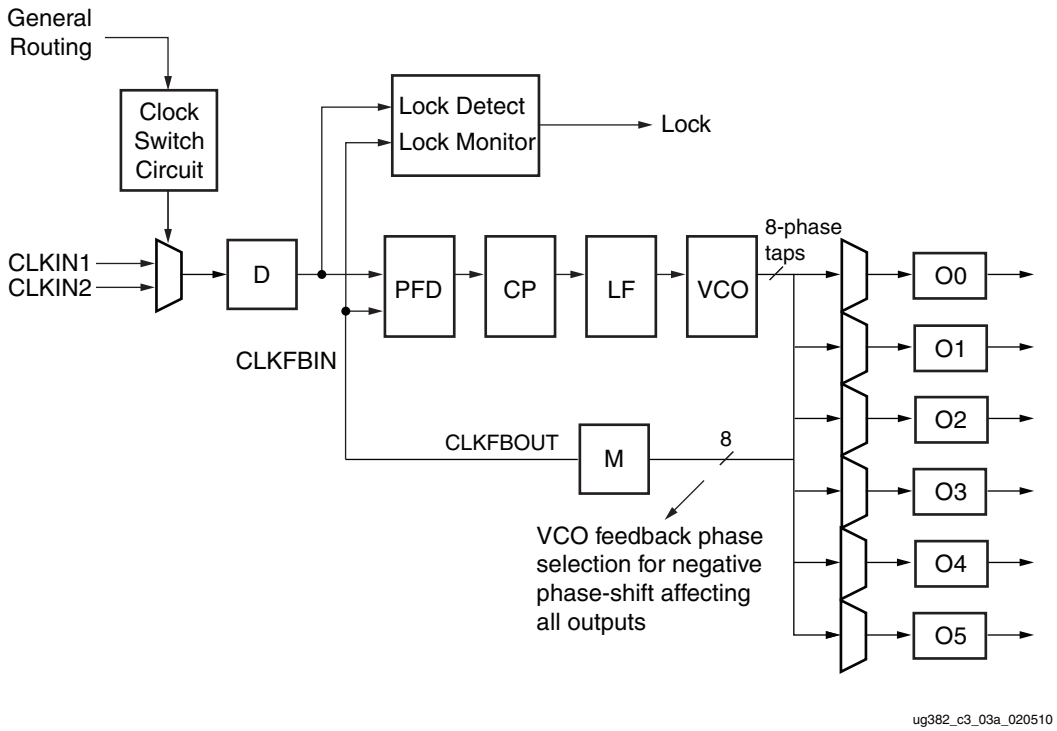


Figure 3-3: **Detailed PLL Block Diagram: CLK_FEEDBACK = CLKFBOUT**

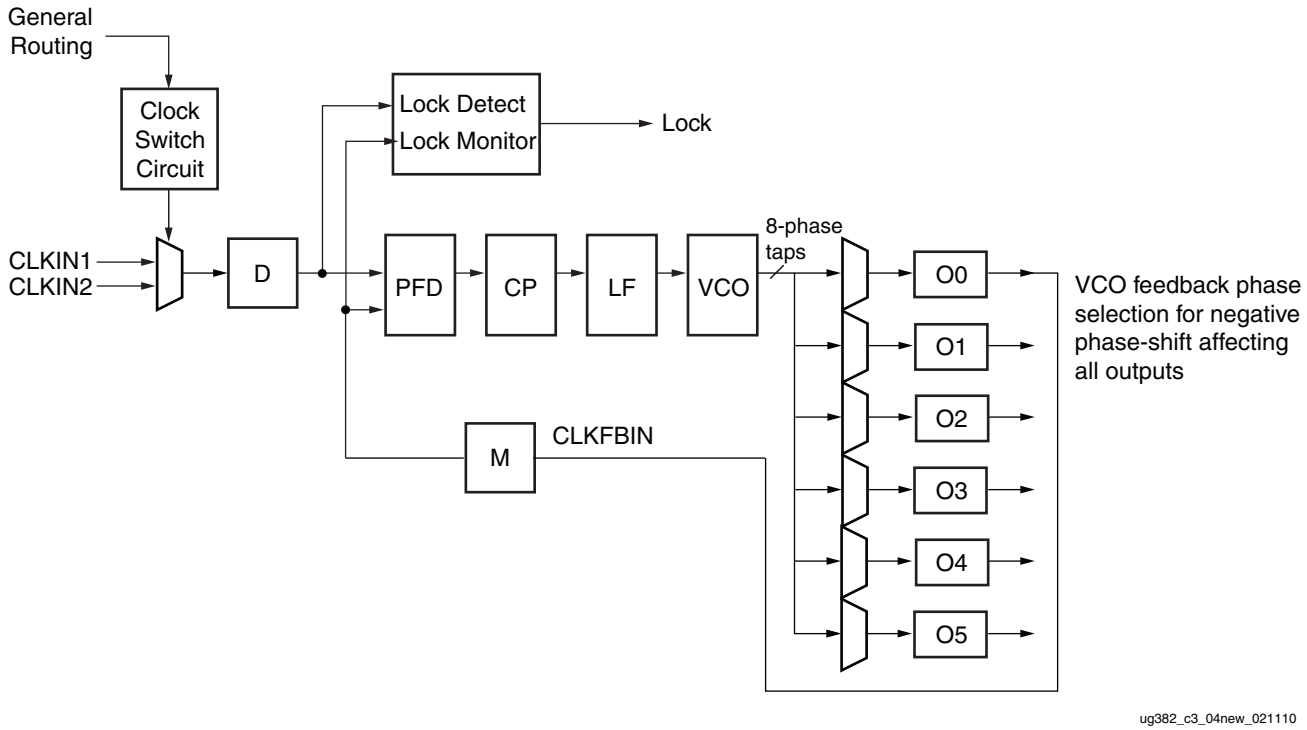


Figure 3-4: **Detailed PLL Block Diagram: CLK_FEEDBACK = CLKOUT0**

Aligning PLL using CLK_FEEDBACK and BUFIO2FB

The Spartan-6 FPGA PLL contains dedicated feedback routing used to minimize phase noise and increase the performance of the PLL clocking beyond the BUFG performance limitations. To use this dedicated PLL routing, CLK_FEEDBACK must be set to CLKOUT0 and use the BUFPLL and BUFIO2FB as shown in Figure 3-5.

BUFPLL and BUFPLL_MCB input clocks can be connected to either CLKOUT0 or CLKOUT1 from the PLL.

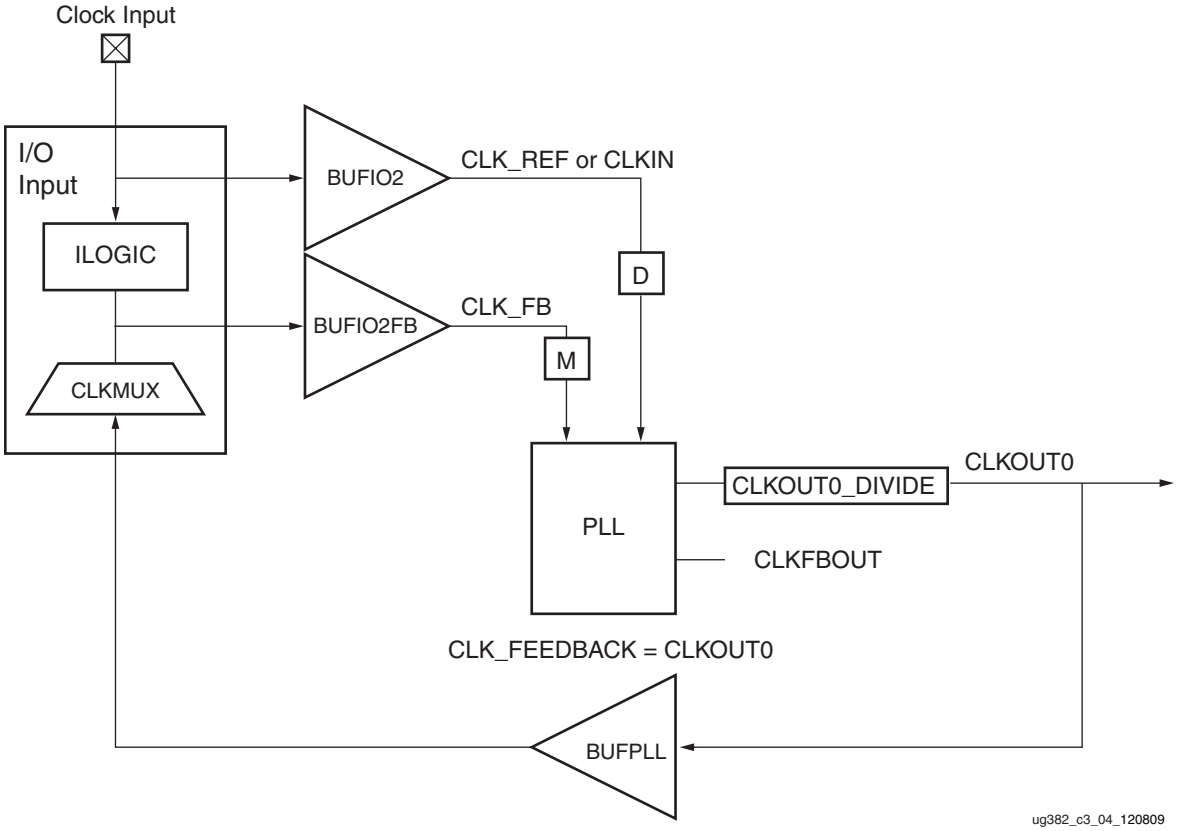


Figure 3-5: **PLL Using CLKOUT0 Feedback**

When using the dedicated feedback from CLKOUT0, the output counter CLKOUT0_DIVIDE will affect the VCO frequency.

$$f_{VCO} = \frac{f_{IN} \times M \times CLKOUT0_DIVIDE}{D} \qquad \text{Equation 3-1}$$

To accurately deskew the input routing, the BUFIO2FB buffer must be used as shown in Figure 1-33, page 51. The BUFIO2FB is matched to the BUFIO2 buffer limiting deskewing to a single DCM.

When using CLK_FEEDBACK = CLKOUT0, the frequency for the CLKFBIN can be different than the frequency at the PFD. Be careful when setting CLK_FEEDBACK = CLKOUT0, because the PFD matches the frequency between the input clock (Equation 3-2) and the frequency from the feedback clock.

$$F_{PFD_CLKIN} = \frac{F_{CLKIN}}{DIVCLK_DIVIDE} \quad \text{Equation 3-2}$$

When CLK_FEEDBACK = CLKFBOUT, the frequency of CLKFBOUT (Equation 3-3) matches the feedback frequency for the PFD.

$$F_{CLKFBOUT} = \frac{F_{VCO}}{CLKFBOUT_MULT} \quad \text{Equation 3-3}$$

$$F_{PFD_CLKFBOUT} = F_{CLKFB} \quad \text{Equation 3-4}$$

When CLK_FEEDBACK = CLKOUT0, the output frequency for CLKOUT0 (Equation 3-5) can be different than the feedback frequency depending on CLKFB_MULT. As shown in Figure 3-4, the frequency for CLKOUT0 is divided by CLKFB_MULT resulting in a PFD frequency that is dependent on CLKFB_MULT (Equation 3-6).

$$F_{CLKOUT0} = \frac{F_{VCO}}{CLKOUT0_DIVIDE} \quad \text{Equation 3-5}$$

$$F_{PFD_CLKOUT0} = \frac{F_{CLKOUT0}}{CLKFB_MULT} \quad \text{Equation 3-6}$$

From Equation 3-5, the output frequency for CLKOUT0 can be different than the VCO frequency.

General Usage Description

PLL Primitives

The two Spartan-6 FPGA PLL primitives, PLL_BASE and PLL_ADV, are shown in Figure 3-6.

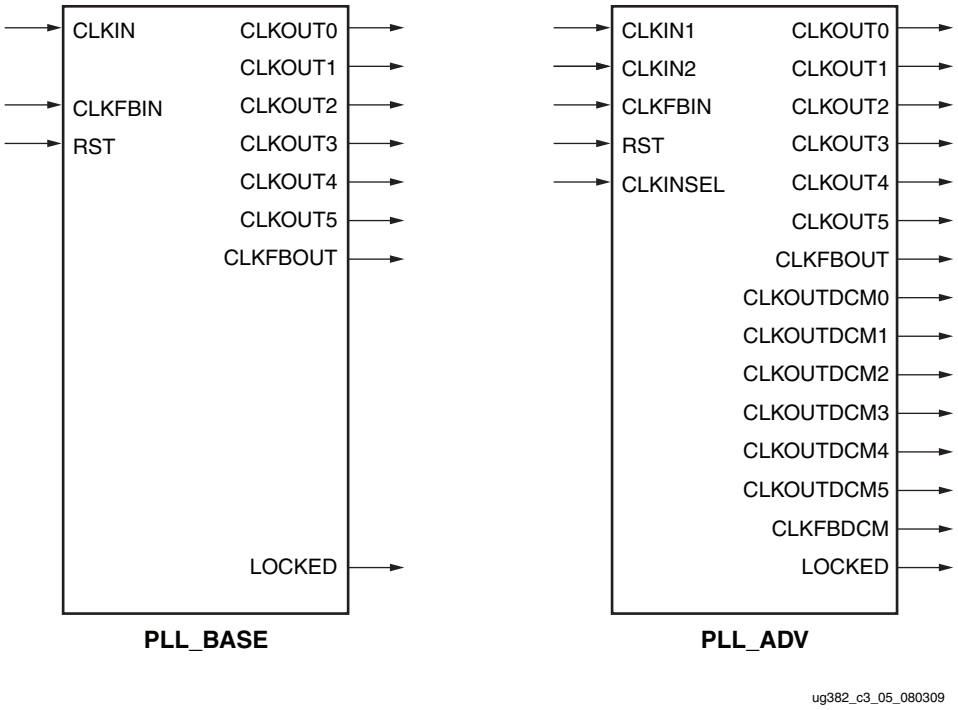


Figure 3-6: **PLL Primitives**

PLL_BASE Primitive

The PLL_BASE primitive provides access to the most frequently used features of a stand alone PLL. Clock deskew, frequency synthesis, coarse phase shifting, and duty cycle programming are available to use with the PLL_BASE. The ports are listed in Table 3-2.

Table 3-2: **PLL_BASE Ports**

Description	Port
Clock Input	CLKIN, CLKFBIN
Control Inputs	RST
Clock Output	CLKOUT0 to CLKOUT5, CLKFBOUT
Status and Data Outputs	LOCKED

PLL_ADV Primitive

The PLL_ADV primitive provides access to all PLL_BASE features. PLL_ADV is only provided in this document as a reference. It can be used for retargeting purposes. For most design situations, use the PLL_BASE primitive or the clocking wizard. The ports are listed in Table 3-3.

Table 3-3: **PLL_ADV Ports**

Description	Port
Clock Input	CLKIN1, CLKIN2, CLKFBIN
Control and Data Input	RST, CLKINSEL
Clock Output	CLKOUT0 to CLKOUT5, CLKFBOUT, CLKOUTDCM0 to CLKOUTDCM5, CLKFBDCM
Status and Data Output	LOCKED

The Spartan-6 FPGA PLL is a mixed signal block designed to support clock network deskew, frequency synthesis, and jitter reduction. These three modes of operation are discussed in more detail within this section. The VCO operating frequency can be determined by using the following relationships:

CLK_FEEDBACK = CLKFBOUT is described in Equation 3-7.

$$F_{VCO} = F_{CLKIN} \times \frac{M}{D} \quad \text{Equation 3-7}$$

CLK_FEEDBACK = CLKOUT0 is described in Equation 3-8.

$$F_{VCO} = F_{CLKIN} \times \frac{M \times O}{D} \quad \text{Equation 3-8}$$

$$F_{OUT} = \frac{F_{VCO}}{O} \quad \text{Equation 3-9}$$

where the M, D, and O counters are shown in Figure 3-3.

The six "O" counters can be independently programmed. For example, O0 can be programmed to do a divide-by-two while O1 is programmed for a divide by three. The only constraint is that the VCO operating frequency must be the same for all the output counters since a single VCO drives all the counters.

Clock Network Deskew

In many cases, designers do not want to incur the delay on a clock network in their I/O timing budget therefore they use a PLL or DLL to compensate for the clock network delay. Spartan-6 FPGA PLLs support this feature. A clock output matching the reference clock CLKIN frequency (usually CLKFBOUT or CLKOUT) is connected to a BUFG and fed back to the CLKFBIN feedback pin of the PLL. The remaining outputs can still be used to divide the clock down for additionally synthesized frequencies. In this case, all output clocks have a defined phase relationship to the input reference clock.

To accurately deskew the input routing, the BUFIO2FB buffer must be used as shown in Figure 1-33.

Frequency Synthesis Only

PLLs can also be used for stand-alone frequency synthesis. In this application, a PLL can not be used to deskew a clock network, however, it is used generate an output clock frequency for other blocks. In this mode, the PLL feedback path should be set to INTERNAL since it keeps all the routing local and should minimize the jitter. Figure 3-7 shows the PLL configured as a frequency synthesizer. In this example, a clocking configuration for PCI Express x1 Gen1 is given. A 100 MHz reference clock is fed from the REFCLKOUT of the GTP transceiver. Setting the counters M = 5 and D = 1 makes the VCO oscillate at 500 MHz (100 MHz x 5). Ensure the VCO frequency meets the range specified in the Spartan-6 FPGA data sheet. Four of the six PLL outputs are programmed to provide:

- 250 MHz clock to the GTP transceiver's TXUSRCLK and RXUSRCLK
- 125 MHz clock for the PCI Express PHY interface as well as the GTP transceiver's TXUSRCLK2 and RXUSRCLK2 for data exchange in a 2-byte mode
- 62.5 MHz clock for the PCI Express User Interface and block RAM interface
- 50 MHz clock for other glue logic

In this example, no phase relationships between the reference clock and the output clocks are required, however, there are phase relationships required between the output clocks.

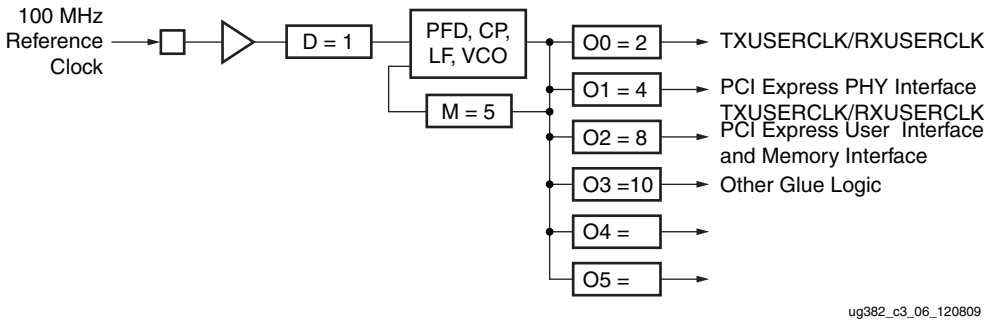


Figure 3-7: **PLL as a Frequency Synthesizer**

Jitter Filter

PLLs always reduce the jitter inherent on a reference clock. The PLL can be instantiated as a standalone function to simply support filtering jitter from an external clock before it is driven into the another block (including the DCM). As a jitter filter, it is usually assumed that the PLL acts as a buffer and regenerates the input frequency on the output (e.g., F_{IN} = 100 MHz, F_{OUT} = 100 MHz). In general, greater jitter filtering is possible by using the PLL attribute BANDWIDTH set to Low. Setting the BANDWIDTH to Low can incur an increase in the static offset of the PLL.

Limitations

The PLL has some restrictions that must be adhered to. These are summarized in the PLL electrical specification in the *Spartan-6 FPGA Data Sheet*. In general, the major limitations are VCO operation range, input frequency, duty cycle programmability, and phase shift.

VCO Operating Range

The minimum and maximum VCO operating frequencies are defined in the electrical specification of the *Spartan-6 FPGA Data Sheet*. These values can also be extracted from the speed specification.

Minimum and Maximum Input Frequency

The minimum and maximum CLKIN input frequency are defined in the electrical specification of the *Spartan-6 FPGA Data Sheet*.

Duty Cycle Programmability

Only discrete duty cycles are possible given a VCO operating frequency. The counter settings to determine the output duty cycle is further discussed under Counter Control.

Phase Shift

In many cases, there needs to be a phase shift between clocks. The phase shift resolution in time units is defined as: PS = 1/8 F_{VCO} or D/8MF_{IN} since the VCO can provide eight phase shifted clocks at 45° each.

The higher the VCO frequency, the smaller the phase shift resolution. Since the VCO has a distinct operating range, it is possible to bound the phase shift resolution using from 1/8 F_{VCO_MIN} to 1/8 F_{VCO_MAX}.

Each output counter is individually programmable allowing each counter to have a different phase shift based on the output frequency of the VCO.

Note: Phase shifts other than 45° are possible. A finer phase shift resolution depends on the output duty cycle and 0 value. Consult the clocking wizard for other phase-shift settings.

PLL Programming

Programming of the PLL must follow a set flow to ensure configuration that guarantees stability and performance. This section describes how to program the PLL based on certain design requirements. A design can be implement in two ways, directly through the GUI interface (the clocking wizard) or directly implementing the PLL through instantiation. Regardless of the method selected, the following information is necessary to program the PLL:

- Reference clock period
- Output clock frequencies (up to six maximum)
- Output clock duty cycle (default is 50%)
- Output clock phase shift relative in number of clock cycles relative to the fastest output clock.
- Desired bandwidth of the PLL (default is OPTIMIZED and the bandwidth is chosen in software)
- Compensation mode (automatically determined by the software)
- Reference clock jitter in UI (i.e., a percentage of the reference clock period)

Determine the Input Frequency

The first step is to determine the input frequency. This allows all possible output frequencies to be determined by using the minimum and maximum input frequencies to

define the D counter range, the VCO operating range to determine the M counter range, and the output counter range since it has no restrictions. There can be a very large number of frequencies. In the worst case, there will be 128 x 128 x 128 = 2,097,152 possible combinations. In reality, the total number of different frequencies is less since the entire range of the M and D counters cannot be realized and there is overlap between the various settings. As an example, consider F_{IN} = 100 MHz. If the minimum PFD frequency is 19 MHz, then D can only go from 1 to 5. For D = 1, M can only have values from four to 10. If D = 2, M can have values from 8 to 20. In addition, D = 1 M = 4 is a subset of D = 2 M = 8 allowing the D = 2 M = 8 case to be dropped.

This drastically reduces the number of possible output frequencies. The output frequencies are sequentially selected. The desired output frequency should be checked against the possible output frequencies generated. Once the first output frequency is determined, an additional constraint can be imposed on the values of M and D. This can further limit the possible output frequencies for the second output frequency. Continue this process until all the output frequencies are selected.

The constraints used to determine the allowed M and D values are shown in the following equations:

$$D_{MIN} = roundup\frac{f_{IN}}{f_{PFD\ MAX}} \quad \text{Equation 3-10}$$

$$D_{MAX} = rounddown\frac{f_{IN}}{f_{PFD\ MIN}} \quad \text{Equation 3-11}$$

$$M_{MIN} = \left(roundup\frac{f_{VCOMIN}}{f_{IN}}\right) \times D_{MIN} \quad \text{Equation 3-12}$$

$$M_{MAX} = rounddown\frac{D_{MAX} \times f_{VCOMAX}}{f_{IN}} \quad \text{Equation 3-13}$$

Determine the M and D Values

Determining the input frequency can result in several possible M and D values. The next step is to determine the optimum M and D values. The starting M value is first determined. This is based off the VCO target frequency, the ideal operating frequency of the VCO.

$$M_{IDEAL} = \frac{D_{MIN} \times f_{VCOMAX}}{f_{IN}} \quad \text{Equation 3-14}$$

The goal is to find the M value closest to the ideal operating point of the VCO. The minimum D value is used to start the process. The goal is to make D and M values as small as possible while keeping f_{VCO} as high as possible.

PLL Ports

Table 3-4 summarizes the PLL ports. Table 3-5 lists the PLL attributes.

Table 3-4: **PLL Ports**

Pin Name	I/O	Pin Description
CLKIN	Input	General clock input.
CLKIN1	Input	PLL_ADV pin used for retargeting. General clock input.
CLKIN2	Input	PLL_ADV pin used for retargeting. Secondary clock input.
CLKFBIN	Input	Feedback clock input.
CLKINSEL	Input	PLL_ADV pin used for retargeting. Connect to a static High or static Low to control the choice of clock input for PLL_ADV. High = CLKIN1, Low = CLKIN2.
RST	Input	Asynchronous reset signal. The RST signal is an asynchronous reset for the PLL. The PLL will synchronously re-enable itself when this signal is released (i.e., PLL re-enabled). A reset is required when the input clock conditions change (e.g., frequency).
CLKOUT[0:5](1)	Output	User configurable clock outputs (0 through 5) that can be divided versions of the VCO phase outputs (user controllable) from 1 (bypassed) to 128. The input clock and output clocks are phase aligned.
CLKFBOUT	Output	Dedicated PLL feedback output.
CLKOUTDCM[0:5](1)	Output	PLL_ADV pin used for retargeting. User configurable clocks (0 through 5) that can only connect to the DCM within the same CMT as the PLL.
CLKFBDCM	Output	PLL_ADV pin used for retargeting. PLL feedback used to compensate if the PLL is driving the DCM. If the CLKFBOUT pin is used for this purpose, the software will automatically map to the correct port.
LOCKED	Output	Asynchronous output from the PLL that indicates when the PLL has achieved phase alignment within a predefined window and frequency matching within a predefined PPM range. The PLL automatically locks after power on, no extra reset is required. LOCKED will be deasserted if the input clock stops or the phase alignment is violated (e.g., input clock phase shift). The PLL must be reset after LOCKED is deasserted.
DO[15:0]	Output	PLL_ADV pin not supported.
DRDY	Output	PLL_ADV pin not supported.

Notes:

1. $CLKOUT_N$ and $CLKOUTDCM_N$ are utilizing the same output counters and can not be operated independently.

PLL Attributes

Table 3-5: **PLL Attributes**

Attribute	Type	Allowed Values	Default	Description
COMPENSATION	String	SYSTEM_SYNCHRONOUS SOURCE_SYNCHRONOUS EXTERNAL	SYSTEM_ SYNCHRONOUS	Specifies the PLL phase compensation for the incoming clock. SYSTEM_SYNCHRONOUS attempts to compensate all clock delay for 0 hold time. SOURCE_SYNCHRONOUS is used when a clock is provided with data and thus phased with the clock. EXTERNAL is used to compensate by routing the clock external to the FPGA. Additional attributes automatically selected by the ISE software: INTERNAL DCM2PLL PLL2DCM
BANDWIDTH	String	HIGH LOW OPTIMIZED	OPTIMIZED	Specifies the PLL programming algorithm affecting the jitter, phase margin and other characteristics of the PLL.
CLKOUT[0:5]_DIVIDE	Integer	1 to 128	1	Specifies the amount to divide the associated CLKOUT clock output if a different frequency is desired. This number in combination with the CLKFBOUT_MULT and DIVCLK_DIVIDE values will determine the output frequency.
CLKOUT[0:5]_PHASE	Real	–360.0 to 360.0	0.0	Allows specification of the output phase relationship of the associated CLKOUT clock output in number of degrees offset (i.e., 90 indicates a 90° or ¼ cycle offset phase offset while 180 indicates a 180° offset or ½ cycle phase offset). When setting CLK_FEEDBACK = CLKOUT0, phase shifting results in a negative phase shift of all remaining clock outputs.
CLKOUT[0:5]_ DUTY_CYCLE	Real	0.01 to 0.99	0.50	Specifies the Duty Cycle of the associated CLKOUT clock output in percentage (i.e., 0.50 will generate a 50% duty cycle).
CLKFBOUT_MULT	Integer	1 to 64	1	Specifies the amount to multiply all CLKOUT clock outputs if a different frequency is desired. This number, in combination with the associated CLKOUT#_DIVIDE value and DIVCLK_DIVIDE value, will determine the output frequency.

Table 3-5: **PLL Attributes *(Cont'd)***

Attribute	Type	Allowed Values	Default	Description
DIVCLK_DIVIDE	Integer	1 to 52	1	Specifies the division ratio for all output clocks with respect to the input clock.
CLKFBOUT_PHASE	Real	0.0 to 360.0	0.0	Specifies the phase offset in degrees of the clock feedback output. Shifting the feedback clock results in a negative phase shift of all output clocks to the PLL.
REF_JITTER	Real	0.000 to 0.999	0.100	Allows specification of the expected jitter on the reference clock in order to better optimize PLL performance. A bandwidth setting of OPTIMIZED will attempt to choose the best parameter for input clocking when unknown. If known, then the value provided should be specified in terms of the UI percentage (the maximum peak to peak value) of the expected jitter on the input clock.
CLKIN1_PERIOD	Real	1.408 to 52.630	0.000	Specifies the input period in ns to the PLL CLKIN1 input. Resolution is down to the ps. This information is mandatory and must be supplied.
CLKIN2_PERIOD	Real	1.408 to 52.630	0.000	Specifies the input period in ns to the PLL CLKIN2 input. Resolution is down to the ps. This information is mandatory and must be supplied.
CLK_FEEDBACK	String	CLKFBOUT or CLKOUT0	CLKFBOUT	Specifies the clock source to drive CLKFB_IN. See Figure 3-5, page 86 for correct usage of feedback resources and calculating VCO frequency.
RESET_ON_LOSS _OF_LOCK	String	FALSE	FALSE	Must be set to FALSE, not supported in silicon.

PLL Clock Input Signals

The PLL clock source can come from several sources including:

- IBUFG - Global clock input buffer, the PLL will compensate the delay of this path.
- BUFG - Internal global clock buffer, the PLL will not compensate the delay of this path.
- IBUF - Not recommended since the PLL can not compensate for the delay of the general route. An IBUF clock input must route to a BUFG before routing to a PLL.
- DCMOUT - Any DCM output to PLL will compensate the delay of this path.
- BUFIO2 - When used with IBUFG, the DIVCLK output directly connects to the PLL clock input. The PLL compensates for this delay.

When global clock inputs are used to connect to a PLL, a BUFIO2 clock buffer will be inferred for optimal performance, as shown in Figure 1-13, page 30. Each BUFIO2 either routes to the CMT on the top-half or the bottom-half of the device. The inferred BUFIO2 buffer can restrict routing to ensure proper phase alignment.

BUFIO2 buffers from BUFIO2 clocking regions TL, TR, RT, and LT route to the DCM/PLL on the top half of the device. Similarly, BUFIO2 buffers BUFIO2 clocking regions BL, BR, RB, and LB connect to the DCM/PLL on the bottom half of the device.

Counter Control

The PLL output counters provide a wide variety of synthesized clocks using a combination of DIVIDE, DUTY_CYCLE, and PHASE. Figure 3-8 illustrates how the counter settings impact the counter output.

The top waveform represents the output from the VCO in PLL mode.

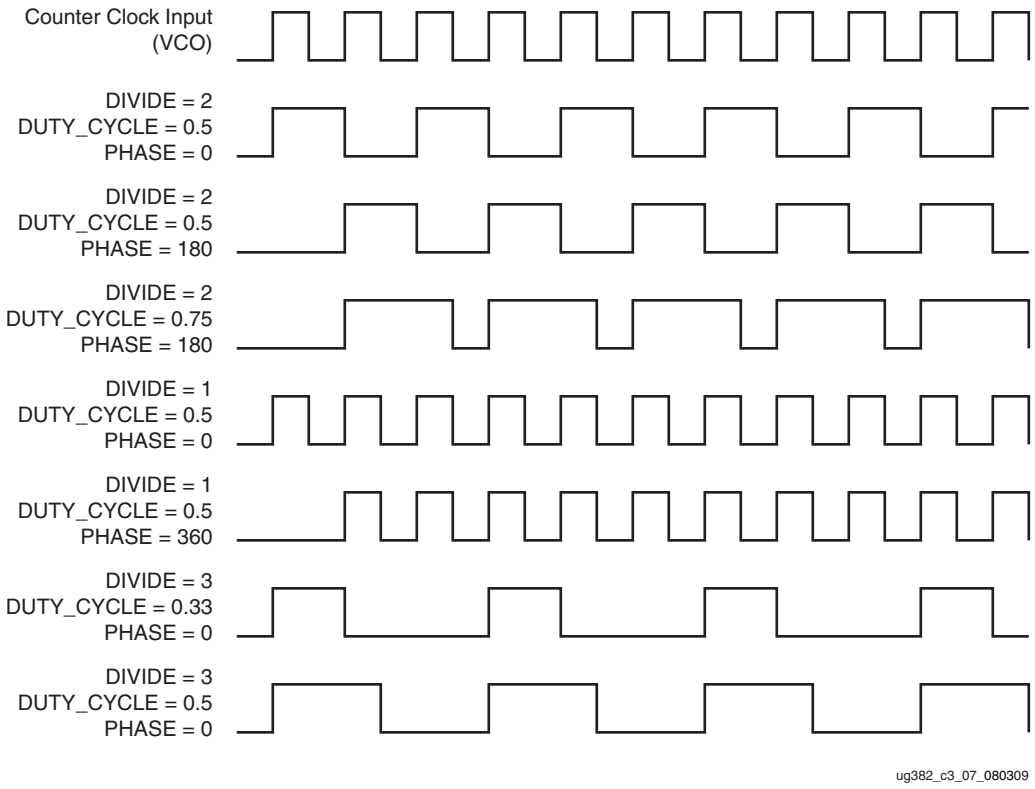


Figure 3-8: **Output Counter Clock Synthesis Examples**

Clock Shifting

The PLL output clocks can be shifted by inserting delay by selecting one of the eight phases in either the reference or the feedback path. Figure 3-9 shows the effect on a clock signal edge at the output of the PLL without any shifting versus the two cases (delay inserted in the feedback path and delay inserted in the reference path).

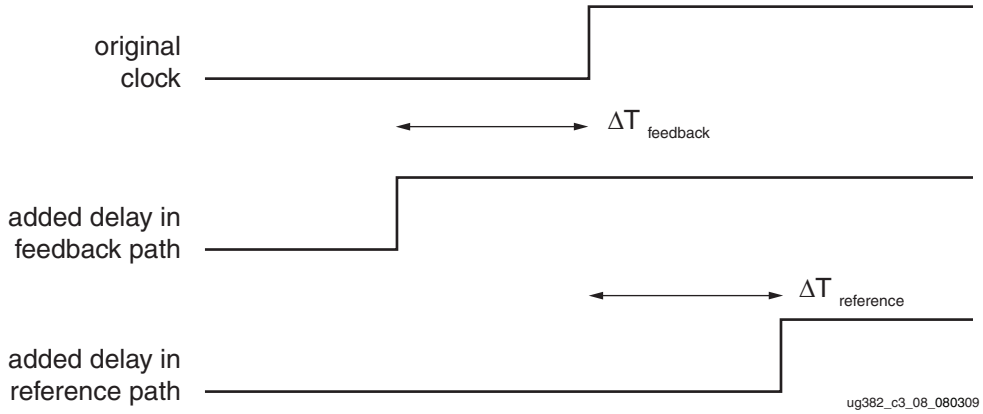


Figure 3-9: **Basic Output Clock Shifting**

Detailed VCO and Output Counter Waveforms

Figure 3-10 shows the eight VCO phase outputs and four different counter outputs. Each VCO phase is shown with the appropriate start-up sequence. The phase relationship and start-up sequence are guaranteed to insure the correct phase is maintained. This means the rising edge of the 0° phase will happen before the rising edge of the 45° phase. The O0 counter is programmed to do a simple divide by two with the 0° phase tap as the reference clock. The O1 counter is programmed to do a simple divide by two but uses the 180° phase tap from the VCO. Phase shifts greater than one VCO period are possible. This counter setting could be used to generate a clock for a DDR interface where the reference clock is edge aligned to the data transition. The O2 counter is programmed to do a divide by three. The O3 output has the same programming as the O2 output except the phase is set for a one cycle delay.

If the PLL is configured to provide a certain phase relationship and the input frequency is changed, then this phase relationship is also changed since the VCO frequency changes and therefore the absolute shift in picoseconds will change. This aspect must be considered when designing with the PLL. When an important aspect of the design is to maintain a certain phase relationship amongst various clock outputs, (e.g., CLK and CLK90) then this relationship will be maintained regardless of the input frequency.

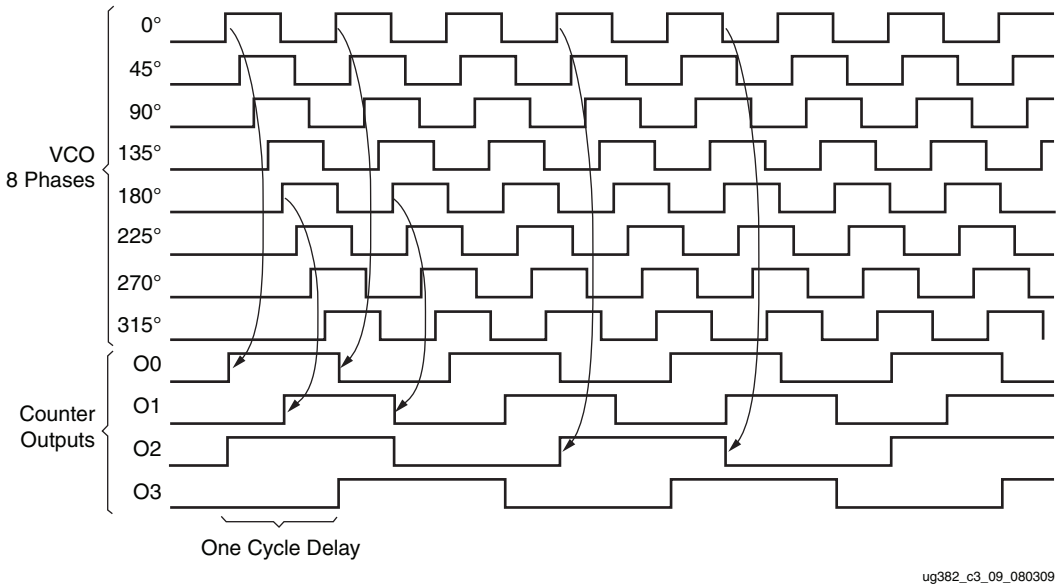


Figure 3-10: **Selecting VCO Phases**

All "O" counters are equivalent, anything O0 can do, O1 can do. The PLL outputs are flexible when connecting to the global clock network since they are identical. In most cases, this level of detail is imperceptible to the designer as the software and clocking wizard determines the proper settings through the PLL attributes and Wizard inputs.

Missing Input Clock or Feedback Clock

When the input clock or feedback clock is lost, the PLL will drive the output clocks to a lower or higher frequency, causing all of the output clocks to increase/decrease in frequency. The frequency increase/decrease can cause the clock output frequencies to change to as much as six times the original configuration.

PLL Use Models

There are several methods to design with the PLL. The clocking wizard in ISE software can assist with generating the various PLL parameters. Additionally, the PLL can be manually instantiated as a component. It is also possible for the PLL to be merged with an IP core. The IP core would contain and manage the PLL.

Clock Network Deskew

One of the predominant uses of the PLL is for clock network deskew. Figure 3-11 shows the PLL in this mode. The clock output from one of the O counters is used to drive logic within the fabric and/or the I/Os. The feedback counter is used to control the exact phase relationship between the input clock and the output clock (if, for example a 90° phase shift is required). The associated clock waveforms are shown to the right for the case where the input clock and output clock need to be phase aligned. This configuration is the most flexible, but it does require two global clock networks (Figure 3-11).

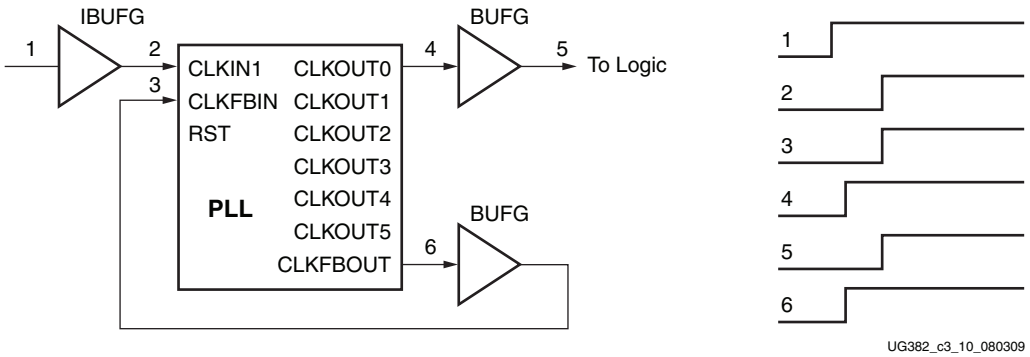


Figure 3-11: **Clock Deskew Using Two BUFGs**

There are certain restrictions on implementing the feedback. The CLKFBOUT output can be used to provide the feedback clock signal. The fundamental restriction is that both input frequencies to the PFD must be identical. Therefore, the following relationship must be met:

$$\frac{f_{IN}}{D} = f_{FB} = \frac{f_{VCO}}{M} \qquad \textit{Equation 3-15}$$

As an example, if f_{IN} is 166 MHz, D = 1, M = 3, and O = 1, then VCO and the clock output frequency are both 498 MHz. Since the M value in the feedback path is 3, both input frequencies at the PFD are 166 MHz.

In another more complex scenario has an input frequency of 66.66 MHz and D = 2, M = 15, and O = 2. The VCO frequency in this case is 500 MHz and the O output frequency is 250 MHz. Therefore, the feedback frequency at the PFD is 500/15 or 33.33 MHz, matching the 66.66MHz/2 input clock frequency at the PFD.

PLL with Internal Feedback

The PLL feedback can be internal to the PLL when the PLL is used as a synthesizer or jitter filter and there is no required phase relationship between the PLL input clock and the PLL output clock. The PLL performance should increase since the feedback clock is not subjected to noise on the core supply since it never passes through a block powered by this supply. Of course, noise introduced on the CLKIN signal and the BUFG will still be present (Figure 3-12).

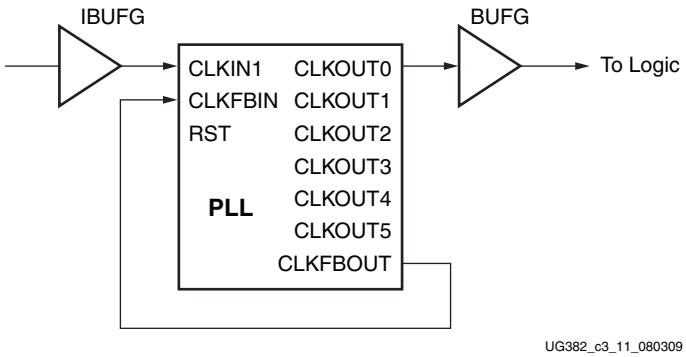


Figure 3-12: **PLL with Internal Feedback**

Zero Delay Buffer

The PLL can also be used to generate a zero delay buffer clock. A zero delay buffer can be useful for applications where there is a single clock signal fan out to multiple destinations with a low skew between them. This configuration is shown in Figure 3-13. Here, the feedback signal drives off chip and the board trace feedback is designed to match the trace to the external components. In this configuration, it is assumed that the clock edges are aligned at the input of the FPGA and the input of the external component. There will be a limitation on the maximum delay allowed in the feedback path.

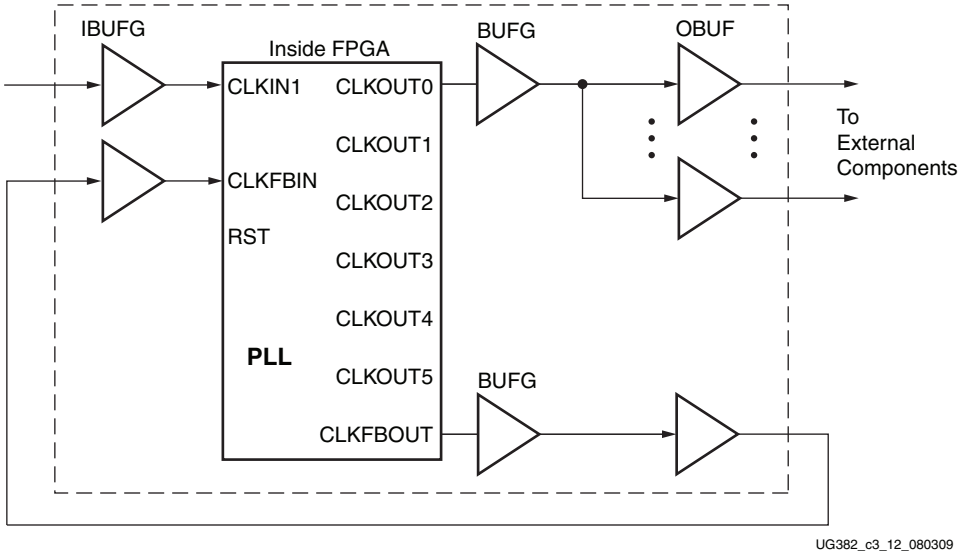


Figure 3-13: **Zero Delay Buffer**

In some cases precise alignment will not occur because of the difference in loading between the input capacitance of the external component and the feedback path capacitance of the FPGA. For example, the external components can have an input capacitance on 1 pF to 4 pF while the FPGA has an input capacitance of around 8 pF. There is a difference in the signal slope, which is basically skew. Designers need to be aware of this effect to ensure timing.

DCM Driving PLL

The DCM provides an excellent method for generating precision phase-shifted clocks. However, the DCM cannot reduce the jitter on the reference clock. The PLL can be used to reduce the output jitter of one DCM clock output. This configuration is shown in Figure 3-14. The PLL is configured to not introduce any phase shift (zero delay through the PLL). The associated waveforms are shown to the right of the block diagram. When the output of the DCM is used to drive the PLL directly, both DCM and PLL *must* reside within the same CMT block. This is the preferred implementation since it produces a minimal amount of noise on the local, dedicated route. However, a connection can also be made by connecting the DCM to a BUFG and then to the CLKIN input of a PLL.

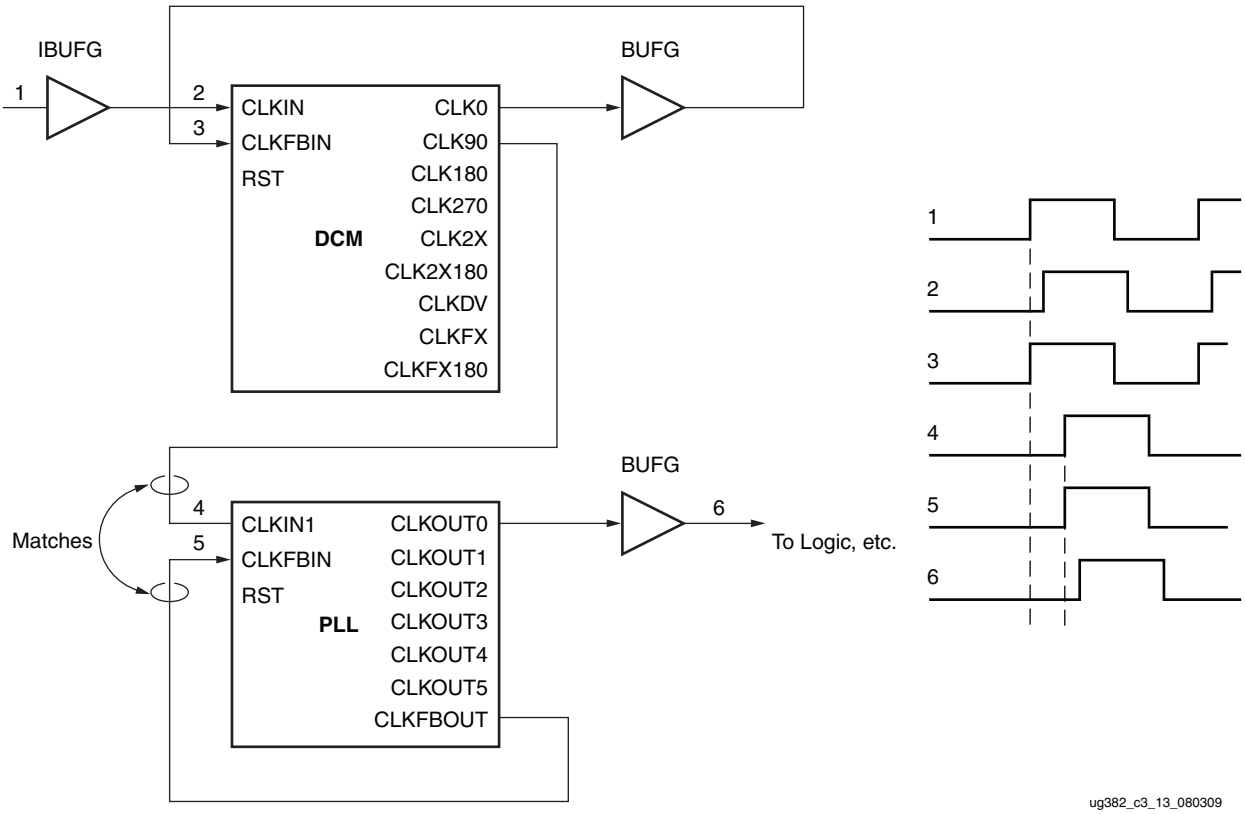


Figure 3-14: **DCM Driving a PLL**

PLL Driving DCM

A second option for reduce clock jitter is to use the PLL to clean-up the input clock jitter before driving into the DCM. This will improve the output jitter of all DCM outputs, but any added jitter by the DCM will still be passed to the clock outputs. Both PLL and DCM should reside in the same CMT block because dedicated resources exist between the PLL and DCM to support the zero delay mode. When the PLL and DCM do not reside in the same CMT, then the only connection is through a BUFG hindering the possibility of deskew.

One PLL can drive multiple DCMs as long as the reference frequency can be generated by a single PLL. For example, if a 33 MHz reference clock is driven into the PLL, and the design uses one DCM to operate at 200 MHz and the other to run at 100 MHz, then the VCO can be operated at 600 MHz (M1 = 18). The VCO frequency can be divided by three to generate a 200 MHz clock and another counter can be divided by six to generate the 100 MHz clock. For the example in Figure 3-15, one PLL drives two DCMs.

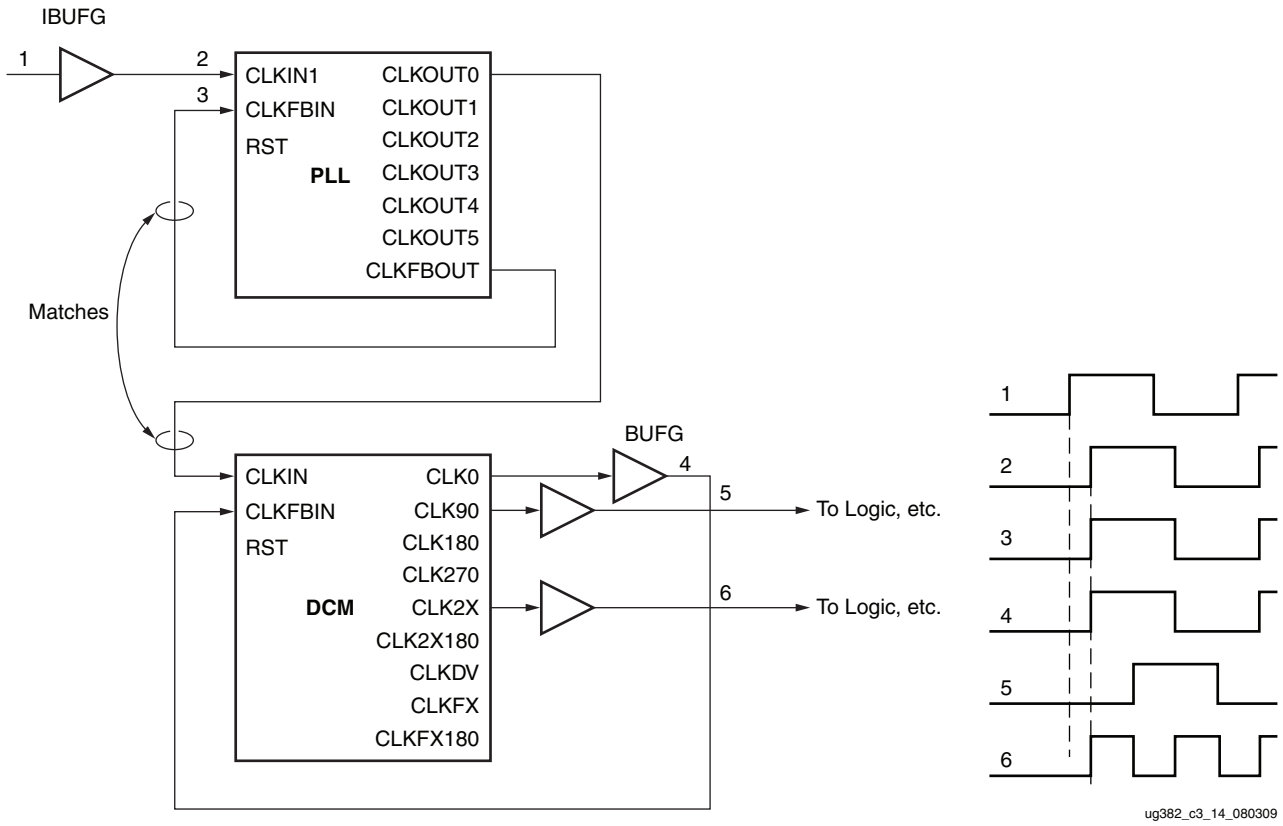


Figure 3-15: **PLL Driving a DCM**

PLL to PLL Connection

The PLL can be cascaded to allow generation of a greater range of clock frequencies. The frequency range restrictions still apply. Equation 3-16 shows the relationship between the final output frequency and the input frequency and counter settings of the two PLLs (Figure 3-16.) The phase relationship between the output clock of the second PLL and the input clock is undefined.To cascade PLLs, route the output of the first PLL to a BUFG and then to the CLKIN pin of the second PLL. This path provides the lowest device jitter.

$$f_{OUTPLL2} = f_{OUTPLL1}\frac{M_{PLL2}}{D_{PLL2} \times O_{PLL2}} = f_{IN}\frac{M_{PLL1}}{D_{PLL1} \times O_{PLL1}} \times \frac{M_{PLL2}}{D_{PLL2} \times O_{PLL2}} \quad \text{Equation 3-16}$$

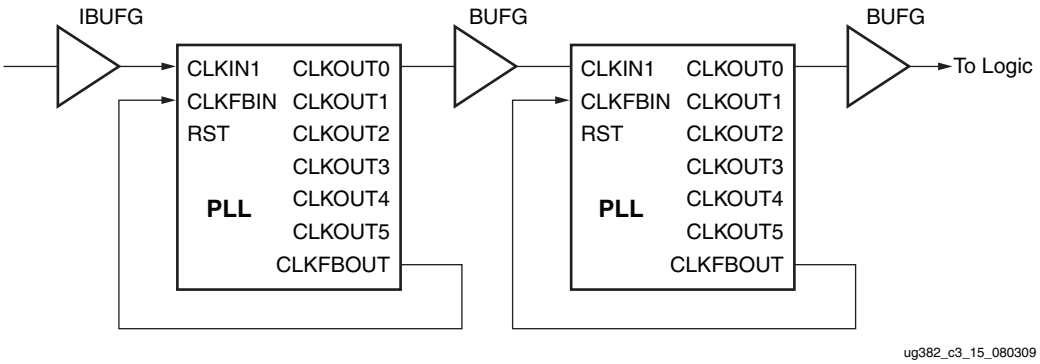


Figure 3-16: **Cascading Two PLLs**

Application Guidelines

This section summarizes when to select a DCM over a PLL, or a PLL over a DCM.

Spartan-6 FPGA PLLs support up to six independent outputs. Designs using several different outputs should use PLLs. An example of designs using several different outputs follows. The PLL is an ideal solution for this type of application because it can generate a configurable set of outputs over a wide range while the DCM has a fixed number of predetermined outputs based off the reference clock. When the application requires a fine phase shift or a dynamic variable phase shift, a DCM could be a better solution.

PLL Application Example

The following PLL attribute settings result in a wide variety of synthesized clocks:

```
CLKOUT0_PHASE = 0;
CLKOUT0_DUTY_CYCLE = 0.5;
CLKOUT0_DIVIDE = 2;
CLKOUT1_PHASE = 90;
CLKOUT1_DUTY_CYCLE = 0.5;
CLKOUT1_DIVIDE = 2;
CLKOUT2_PHASE = 0;
CLKOUT2_DUTY_CYCLE = 0.25;
CLKOUT2_DIVIDE = 4;
CLKOUT3_PHASE = 90;
CLKOUT3_DUTY_CYCLE = 0.5;
CLKOUT3_DIVIDE = 8;
CLKOUT4_PHASE = 0;
CLKOUT4_DUTY_CYCLE = 0.5;
CLKOUT4_DIVIDE = 8;
CLKOUT5_PHASE = 135;
CLKOUT5_DUTY_CYCLE = 0.5;
CLKOUT5_DIVIDE = 8;
CLKFBOUT_PHASE = 0;
CLKFBOUT_MULT = 8;
DIVCLK_DIVIDE = 1;
CLKIN1_PERIOD = 10.0;
```

Figure 3-17 displays the resulting waveforms.

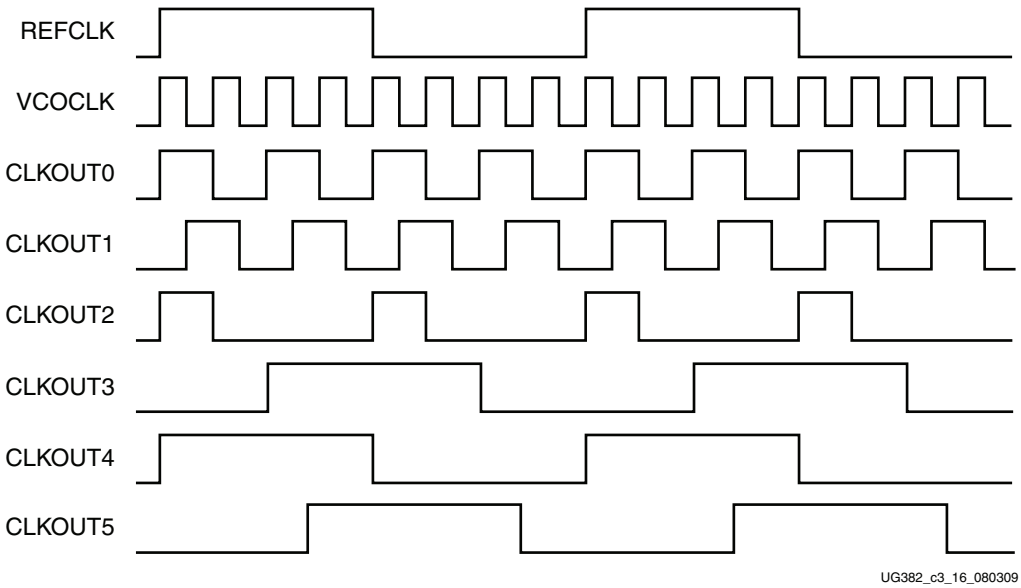


Figure 3-17: **Example Waveform**