

# Divider Generator v5.1

## *LogiCORE IP Product Guide*

**Vivado Design Suite**

**PG151 October 5, 2016**

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## Introduction

The Xilinx® LogiCORE™ IP Divider Generator core creates a circuit for integer division based on Radix-2 non-restoring division, or High Radix division with prescaling. The Radix-2 algorithm exploits FPGA logic to achieve a range of throughput options that includes single cycle, and the High Radix algorithm exploits DSP slices at lower throughput, but with reuse to reduce resources.

## Features

- AXI4-Stream-compliant interfaces.
- Integer division with operands of up to 64 bits wide.
- Offers Radix-2, LUTMult and High Radix implementation algorithms to allow choice of resource and latency trade-offs.
- Optional operand widths, synchronous controls, and selectable latency.
- Optional divide by zero detection.
- C model for system-level simulation (bit accurate with core except for division by zero).

LogiCORE IP Facts Table	
<b>Core Specifics</b>	
Supported Device Family <sup>(1)</sup>	UltraScale+™ UltraScale™ Zynq®-7000 All Programmable SoC 7 Series
Supported User Interfaces	AXI4-Stream
Resources	<a href="#">Performance and Resource Utilization web page</a>
<b>Provided with Core</b>	
Design Files	Encrypted RTL
Example Design	Not Provided
Test Bench	VHDL
Constraints File	Not Provided
Simulation Model	Encrypted VHDL C Model
Supported S/W Driver	N/A
<b>Tested Design Flows<sup>(2)</sup></b>	
Design Entry	Vivado® Design Suite System Generator for DSP
Simulation	For supported simulators, see the <a href="#">Xilinx Design Tools: Release Notes Guide</a> .
Synthesis	Vivado Synthesis
<b>Support</b>	
Provided by Xilinx at the <a href="#">Xilinx Support web page</a>	

### Notes:

1. For a complete list of supported devices, see the Vivado IP catalog.
2. For the supported versions of the tools, see the [Xilinx Design Tools: Release Notes Guide](#).

## Overview

Three implementations of division are supported by Divider Generator:

- **LUTMult.** A simple lookup estimate of the reciprocal of the divisor followed by a multiplier. Only remainder output type is supported because of the bias required in the reciprocal estimate. This bias would introduce an offset (error) if used to create a fractional output. This is recommended for operand widths less than or equal to 12 bits. This implementation uses DSP slices, block RAM and a small amount of FPGA logic primitives (registers and LUTs). For operand widths where either Radix2 or the LUTMult options are possible, the LUTMult solution offers a solution using fewer FPGA logic resources because of the use of DSP and block RAM primitives.
- **Radix-2.** Radix-2 non-restoring integer division using integer operands, allowing either a fractional or an integer remainder to be generated. This is recommended for operand widths less than around 16 bits or for applications requiring high throughput. The implementation uses FPGA logic primitives (registers and LUTs). The Radix2 solution does not use DSP or block RAM primitives, so this implementation is recommended when these primitives are needed elsewhere.
- **High Radix.** High Radix division with prescaling. This is recommended for operand widths greater than around 16 bits. This implementation uses DSP slices and block RAMs.

A detailed explanation of each implementation is provided in [LUTMult Solution](#), [Radix-2 Solution](#) and [High Radix Solution](#).

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## Feature Summary

### LUTMult Solution

- Provides quotient with integer remainder
- Pipelined, parallel architecture for increased throughput
- Configurable latency
- Dividend width from 2 to 17 bits

- Divisor width from 2 to 12 bits (sum of dividend width and divisor width limited to 23 bits)
- Independent dividend and divisor bit widths
- Fully synchronous design using a single clock
- Supports unsigned or twos complement signed numbers

## Radix-2 Solution

- Provides quotient with integer or fractional remainder
- Pipelined, parallel architecture for increased throughput
- Pipeline reduction for size versus throughput selections
- Dividend width from 2 to 64 bits
- Divisor width from 2 to 64 bits
- Independent dividend, divisor and fractional bit widths
- Fully synchronous design using a single clock
- Supports unsigned or twos complement signed numbers
- Can implement 1/X (reciprocal) function

## High Radix Solution

- High Radix division enabled by prescaling
- Provides quotient and, optionally, fractional outputs
- Configurable widths, synchronous controls, selectable latency and detection of division by zero
- Uses DSP Slices

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## Applications

Division is the most complex of the four basic arithmetic operations. Because hardware solutions are correspondingly larger and more complex than the solutions for other operations, it is best to minimize the number of divisions in any algorithm. There are many forms of division implementation, each of which can offer the optimal solution in different circumstances.

The Divider Generator core provides three division algorithms, offering a portfolio of solutions to allow trade-offs between throughput, latency and resource use.

The LUTMult solution uses a simple lookup estimate of the reciprocal of the divisor followed by a multiplication by the dividend. The implementation is fully pipelined and can achieve throughput of one operation per clock cycle. FPGA logic resources use can be minimized by configuring the latency to be less than fully pipelined at the expense of achievable clock speed.

The Radix-2 non-restoring algorithm solves one bit of the quotient per cycle using addition and subtraction. The design is fully pipelined, and can achieve a throughput of one division per clock cycle. If full throughput is not required, the divisions per clock parameter can be set to 2, 4 or 8. This causes an iterative solution to be generated which uses less resource by re-using the calculation engine. This algorithm naturally generates a remainder, so is the choice for applications requiring integer remainders or modulus results.

The High Radix with prescaling algorithm resolves multiple bits of the quotient at a time. It is implemented as an iterative engine and so throughput is a function of the number of iterations required. The prescaling prior to the iterative operation causes an overhead of resource which makes this algorithm less suitable for smaller operands. Although the iterative calculation is more complex than for Radix-2, taking more cycles to perform, the number of bits of quotient resolved per iteration and its use of DSP slices makes this the preferred option for larger operand widths.

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## Licensing and Ordering Information

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

# Product Specification

The Divider Generator core uses one of three implementations. The LUTMult is recommended for very small operand widths, for high throughput and where slice use must be minimized. The Radix-2 solution is recommended for smaller operand widths, for high throughput, or situations where DSP slice use must be minimized. The High Radix solution is recommended for larger operand widths. Because the solutions differ in many aspects of parameter ranges, throughput, and latency, they are described in this chapter separately.

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## Performance

This section details the performance information for various core configurations.

### Maximum Frequencies

For details about maximum frequencies, visit [Performance and Resource Utilization](#).

### Latency

The latency of the divider core is a function of the AXI4-Stream configuration parameters and the latency of the algorithm selected. Latency is only a constant when the AXI4-Stream mode is set to Non-Blocking and when the core algorithm and throughput are set such that one sample is input per clock cycle. If the core is set to accept data only one in N cycles, then data is only accepted on cycles N, 2N, 3N, .... It is not the case that data is accepted immediately as long as  $\geq N$  cycles have passed since the previous input. Hence, latency appears to be increased if data is presented before the core is able to accept it. Another effect which can cause latency to vary and increase is if full AXI4-Stream behavior is selected. This is because a FIFO is used to manage data for this mode and the depth of the FIFO adds to the latency. However, it should be noted that the intention of selecting AXI4-Stream is to replace the need to balance latency with a handshake which manages data flow at runtime, so latency should be less of a consideration. Because latency can vary due to these effects, only minimum latency can be determined as a constant for any given configuration of the core. In the following sections the latency of the algorithm alone is discussed.

#### ***LUTMult***

The latency of the fully pipelined LUTMult is 8.



## Radix-2

The latency (number of enabled clock cycles required before the core generates the first valid output) for a fully pipelined divider is a function of the bit width of the dividend. If fractional output is required, the fully pipelined latency is also a function of the fractional bit width. In general:

- Fully pipelined latency is of the order M for integer remainder dividers, where M is the width of the Quotient
- Fully pipelined latency is of the order M + F for fractional remainder dividers where F is the width of the Fractional output

Table 2-1 provides a list of the fully pipelined latency formula for divider selections. With full pipelining, maximum possible performance is achieved. When clocks per division is 1, latency can be set manually to a figure between 0 and the value shown in Table 2-1. This allows the latency of the core to be reduced at the expense of reducing the maximum clock frequency at which the core can be clocked. Reducing the latency reduces the number of registers used, but the LUT count remains approximately the same.

Table 2-1: Latency of Radix-2 Solution Based on Divider Parameters

Signed	Fractional	Clocks Per Division	Fully Pipelined Latency <sup>(1)</sup>
FALSE	FALSE	1	M+A+2
FALSE	FALSE	>1	M+A+3
FALSE	TRUE	1	M+F+A+2
FALSE	TRUE	>1	M+F+A+3
TRUE	FALSE	1	M+A+4
TRUE	FALSE	>1	M+A+5
TRUE	TRUE	1	M+F+A+4
TRUE	TRUE	>1	M+F+A+5

**Notes:**

1. M = Dividend and Quotient Width, F = Fractional Width, A = total Latency of AXI interfaces.

## High Radix Solution

Tables 2-2 and 2-3 show latency for the High Radix solution. To this, add 0 for NonBlocking mode, 1 for Blocking mode with no output `tredy` and 3 for Blocking mode with output `tredy`.

Table 2-2: Minimum Latency of High Radix Solution Based on Divider Parameters

Dividend and Quotient Width + Fractional Width					
4 to 12	13 to 26	27 to 40	41 to 54	55 to 68	69 to 82
2	3	4	5	6	7

Table 2-3: Maximum Latency of High Radix Solution Based on Divider Parameters

Divisor Width	Dividend and Quotient Width + Fractional Width					
	4 to 12	13 to 26	27 to 40	41 to 54	55 to 68	69 to 82
4 to 8	16	20	24	29	33	37
9 to 18	17	21	25	30	34	38
19 to 32	18	22	26	31	35	39
33 to 35	19	23	27	32	36	40
36 to 48	20	24	28	33	37	41
49 to 52	22	26	30	35	39	43
53 to 54	23	27	31	36	40	44

## Throughput

### ***LUTMult Solution***

This solution always supports full throughput.

### ***Radix-2 Solution***

The Clocks per Division parameter allows a range of choices of throughput versus resources. With Clocks per Division set to 1, the core is fully pipelined, so it has maximal throughput of one division per clock cycle, but uses the most resources. Clock per Division settings of 2, 4, and 8 reduce the throughput by those respective factors for smaller core sizes.

AXI interfaces give an additional latency of 0 for Non-Blocking, 1 for Blocking with no output `tready` and 3 for Blocking with output `tready` (`m_axis_dout_tready`). However, when Blocking mode is selected, latency varies by run time.

### ***High Radix Solution***

The iterative process is implemented as a loop rather than an unrolled data pipeline to reduce resources. This means that new input must be held off until previous calculations are finished within the iterative circuit. The maximum possible throughput is therefore  $1/N$  divisions per clock, where  $N$  is the number of iterations required. However, to achieve this maximum throughput the input might be required to be bursty. This is because the iterative engine can be pipelined with each stage of the pipe offering a carousel place for interlaced divisions.

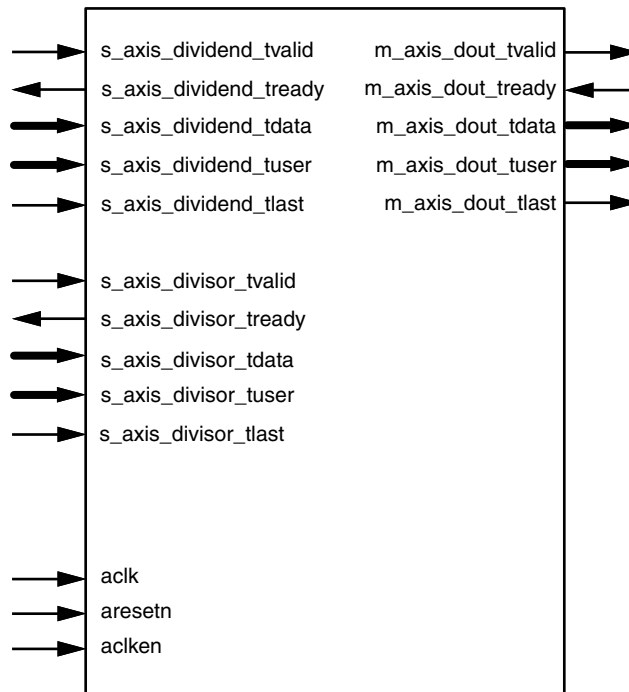
With the addition of AXI4-Stream interfaces, average throughput is unchanged. The Blocking modes provide an element of FIFO buffering to the data, so it is not possible to make deterministic predictions of when the core is ready to accept new data. For NonBlocking mode timing is more predictable. The Divider Generator interface in the Vivado IDE provides feedback of the rate (1 in  $N$ ) at which the divider can accept input on a continuous basis with a constant interval. This is expressed on the *Throughput* field of the interface and is expressed in terms of 1 input every  $N$  enabled clock cycles.

## Resource Utilization

For details about resource utilization, visit [Performance and Resource Utilization](#).

## Port Descriptions

The core pinout and signal names are shown in [Figure 2-1](#) and defined in [Table 2-4](#).



DS819\_01\_030811

Figure 2-1: Core Pinout Diagram

Table 2-4: Signal Pinout

Signal	Direction <sup>(1)</sup>	Optional	Description
aclk	Input	No	Rising edge clock.
ACLKEN	Input	Yes	Active-High clock enable.
ARESETn	Input	Yes	Active-Low synchronous clear (optional, always take priority over ACLKEN) ARESETn should be asserted or deasserted for not less than two aclk cycles.
s_axis_dividend_tvalid	Input	No	tvalid for s_axis_dividend channel. See <a href="#">AXI4-Stream Considerations in Chapter 3</a> for protocol.
s_axis_dividend_tready	Output	Yes	tready for s_axis_dividend channel.

Table 2-4: Signal Pinout (Cont'd)

Signal	Direction <sup>(1)</sup>	Optional	Description
s_axis_dividend_tdata	Input	No	tdata for s_axis_dividend channel. See <a href="#">TDATA Packing in Chapter 3</a> for internal structure and width.
s_axis_dividend_tuser	Input	Yes	tuser for s_axis_dividend channel.
s_axis_dividend_tlast	Input	Yes	tlast for s_axis_dividend channel.
s_axis_divisor_tvalid	Input	No	tvalid for s_axis_divisor channel.
s_axis_divisor_tready	Output	Yes	tready for s_axis_divisor channel.
s_axis_divisor_tdata	Input	No	tdata for s_axis_divisor channel. See <a href="#">TDATA Packing in Chapter 3</a> for internal structure and width.
s_axis_divisor_tuser	Input	Yes	tuser for s_axis_divisor channel.
s_axis_divisor_tlast	Input	Yes	tlast for s_axis_divisor channel.
m_axis_dout_tvalid	Output	No	tvalid for m_axis_dout channel.
m_axis_dout_tready	Input	Yes	tready for m_axis_dout channel.
m_axis_dout_tdata	Output	No	tdata for m_axis_dout channel. See <a href="#">TDATA Packing in Chapter 3</a> for internal structure and width.
m_axis_dout_tuser	Output	Yes	tuser for m_axis_dout channel.
m_axis_dout_tlast	Output	Yes	tlast for m_axis_dout channel.

**Notes:**

1. Dividend and quotient width must be set to satisfy the largest possible quotient result. Due to the non-symmetry of two's complement representation bit growth from the dividend to quotient is possible, but only for the single combination of the most negative number divided by negative one (that is,  $-2^{(M-1)}/-1$ ). The width of dividend and quotient can be extended by 1 bit should this situation need to be accommodated.

# Designing with the Core

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

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## General Design Guidelines

The following sections provide details about the different divider solutions available in the core. These details allow you to select the core parameters to provide the optimum solution for your application.

### LUTMult Solution

This parameterized solution divides an M-bit-wide variable dividend by an N-bit-wide variable divisor. The output consists of the quotient and an integer remainder. The result of the division is an M-bit-wide quotient with an N-bit-wide integer remainder (Equation 3-1). When signed operation is selected, all operands and results employ a two's complement sign but, resulting in one less bit of magnitude result (Equation 3-3). The LUTMult solution supports an optional division by zero output. For division by zero, quotient and remainder results are undefined. The LUTMult solution always supports full throughput (one result per clock cycle). Latency can be configured up to the maximum required for full pipelining (beyond which further registers would not improve performance).

Because the LUTMult solution uses a constant finite precision estimate of the reciprocal to multiply the dividend and hence obtain the result, the maximum width of the divisor is a function of the width of the dividend. The sum of the operand widths is limited to 23 bits. The LUTMult solution handles negative operands in the same manner as the Radix2 solution in terms of the sign of the quotient and remainder.

### Radix-2 Solution

This parameterized solution divides an M-bit-wide variable dividend by an N-bit-wide variable divisor. The output consists of the quotient and either an integer remainder or fractional result (quotient continued past the binary point). In the integer remainder case, the result of the division is an M-bit-wide field for the quotient with an N-bit-wide field for the integer remainder (Equation 3-1). In the fractional case, the result is an M-bit-wide field for the quotient with an F-bit-wide field for the fractional part of the result (Equation 3-2).

When signed operation is selected, all operands and results employ a twos complement sign bit, resulting in one less bit of magnitude result (Equation 3-3).

Integer remainder case:

$$Dividend = Quotient \times Divisor + IntRmd \quad \text{Equation 3-1}$$

F-bit-wide fractional field in the unsigned case:

$$FractRmd = \frac{IntRmd \times 2^F}{Divisor} \quad \text{Equation 3-2}$$

F-bit-wide fractional field in the signed case:

$$FractRmd = \frac{IntRmd \times 2^{F-1}}{Divisor} \quad \text{Equation 3-3}$$

For signed mode with integer remainder, the sign of the quotient and remainder correspond exactly to Equation 3-1.

Thus,

$$6/-4 = -1 \text{ REMD } 2$$

whereas

$$-6/4 = -1 \text{ REMD } -2$$

For signed mode with fractional output, the sign bit is present both in the quotient and the fractional field. For example, for a five-bit dividend, divisor and fractional output:

$$-9/4 = 9/-4 = -(2 \frac{1}{4})$$

This corresponds to:

$$10111/00100 \text{ or } 01001/11100$$

Giving the result:

$$\text{Quotient} = 11110 (= -2)$$

$$\text{Remainder} = 11100 (= -1/4)$$

For division by zero, the quotient, remainder, and fractional results are undefined.

The core is highly pipelined. The throughput of the core is configurable and can be reduced from 1 clock cycle per division to 2, 4, or 8 clock cycles per division to reduce resources.

The dividend and divisor bit widths can be set independently. The bit width of the quotient is equal to the bit width of the dividend. The bit width of the integer remainder is equal to the width of the divisor. For fractional output, the remainder bit width is independent of the

dividend and divisor. The core handles data ranges of 2 to 64 bits for dividend, divisor, and fractional outputs.

The divider can be used to implement the reciprocal of X; that is the  $1/X$  function. To do this, the dividend bit width is set to 2 and fractional mode is selected. The dividend input is then tied to 01 for both unsigned or signed operation, and the X value is provided through the divisor input.

Following a power-on reset or `ARESETn`, the core outputs zeros on `QUOTIENT` and `FRACTIONAL` (see [TDATA Structure for Output \(DOUT\) Channel in Chapter 3](#)) outputs until new results appear.

## High Radix Solution

The High Radix implementation performs division by pre-scaling operands before employing an accelerated High Radix division algorithm. The design is fully pipelined for maximum clock frequency. First, the divisor is normalized, then an estimate of its reciprocal is made. Both operands are multiplied by this estimate to bring the divisor closer to 1. The precision and accuracy of the pre-scale determines how many bits of quotient can be resolved on each subsequent iteration. The fact that the pre-scaled divisor is close to one allows the estimate of new quotient bits to be just the top bits of the residue left from the previous iteration. The iterative operation itself is performed in carry-save notation, so that no long carry chains limit performance. Because only the top bits of the residue are used as the estimate and the divisor is not exactly 1, errors do occur in the internal result of each iteration; thus, the quotient bits resolved on each iteration overlap slightly with the previously resolved bits to allow correction of errors in subsequent iterations.

Because the iteration calculation consists of a carry-save multiplication and subtraction, it is ideally suited to the DSP (multiply-add) slices, providing an efficient, low-latency iteration.

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## Clocking

This core has only one clock and there are no special considerations nor clock domain crossing considerations.

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## Resets

The core can be reset using the `ARESETn` pin. This is a global synchronous, active-Low reset that must be asserted for at least two `ac1k` cycles. All control circuitry is returned to the power-on state. Data registers might or might not be reset, but outputs are qualified by `tvalid`. Any residue output in the `ac1k` cycles following reset and before `tvalid` is asserted can be ignored.

## Protocol Description

This core adheres to the AXI4-Stream specification. Details of the AXI4-Stream are provided in this section.

### AXI4-Stream Considerations

The conversion to AXI4-Stream interfaces brings standardization and enhances interoperability of Xilinx® LogiCORE™ IP solutions. Other than general control signals such as `ac1k`, `ACLKEN` and `ARESETn`, all inputs and outputs to the Divider Generator core are conveyed on AXI4-Stream channels. A channel consists of `tvalid` and `tdata` always, plus several optional ports and fields. In the Divider Generator core, the optional ports supported are `tready`, `tlast` and `tuser`. Together, `tvalid` and `tready` perform a handshake to transfer a message, where the payload is `tdata`, `tuser` and `tlast`. The Divider Generator core operates on the operands contained in the `tdata` fields and outputs the result in the `tdata` field of the output channel. The Divider Generator core does not use inputs, `tuser` and `tlast` as such, but the core provides the facility to convey these fields with the same latency as for `tdata`. The Divider Generator core does use the output `tuser` to hold the `divide_by_zero` indication signal. This facility of passing `tlast` and `tuser` from input to output is intended to ease use of the Divider Generator core in a system. For example, the Divider Generator core might operate on streaming packetized data. In this example, the core could be configured to pass the `tlast` of the packetized data channel, thus saving the system designer the effort of constructing a bypass path for this information.

For further details on AXI4-Stream Interfaces see the *Xilinx AXI Design Reference Guide* (UG761) [Ref 1] and the *AMBA® AXI4-Stream Protocol Specification* (ARM IHI 0051A) [Ref 2].

#### **Basic Handshake**

Figure 3-1 shows the transfer of data in an AXI4-Stream channel. `tvalid` is driven by the source (master) side of the channel and `tready` is driven by the receiver (slave). `tvalid` indicates that the value in the payload fields (`tdata`, `tuser` and `tlast`) is valid. `tready` indicates that the slave is ready to receive data. When both `tvalid` and `tready` are TRUE in a cycle, a transfer occurs. The master and slave set `tvalid` and `tready` respectively for the next transfer appropriately.



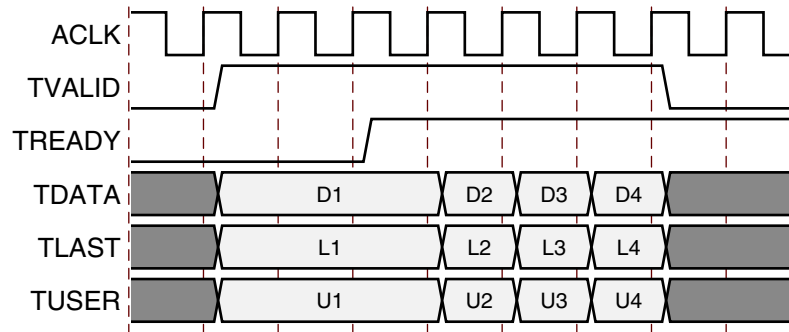


Figure 3-1: Data Transfer in an AXI-Stream Channel

### Non Blocking Mode

The Divider Generator core provides a mode intended to ease the migration from previous, non-AXI versions of this core. The term “Non-Blocking” is used to indicate that lack of data on one input channel does not cause incoming data on the other channel to be buffered. Also, back pressure from the output is not possible because in NonBlocking mode the output channel does not have a `tready` signal. The full flow control of AXI4-Stream is not always required. Blocking or Non-Blocking behavior is selected using the `FlowControl` parameter or user interface field. The choice of Blocking or NonBlocking applies to the whole core, not each channel individually. Channels still have the non-optional `tvalid` signal, which is analogous to the New Data (ND) signal on many cores prior to the adoption of AXI4-Stream. Without the facility to block dataflow, the internal implementation is much simplified, so fewer resources are required for this mode. This mode is recommended for users wishing to move to this version from a pre-AXI version with minimal change.

When all of the present input channels receive an active `tvalid` (and `tready`, if present, is asserted), an operation is validated and the output `tvalid` (suitably delayed by the latency of the core) is asserted to qualify the result. This is to allow a minimal migration from v3.0. If one channel receives `tvalid` and the other does not, then an operation does not occur, even if `tready` is present and asserted. Hence, unlike Blocking mode which is fully AXI4-Stream compliant, valid transactions on an individual channel can be ignored in NonBlocking mode.

For performance, `ARESETn` is registered internally, which delays its action by a clock cycle. The effect is that the cycle following the deassertion of `ARESETn` the core is still reset and does not accept input. `tvalid` is also inactive on the output channel for this cycle.

Figure 3-2 shows the NonBlocking mode in operation. For simplicity of illustration, the latency of the core is zero. As indicated by `s_axis_dividend_tready` and `s_axis_divisor_tready`, which are ultimately the same signal, the core can accept data on every third cycle. Data A1 in the dividend channel is ignored because `s_axis_divisor_tvalid` is deasserted. Data inputs A2 and B1 are accepted because both `tvalids` and `tready` are asserted.

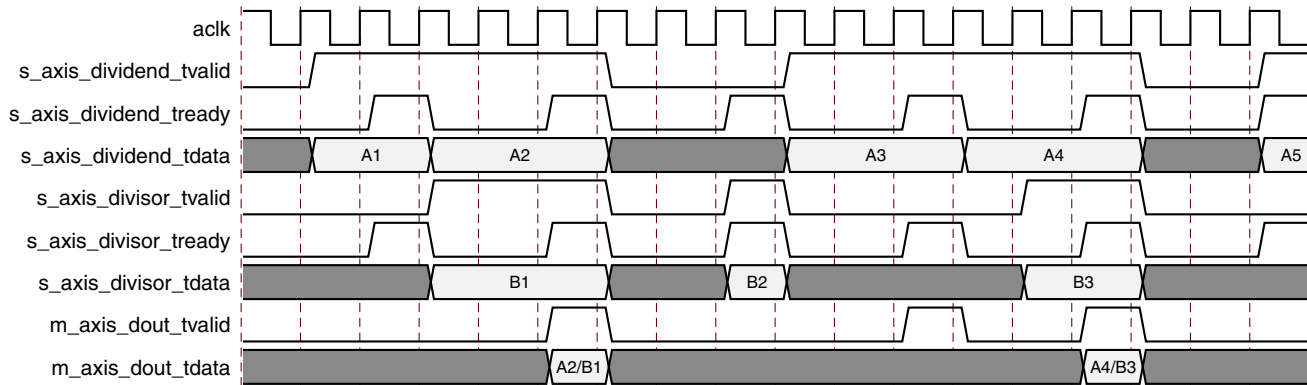


Figure 3-2: Non Blocking Mode

### Blocking Mode

The term 'Blocking' means that each channel with `tready` buffers data for use. The full flow control of AXI4-Stream aids system design because the flow of data is self-regulating. Blocking or Non-Blocking behavior is selected using the FlowControl parameter. Data loss is prevented by the presence of back pressure (`tready`), so that data is only propagated when the downstream datapath is ready to process the data.

The Divider Generator core has two input channels and one output channel. When all input channels have validated data available, an operation occurs and the result becomes available on the output. If the output is prevented from off-loading data because `m_axis_dout_tready` is Low then data accumulates in the output buffer internal to the core. When this output buffer is nearly full the core stops further operations. This prevents the input buffers from off-loading data for new operations so the input buffers fill as new data is input. When the input buffers fill, their respective `tready`s (`s_axis_divisor_tready` and `s_axis_dividend_tready`) are deasserted to prevent further input. This is the normal action of back pressure.

The two input channels are tied in the sense that each must receive validated data before an operation can proceed. Therefore, there is an additional blocking mechanism, where one input channel does not receive validated data while the other does. In this case, the validated data is stored in the input buffer of the channel. After a few cycles of this scenario, the buffer of the channel receiving data fills and `tready` for that channel is deasserted until the starved channel receives some data. Figure 3-3 shows both blocking behavior and back pressure. The first data on channel `s_axis_dividend` is paired with the first data on channel `s_axis_divisor`, the second with the second and so on. This demonstrates the "blocking" concept. The channel names `s_axis_dividend` and `s_axis_divisor` are used conceptually. Either can be taken to mean the divisor or dividend channel. Figure 3-3 further shows how data output is delayed not only by latency, but also by the handshake signal `m_axis_dout_tready`. This is back pressure. Sustained back pressure on the output along with data availability on the inputs eventually leads to a saturation of the core buffers, leading the core to signal that it can no longer accept further input by deasserting

the input channel `tready` signals. The minimum latency in this example is two cycles, but it should be noted that in Blocking operation latency is not a useful concept. Instead, as the diagram shows, the important idea is that each channel acts as a queue, ensuring that the first, second, third data samples on each channel are paired with the corresponding samples on the other channels for each operation.

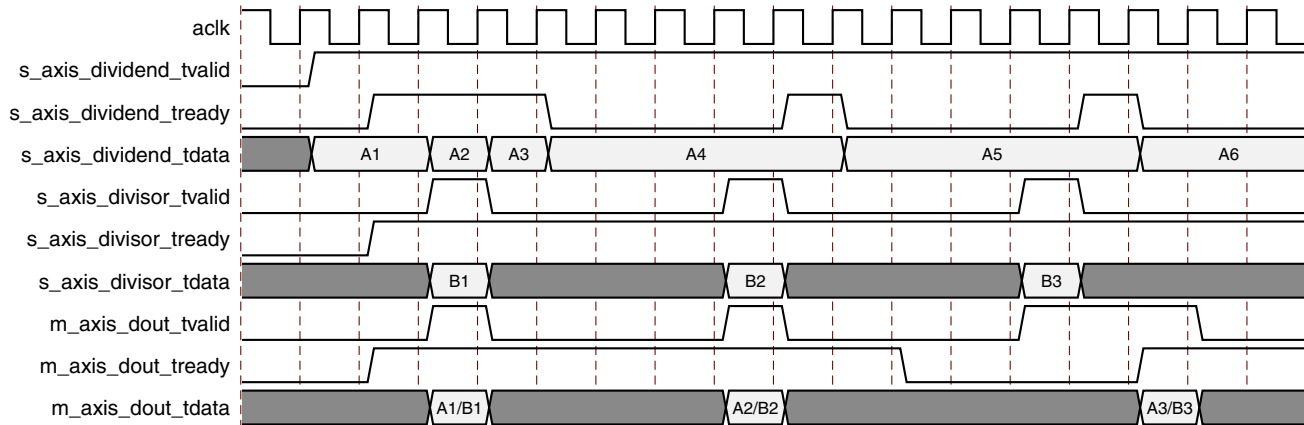


Figure 3-3: Blocking Mode

**Note:** This diagram is for illustration of the blocking behavior and handshake protocol. The latency of the core is zero in the diagram which in reality is not the case.

### TDATA Packing

Fields within an AXI4-Stream interface follow a specific naming nomenclature. In this core the operands are both passed to or from the core on the channel `tdata` port. To ease interoperability with byte-oriented protocols, each subfield within `tdata` which could be used independently is first extended, if necessary, to fit a bit field which is a multiple of 8 bits. For the output DOUT channel, result fields are sign extended to the byte boundary. The bits added by byte orientation are ignored by the core and do not result in additional resource use.

### TDATA Structure for Dividend and Divisor Channels

Input channels Dividend and Divisor carry their operands only in their `tdata` field. For each, the operand occupies the least significant bits. The `tdata` port width itself is the minimum multiple of bytes wide required to contain the operand. See Figure 3-4.

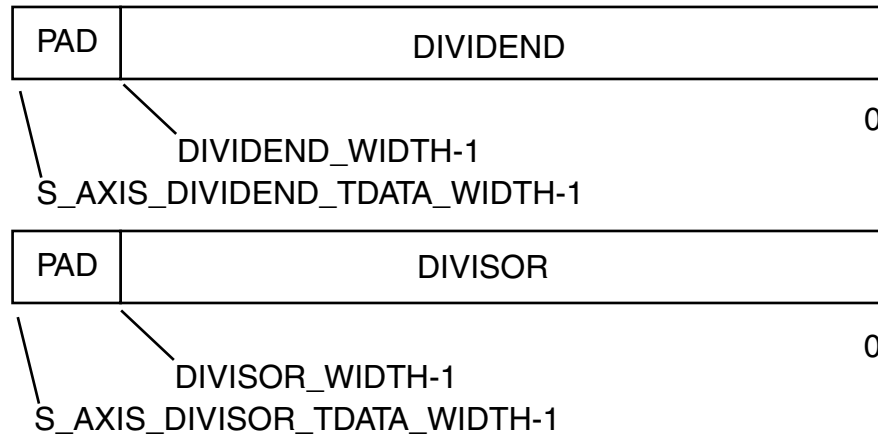


Figure 3-4: Input Data TDATA Structure

**TDATA Structure for Output (DOUT) Channel**

The structure of `m_axis_dout_tdata` is more complex. This port contains both quotient and, if present, remainder or fractional outputs. When the remainder type is set to remainder, the two outputs are considered separate and so are byte-oriented before being concatenated to make the `m_axis_dout_tdata` signal. When remainder type is fractional, the fractional part is considered an extension of the quotient so these two fields are concatenated before being padded to the next byte boundary.

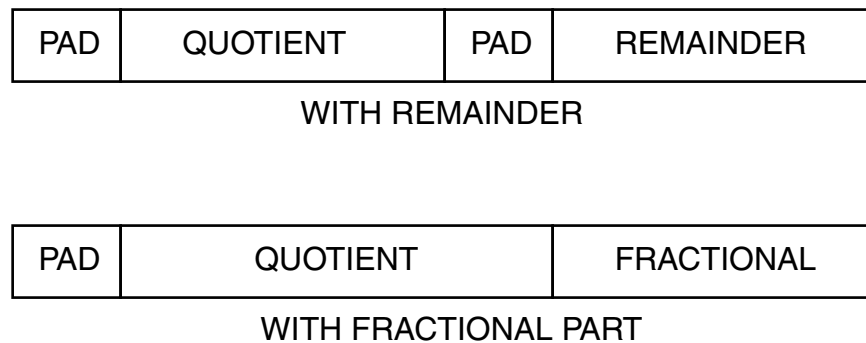


Figure 3-5: Data Out TDATA Structure

***TLAST and TUSER Handling***

`tlast` in AXI4-Stream is used to denote the last transfer of a block of data. `tuser` is for ancillary information which qualifies or augments the primary data in `tdata`. The Divider Generator core operates on a per-sample basis where each operation is independent of any before or after. Because of this, there is no need for `tlast` on a divider. The `tlast` and `tuser` signals are supported on each input channel purely as an optional aid to system design for the scenario in which the data stream being passed through the Divider Generator core does indeed have some packetization or ancillary field, but which is not

relevant to the divider. The facility to pass `tlast` and/or `tuser` removes the burden of matching latency to the `tdata` path, which can be variable, through the divider.

When `Divide_by_zero` detect is selected, the signal indicating a division by zero is output on the least significant bit of the output channel `tuser` port.

### TLAST Options

`tlast` for each input channel is optional. Each, when present, can be passed through the divider, or, when more than one channel has `tlast` enabled, can pass a logical AND or logical OR of the `tlasts` input. When no `tlasts` are present on any input channel, the output channel does not have `tlast` either.

### TUSER Options

`tuser` for each input channel is optional. Each has user-selectable width. The Divider Generator core might also generate a `tuser` bit. This is when `divide_by_zero` detection is selected. These fields are concatenated, without any byte-orientation or padding, to form the output channel `tuser` field. The `divide_by_zero` bit occupies the least significant position, followed by the `tuser` field from the Divisor channel then `tuser` from the Dividend channel in the most significant position.

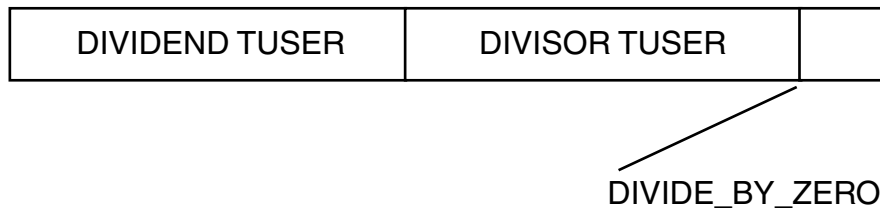


Figure 3-6: Data Out TUSER Structure

# Design Flow Steps

This chapter describes customizing and generating the core, constraining the core, and the simulation, synthesis and implementation steps that are specific to this IP core. More detailed information about the standard Vivado® design flows and the IP integrator can be found in the following Vivado Design Suite user guides:

- *Vivado Design Suite User Guide: Designing IP Subsystems using IP Integrator* (UG994) [Ref 3]
- *Vivado Design Suite User Guide: Designing with IP* (UG896) [Ref 4]
- *Vivado Design Suite User Guide: Getting Started* (UG910) [Ref 5]
- *Vivado Design Suite User Guide: Logic Simulation* (UG900) [Ref 6]

---

## Customizing and Generating the Core

This section includes information about using Xilinx® tools to customize and generate the core in the Vivado Design Suite.

If you are customizing and generating the core in the Vivado IP integrator, see the *Vivado Design Suite User Guide: Designing IP Subsystems using IP Integrator* (UG994) [Ref 3] for detailed information. IP integrator might auto-compute certain configuration values when validating or generating the design. To check whether the values do change, see the description of the parameter in this chapter. To view the parameter value, run the `validate_bd_design` command in the Tcl console.

You can customize the IP for use in your design by specifying values for the various parameters associated with the IP core using the following steps:

1. Select the IP from the IP catalog.
2. Double-click on the selected IP or select the Customize IP command from the toolbar or right-click menu.

For details, see the *Vivado Design Suite User Guide: Designing with IP* (UG896) [Ref 4] and the *Vivado Design Suite User Guide: Getting Started* (UG910) [Ref 5].

The Divider Generator core can be found in the Xilinx Blockset in the Math section. The block is called *Divider Generator 5.1* The Divider Generator core interface in the Vivado

Integrated Design Environment (IDE) provides one page split into sections to set parameter values for the particular instantiation required. This section provides a description of each interface field. These fields are grouped as follows:

- **Component Name:** The base name of the output files generated for the core. Names must begin with a letter and be composed of any of the following characters: a to z, 0 to 9 and “\_”.

### ***Common Options***

Describes parameters common to both implementations and allows the selection of the divider implementation.

- **Algorithm Type:** This selects between Radix-2, LUTMult and High Radix division solutions.

### ***Dividend Channel***

- **Dividend Width:** Specifies the number of integer bits provided on the DIVIDEND (`s_axis_dividend_tdata`) and QUOTIENT fields (subfield of `m_axis_dout_tdata`). This must be set to satisfy the largest possible quotient result. Due to the non-symmetry of twos complement representation bit growth from the dividend to quotient is possible, but only for the single combination of the most negative number divided by negative one (that is,  $-2^{(M-1)}/-1$ ). The width of dividend (and hence quotient) can be extended by 1 bit should this situation need to be accommodated
- **Has TLAST:** Specifies whether the this channel has a `tlast` port. The Divider Generator core does not use this information. The facility is provided to ease system design. `tlast` information is conveyed to the output channel with the same latency as the datapath.
- **Has TUSER:** Specifies whether this channel has a `tuser` port. As with `tlast`, the Divider Generator core does not use this information. `tuser` exists to ease system design. `tuser` bits are conveyed to the output with the same latency as the datapath.
- **TUSER Width:** Available when Has `tuser` is TRUE, this sets the width of the `tuser` port for this channel.

### ***Divisor Channel***

- **Divisor Width:** Specifies the number of integer bits provided on the DIVISOR field of `s_axis_divisor_tdata`. When the core is configured with remainder output, the width of the remainder is also equal to the value of this parameter.
- **Has TLAST:** Specifies whether the this channel has a `tlast` port. The Divider Generator core does not use this information. The facility is provided to ease system design. `tlast` information is conveyed to the output channel with the same latency as the datapath.

- **Has TUSER:** Specifies whether this channel has a `tuser` port. As with `tlast`, the Divider Generator core does not use this information. `tuser` exists to ease system design. `tuser` bits are conveyed to the output with the same latency as the datapath.
- **TUSER Width:** Available when Has `tuser` is TRUE, this sets the width of the `tuser` port for this channel.

### Output Channel

- **Remainder Type:** This selects between remainder types Fractional and Remainder presented on the FRACTIONAL field of the output `tdata` port (`m_axis_dout_tdata`). Fractional remainder type is the only option for High Radix.
- **Fractional Width:** If Fractional remainder type is selected, this determines the number of bits provided on the FRACTIONAL field of the output channel (`m_axis_dout_tdata`). When High Radix is selected, the total output width (quotient part plus fractional part) is limited to 82.

The width of the quotient is equal to the width of the dividend and is set in the Dividend channel section.

The width of the `tuser` port is the sum of the present input channel `tuser` fields plus one if `divide_by_zero` detect is active. See [AXI4-Stream Considerations in Chapter 3](#) for the internal structure of the `tuser` port.

This channel also has a `tlast` port if either of the input channels has a `tlast` port.

### Radix-2 Options

- **Clocks Per Division:** Determines the throughput of the Radix-2 solution (interval in clocks between inputs (or outputs)). A low value for this parameter results in high throughput, but also in greater resource use.

### High Radix and LUTMult Options

- **Number of iterations (High Radix only):** Read-only text field that reports the number of iterations performed by the High Radix engine for each divide. This sets the maximum throughput of the divider. To achieve this throughput, the operands must be supplied as soon as requested by the core `s_axis_dividend_tready` and `s_axis_divisor_tready` outputs.
- **Throughput (High Radix only):** Read-only text field that reports the maximum throughput that can be sustained by the divider when operands are supplied at a constant rate. In AXI blocking modes, throughput might be slightly higher due to buffering. This rate applies when FlowControl is set to NonBlocking and the output channel DOUT has no `tready`.



## Common Options

**Detect Divide-by-Zero:** Check box. Determines if the core has a `DIVIDE_BY_ZERO` field in the output `tuser` port (`m_axis_dout_tuser`) to signal when a division by zero has been performed.

## AXI4-Stream Options

- **Flow Control:** Blocking or NonBlocking. This is more fully explained in [AXI4-Stream Considerations in Chapter 3](#). NonBlocking mode provides an easier migration path from the previous version of the Divider Generator core. Blocking mode eases data flow management to/from other AXI4-Stream blocking mode cores at the expense of some additional resource and latency.
- **Optimize Goal:** This applies only to blocking mode. When `ACLKEN` is selected and Optimize Goal is set to Resources, performance might be reduced. See [Resource Utilization in Chapter 2](#).
- **Output has TREADY:** Selects whether the output channel has a `tready` signal. This is required to allow back pressure from downstream, for example, if connected to another AXI4-Stream Blocking core. Without `tready`, downstream circuitry cannot halt dataflow from the divider, but some resource is saved.
- **Output TLAST Behavior:** Selects the source of the output channel `tlast` signal. When neither or only one input channel has a `tlast` then the output `tlast` is not present or derives from the input `tlast` appropriately. When both input channels have `tlast`, the output channel `tlast` can derive from either alone, the logical OR of both inputs, or the logical AND of both inputs.

## Latency Options

- **Latency Configuration:** Automatic (fully pipelined) or manual (determined by following field). Latency configuration for Radix2 solution is configurable only when clocks per division is set to 1. This is due to iterative feedback and hence non-optional registers when clocks per division is greater than 1.
- **Latency:** When Latency Configuration is set to Automatic, this field provides the latency from input to output in terms of clock enabled clock cycles. When Manual, this field is used to specify the latency required. When high performance (clock frequency) is not required, a lower value in this field can save resources.

## Control Signals

- **ACLKEN:** Determines if the core has a clock enable input (`ACLKEN`).
- **ARESETn:** Determines if the core has an active-Low synchronous clear input (`ARESETn`).

*Note:*

- a. The signal `ARESETn` always takes priority over `ACLKEN`, that is, `ARESETn` takes effect regardless of the state of `ACLKEN`.
- b. The signal `ARESETn` is active-Low.
- c. The signal `ARESETn` should be held active for at least two clock cycles. This is because, for performance, `ARESETn` is internally registered before being fed to the reset port of primitives.

## User Parameters

Table 4-1 shows the relationship between the fields in the Vivado IDE (described in [Customizing and Generating the Core](#)) and the User Parameters (which can be viewed in the Tcl console).

Table 4-1: Vivado IDE Parameter to User Parameter Relationship

Vivado IDE Parameter/Value <sup>(1)</sup>	User Parameter/Value <sup>(1)</sup>	Default Value
Algorithm Type	Algorithm_type	Radix2
High Radix	High_Radix	
Radix2	Radix2	
LutMult	LutMult	
Dividend Width	dividend_and_quotient_width	16
Dividend Channel: Has TUSER	dividend_has_tuser	False
Dividend Channel: TUSER Width	dividend_tuser_width	1
Dividend Channel: Has TLAST	dividend_has_tlast	False
Divisor Width	divisor_width	16
Divisor Channel: Has TUSER	divisor_has_tuser	False
Divisor Channel: TUSER Width	divisor_tuser_width	1
Divisor Channel: Has TLAST	divisor_has_tlast	False
Remainder Type	remainder_type	Remainder
Fractional Width	fractional_width	16
Operand Sign	operand_sign	Signed
Clocks per Division	clocks_per_division	1
Detect Divide-By-Zero	divide_by_zero_detect	False
Flow Control	flowcontrol	NonBlocking
Non Blocking	NonBlocking	
Blocking	Blocking	
Optimize Goal	optimizegoal	Resources
Output has TREADY	outready	False
Output TLAST Behavior	outlastbehv	Null
AND all TLASTs	AND_all_TLASTs	
Null	Null	
OR all TLASTs	OR_all_TLASTs	

Table 4-1: Vivado IDE Parameter to User Parameter Relationship (Cont'd)

Vivado IDE Parameter/Value <sup>(1)</sup>	User Parameter/Value <sup>(1)</sup>	Default Value
Pass Dividend TLAST	Pass_Dividend_TLAST	
Pass Divisor TLAST	Pass_Divisor_TLAST	
Latency Configuration	latency_configuration	Automatic
Latency	latency	18
ACLKEN	aclken	False
ARESETN	aresetn	False

**Notes:**

1. Parameter values are listed in the table where the GUI parameter value differs from the user parameter value. Such values are shown in this table as indented below the associated parameter.

## Output Generation

For details, see the *Vivado Design Suite User Guide: Designing with IP* (UG896) [Ref 4].

## Constraining the Core

This section contains information about constraining the core in the Vivado Design Suite.

### Required Constraints

This section is not applicable for this IP core.

### Device, Package, and Speed Grade Selections

This section is not applicable for this IP core.

### Clock Frequencies

This section is not applicable for this IP core.

### Clock Management

This section is not applicable for this IP core.

### Clock Placement

This section is not applicable for this IP core.

## Banking

This section is not applicable for this IP core.

## Transceiver Placement

This section is not applicable for this IP core.

## I/O Standard and Placement

This section is not applicable for this IP core.

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## Simulation

For comprehensive information about Vivado® simulation components, as well as information about using supported third party tools, see the *Vivado Design Suite User Guide: Logic Simulation* (UG900) [Ref 6].



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**IMPORTANT:** For cores targeting 7 series or Zynq-7000 devices, UNIFAST libraries are not supported. Xilinx IP is tested and qualified with UNISIM libraries only.

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## Synthesis and Implementation

For details about synthesis and implementation, see the *Vivado® Design Suite User Guide: Designing with IP* [Ref 4].

# C Model

This chapter details the C Model provided with the core.

The Divider Generator bit accurate C model is a self-contained, linkable, shared library that models the functionality of this core with finite precision arithmetic. This model provides a bit accurate representation of the various modes of the Divider Generator core and is suitable for inclusion in a larger framework for system-level simulation or core-specific verification.

The C model is an optional output of the Vivado® Design Suite.

---

## Features

- Bit accurate with the Divider Generator core.
- Available for 32-bit and 64-bit Linux platforms.
- Available for 32-bit and 64-bit Windows platforms.
- Supports all features of the Divider Generator core with the exception of those affecting timing or AXI4-Stream configuration (`tuser` is also not included).
- Designed for integration into a larger system model.
- Example C code showing how to use the C model functions.

---

## Overview

The model consists of a set of C functions that reside in a shared library. Example C code is provided to demonstrate how these functions form the interface to the C model. Full details of this interface are given in [C Model Interface](#).

The model is bit accurate but not cycle-accurate; it performs exactly the same operations as the core. However, it does not model the core latency, interface signals or `tuser` feature.

## Unpacking and Model Contents

There are separate ZIP files containing all the files necessary for use. Each ZIP file contains:

- C model shared library
- C model header file
- Example code showing how to call the C model

[Table 5-1](#) and [Table 5-2](#) list the contents of each ZIP file.

**Table 5-1: C Model ZIP File Contents: Linux**

File	Description
div_gen_v5_1_bitacc_cmodel.h	Header file which defined the C model API
libIp_div_gen_v5_1_bitacc_cmodel.so	Model shared object library
run_bitacc_cmodel.c	Example program for calling the C model.
gmp.h	MPIR header file, used by the C model
libgmp.so.11	MPIR library, used by the C model
div_gen_v5_1_bitacc_mex.cpp	MATLAB MEX function source
make_div_gen_v5_1_mex.m	MATLAB MEX function compilation script
run_div_gen_v5_1_mex.m	MATLAB MEX function example script
@div_gen_v5_1_bitacc	MATLAB MEX function class directory

**Table 5-2: C Model ZIP File Contents: Windows**

File	Description
div_gen_v5_1_bitacc_cmodel.h	Header file which defined the C model API
libIp_div_gen_v5_1_bitacc_cmodel.dll	Model dynamically linked library
libIp_div_gen_v5_1_bitacc_cmodel.lib	Model LIB file for compiling
run_bitacc_cmodel.c	Example program for calling the C model
gmp.h	MPIR header file, used by the C model
libgmp.dll	MPIR library, used by the C model
libgmp.lib	MPIR .lib file for compiling
div_gen_v5_1_bitacc_mex.cpp	MATLAB MEX function source
make_div_gen_v5_1_mex.m	MATLAB MEX function compilation script
run_div_gen_v5_1_mex.m	MATLAB MEX function example script
@div_gen_v5_1_bitacc	MATLAB MEX function class directory

## Installation

### Linux

- Unpack the contents of the ZIP file.
- Ensure that the directory where the `libIp_div_gen_v5_1_bitacc_cmodel.so` resides is included in the path of the environment variable `LD_LIBRARY_PATH`.

### Windows

- Unpack the contents of the ZIP file.
- Ensure that the directory where the `libIp_div_gen_v5_1_bitacc_cmodel.dll` resides is:
  - Included in the path of the environment variable `PATH`, or
  - In the directory in which the executable that calls the C model is run.

## C Model Interface

An example file, `run_bitacc_cmodel.c` is included. This demonstrates how to call the C model. See this file for examples of using the interface described in this section.

The Application Programming Interface (API) of the C model is defined in the header file `div_gen_v5_1_bitacc_cmodel.h`. This interface consists of data structures and functions as described in the following sections.

Note that the division by zero output of the C model is always enabled so a data structure must be allocated for this return value set. When division by zero is detected, the outputs of quotient and remainder for that sample are undefined and might differ from the core hdl output. Only in this case is the C model not bit accurate with the HDL.

### Data Types

The C types defined for the Divider Generator C model are listed in [Table 5-3](#).

*Table 5-3: Data Types*

Name	Type	Description
<code>xip_uint</code>	Unsigned integer	Base type for divide by zero output
<code>xip_array_uint</code>	Struct	Structure to hold array of <code>divide_by_output</code> values
<code>xip_array_mpz</code>	Struct	Structure to hold array of operand values (both input and output)

Table 5-3: Data Types (Cont'd)

Name	Type	Description
xip_div_gen_v5_1_status	Int	Error code return from many C model functions. 0 indicates success. Any other value indicates failure
xip_status	Int	Same as xip_div_gen_v5_1_status, but used for functions which are not core-specific
xip_div_gen_v5_1_config	Struct	The configuration of the core itself. The members of this structure are listed in the div_gen_v5_1_bitacc_cmodel.h file. The names closely match the same names in XCI files. The div_gen_v5_1_bitacc_cmodel.h file also contains #defined values for all.
xip_div_gen_v5_1	Struct	Type defined which C (not C++) can use as a handle (pointer) to a C++ object - the C model itself.

The xip\_array\_uint and xip\_array\_mpz types are structures with the following members:

- **Data**: a pointer to the array of data values
- **Data\_size**: of type size\_t, which describes the total size of the data array.
- **Data\_capacity**: also of type size\_t, which described how much of the array is currently populated.
- **Dim**: a pointer to a size\_t array of values which indicate the size of each dimension.
- **Dim\_size**. Also of type size\_t. This indicates the number of dimensions of the data array.
- **Dim\_capacity**: indicates how much of the dimension array is currently populated.
- **Owner**: This unsigned in member is provided as a handle for when the data structure is intended to be passed from one core to another, but is not used by any of the Divider Generator C model functions.

## Data Values

The Divider Generator core input and output fields are in standard unsigned or signed (twos complement) binary form with widths from 2 bits to 64 bits wide per operand or result field.

The Divider Generator C model expects data to be in the C type mpz\_t, equal to the raw value of the twos complement bit vector input to the HDL. The output form is also of mpz\_t, again corresponding to the bit vector of the output. For signed Radix-2 with fractional output, the sign is included as the leading bit of the fractional value just as it is for the core.

## Functions

There are several C model functions accessible to the user.



### Information Functions

Table 5-4 lists the information functions. The prototypes for these functions can be found in the C model header file.

Table 5-4: Information Functions

Name	Return	Arguments	Description
xip_div_gen_get_version	Const char*	None	Return the Divider Generator version as a null terminated string. For v5.1 this is '5.1'.
xip_div_gen_v5_1_get_default_config	xip_div_gen_v5_1_status	xip_div_gen_v5_1_config*	Populates the contents of structure point to by the input argument with the value of a default configuration

### Initialization Functions

The functions to create, configure and destroy the C model and associated data structures are listed in Table 5-5.

Table 5-5: Initialization Functions

Name	Return	Arguments	Description
xip_div_gen_v5_1_create	Pointer to structure holding configuration of C model object	Pointer to structure holding configuration	Creates C model object and returns pointer to config structure (which is pointer to C model itself).
xip_div_gen_v5_1_destroy	xip_div_gen_v5_1_status	Pointer to xip_div_gen_v5_1 (C model itself)	Deallocates memory owned by C model and destroys C model itself.
xip_div_gen_v5_1_get_config	xip_div_gen_v5_1_status	Pointer to C model, pointer to configuration structure	Copied the contents of the configuration of the C model indicates to the designated configuration structure.
xip_array_#TYPE#_create	Pointer to the created data structure	None	Allocates memory for the structure itself, not the array members within it.
xip_array_#TYPE#_reserve_data	xip_status	Pointer to data structure, maximum number of elements in data array.	(Re)allocates enough memory for the maximum size. Error is returned if the data_capacity of the structure is greater than the space allocated

Table 5-5: Initialization Functions

Name	Return	Arguments	Description
xip_array_#TYPE#_reserve_dim	xip_status	Pointer to data structure, maximum number of dimensions.	Allocates a small array which is to contain the size of each dimension of the data array. For example, 100 samples x 4 channels x 3 fields.
xip_array_#TYPE#_destroy	xip_status	Pointer to data structure.	Frees up the memory allocated for the data array, the dimension array, and the data structure itself.
xip_array_#TYPE#_alloc	xip_status	Number of samples (int)	Creates and allocates data structures suitable for divider operands.

### Execution Functions

The run time functions of the C model are described in [Table 5-6](#).

Table 5-6: Execution Functions

Name	Return	Arguments	Description
xip_div_gen_v5_1_data_do	xip_div_gen_v5_1_status	Pointers to C model, Pointers to data structures for divisor, dividend, quotient (inc fractional part), remainder, divide_by_zero, Number of samples (int).	Executes division on input data structures and populates output data structures.

## Compiling

Compilation of user code requires access to the `div_gen_v5_1_bitacc_cmodel.h` header file and the header files of the MPIR dependent libraries, `gmp.h`. The header files should be copied to a location where they are available to the compiler. Depending on the location chosen, the include search path of the compiler might need to be modified.

The `div_gen_v5_1_bitacc_cmodel.h` header file must be included first, because it defines some symbols that are used in the MPIR header files. The `div_gen_v5_1_bitacc_cmodel.h` header file includes the MPIR header files, so these do not need to be explicitly included in source code that uses the C model. When compiling on Windows, the symbol `NT` must be defined, either by a compiler option, or in user source code before the `div_gen_v5_1_bitacc_cmodel.h` header file is included.

## Linking

To use the C model the user executable must be linked against the correct libraries for the target platform.

**Note:** The C model uses MPIR libraries. It is also possible to use GMP or MPIR libraries from other sources, for example, compiled from source code. For details, see [Dependent Libraries](#).

## Linux

The executable must be linked against the following shared object libraries:

- `libgmp.so.11`
- `libIp_div_gen_v5_1_bitacc_cmodel.so`

Using GCC, linking is typically achieved by adding the following command line options:

```
-L. -Wl,-rpath,. -lIp_div_gen_v5_1_bitacc_cmodel
```

This assumes the shared object libraries are in the current directory. If this is not the case, the `-L.` option should be changed to specify the library search path to use.

Using GCC, the provided example program `run_bitacc_cmodel.c` can be compiled and linked using the following command:

```
gcc -x c++ -I. -L. -lIp_div_gen_v5_1_bitacc_cmodel -Wl,-rpath,. -o run_bitacc_cmodel  
run_bitacc_cmodel.c
```

## Windows

The executable must be linked against the following dynamic link libraries:

- `libgmp.dll`
- `libIp_div_gen_v5_1_bitacc_cmodel.dll`

Depending on the compiler, the import libraries might also be required:

- `libgmp.lib`
- `libIp_div_gen_v5_1_bitacc_cmodel.lib`

Using Microsoft Visual Studio, linking is typically achieved by adding the import libraries to the Additional Dependencies entry under the Linker section of Project Properties.

---

## Dependent Libraries

The C model uses the MPIR library. This is governed by the GNU Lesser General Public License. You can obtain source code for the MPIR library from [www.xilinx.com/guest\\_resources/gnu/](http://www.xilinx.com/guest_resources/gnu/). A pre-compiled MPIR library is provided with the C model, using the following version:

MPIR 2.6.0

As MPIR is a compatible alternative to GMP, the GMP library can be used in place of MPIR. It is possible to use GMP or MPIR libraries from other sources, for example, compiled from source code.

GMP and MPIR in particular contain many low level optimizations for specific processors. The libraries provided are compiled for a generic processor on each platform, using no optimized processor-specific code. These libraries work on any processor, but run more slowly than libraries compiled to use optimized processor-specific code. For the fastest performance, compile libraries from source on the machine on which you run the executables.

Source code and compilation scripts are provided for the version of MPIR that was used to compile the provided libraries. Source code and compilation scripts for any version of the libraries can be obtained from the GMP [Ref 7] and MPIR [Ref 8] websites.

**Note:** If compiling MPIR using its `configure` script (for example, on Linux platforms), use the `--enable-gmpcompat` option when running the `configure` script. This generates a `libgmp.so` library and a `gmp.h` header file that provide full compatibility with the GMP library.

---

## Example

See the file provided called `run_bitacc_cmodel` for example C code which creates, sets up, executes and destroys the C model.

---

## MATLAB Interface

A MEX function and MATLAB® software class is provided to simplify the integration with MATLAB. The MEX function provides a low-level wrapper around the underlying C model, while the class file provides a convenient interface to the MEX function.

## Compiling

Source code for a MATLAB MEX function is provided. This can be compiled within MATLAB by changing to the directory which contains the code and running the `make_div_gen_v5_1_bitacc_mex.m` script.

## Installation

To use the MEX function the compiled MEX function must be present on the MATLAB search path. This can be achieved by either of the following:

1. Add the directory where the compiled MEX function is located to the MATLAB search path (see the MATLAB `addpath` function) OR
2. Copy the files to a location already on the MATLAB search path.

As with all uses of the C model, the correct C model libraries also need to be present on the platform library search path (that is, `PATH` or `LD_LIBRARY_PATH`).

## MATLAB Class Interface

The `@div_gen_v5_1_bitacc` class handles the create/destroy semantics on the C model. The class provides objects for each of the data and control structures defined for the C model and previously described in [Data Types](#). MATLAB arrays are used the mapping of types as in [Table 5-7](#).

Table 5-7: C Model Type Mapping

C Model type	MATLAB Type
<code>xip_real</code>	<code>double</code>

The class provides these methods:

### Constructor

```
[model]=div_gen_v5_1_bitacc
[model]=div_gen_v5_1_bitacc(config)
[model]=div_gen_v5_1_bitacc(field, value [, field,value]*)
```

\* indicates an optional parameter

The first version of the function call constructs a model object using the default configuration. The second version constructs a model object from a structure that specified the configuration parameter values to use. The third version is the same as the second, but allows the configuration to be specified as a series of (parameter name, value) pairs rather than a single structure. The names and valid values of configuration parameters are identical to those previously described for the C model in [Data Types](#).

The MATLAB configuration structure can contain an additional element, PersistentMemory. When the element is set to TRUE the internal data memory state of the model is retained following a call to the run function. Otherwise, the model is reset after the data is returned. PersistentMemory is set to false by default.

### **Get Version**

```
[version] = get_version(model)
```

This method returns the version string of the c model library used.

### **Get Configuration**

```
[config] = get_configuration(model)
```

This method returns the current parameters structure of a model object. If the model object is empty the method returns the default configuration. If the model object has been created, the method returns the configuration parameters that were used to create it.

### **Divide**

```
[quotient]=divide(model, dividend, divisor)  
[quotient remainder]=divide(model, dividend, divisor)
```

Each of these methods causes the model to execute. The first form applies if the model has been configured with fractional remainder type. The second form applies if the model has been configured with remainder output.

## **Example**

The `run_div_gen_v5_1_bitacc_mex.m` file contains a MATLAB script with several examples of differently configured models showing how to configure and run each.

To run the sample script:

1. Compile the MEX function with the `make_div_gen_v5_1_bitacc_mex.m` script (see [Compiling](#)).
2. Install the MEX function (see [Installation](#)).
3. Execute the `run_div_gen_v5_1_bitacc_mex.m` script.

# Test Bench

This chapter contains information about the test bench provided in the Vivado® Design Suite.

When the core is generated using the Vivado Design Suite, a demonstration test bench is created. This is a simple VHDL test bench that exercises the core.

The demonstration test bench source code is one VHDL file: `demo_tb/tb_<component_name>.vhd` in the Vivado output directory. The source code is comprehensively commented.

---

## Using the Demonstration Test Bench

The demonstration test bench instantiates the generated Divider Generator core.

Compile the netlist and the demonstration test bench into the work library (see your simulator documentation for more information on how to do this). Then simulate the demonstration test bench. View the test bench signals in your simulator waveform viewer to see the operations of the test bench.

## Demonstration Test Bench in Detail

The demonstration test bench performs the following tasks:

- Instantiates the core
- Generates input data
- Generates a clock signal
- Drives the input signals of the core to demonstrate core features
- Checks that the output signals of the core obey AXI4-Stream protocol rules (data values are not checked to keep the test bench simple)
- Provides signals showing the separate fields of AXI4-Stream `tdata` and `tuser` signals

The demonstration test bench drives the core input signals to demonstrate the features and modes of operation of the core. The operations performed by the demonstration test bench

are appropriate for the configuration of the generated core, and are a subset of the following operations:

1. An initial phase where the core is initialized and no operations are performed.
2. Perform a single operation, and wait for the result.
3. Perform 100 consecutive operations with incrementing data.
4. Perform operations while demonstrating the use and effects of the AXI4-Stream control signals.
5. If `ACLKEN` is present: Demonstrate the effect of toggling `ACLKEN`.
6. If `ARESETn` is present: Demonstrate the effect of asserting `ARESETn`.

The clock frequency of the core can be modified by changing the `CLOCK_PERIOD` constant.



# Migrating and Upgrading

This appendix contains information about migrating a design from the ISE® Design Suite to the Vivado® Design Suite, and for upgrading to a more recent version of the IP core. For customers upgrading in the Vivado Design Suite, important details (where applicable) about any port changes and other impact to user logic are included.

---

## Migrating to the Vivado Design Suite

For information on migrating from Xilinx® ISE Design Suite tools to the Vivado Design Suite, see the *ISE to Vivado Design Suite Migration Guide* (UG911) [\[Ref 9\]](#).

---

## Upgrading in the Vivado Design Suite

This section provides information about any changes to the user logic or port designations that take place when you upgrade to a more current version of this IP core in the Vivado Design Suite.

### Migrating from v4.0 or v5.0 to v5.1

#### ***Port Changes***

There are no changes to ports, parameters or behavior from v4.0 to v5.1, nor from v5.0 to v5.1.

#### ***Latency Changes***

There is no change to latency between v4.0 or v5.0 and v5.1.

#### ***Functionality Changes***

There are no functional changes between v4.0 or v5.0 and v5.1.

## Migrating from v3.0 to v5.1

### Port Changes

Table A-1 details the changes to port naming, additional or deprecated ports and polarity changes.

Table A-1: Port Changes from Version 3.0 to Version 5.1

Version 3.0	Version 5.0	Notes
CLK	aclk	Rename only
CE	ACLKEN	Rename only
SCLR	ARESETn	Rename and change of sense (now active-Low). Note the recommendation that ARESETn should be asserted for a minimum of 2 cycles.
DIVIDEND	s_axis_dividend_tdata(N-1:0)	
DIVISOR	s_axis_divisor_tdata(M-1:0)	
QUOTIENT	m_axis_dout_tdata(S-1:0)	Both Quotient and Fractional (or remainder) map to m_axis_dout_tdata. See <a href="#">TDATA Structure for Output (DOUT) Channel in Chapter 3</a> for details.
FRACTIONAL		
ND		Deprecated. However this is analogous to the tvalid signals. See <a href="#">Instructions for Minimum Change Migration (v3.0 to v5.1)</a> .
RDY		Deprecated. However, this is analogous to tvalid on the output channel. See <a href="#">Instructions for Minimum Change Migration (v3.0 to v5.1)</a> .
RFD		Deprecated. However, this is analogous to TREADY on the input channels. See <a href="#">Instructions for Minimum Change Migration (v3.0 to v5.1)</a> .
DIVIDE_BY_ZERO	m_axis_dout_tuser(0)	When this signal is selected to appear, it occupies the LSB of the output tuser port. See <a href="#">TUSER Options in Chapter 3</a> for details.
	s_axis_dividend_tvalid	tvalid (AXI4-Stream channel handshake signal) for each channel
	s_axis_divisor_tvalid	
m_axis_dout_tvalid		
	s_axis_dividend_tready	tready (AXI4-Stream channel handshake signal) for each channel.
	s_axis_divisor_tready	
	m_axis_dout_tready	
	s_axis_dividend_tlast	tlast (AXI4-Stream packet signal indicating the last transfer of a data structure) for each channel. The Divider Generator core does not use tlast, but provides the facility to pass tlast with the same latency as tdata.
	s_axis_divisor_tlast	
	m_axis_dout_tlast	

Table A-1: Port Changes from Version 3.0 to Version 5.1 (Cont'd)

Version 3.0	Version 5.0	Notes
	s_axis_dividend_tuser	tuser (AXI4-Stream ancillary field for application-specific information) for each channel. The Divider Generator core does not use tuser, but provides the facility to pass tuser with the same latency as tdata.
	s_axis_divisor_tuser	
	m_axis_dout_tuser	

### Latency Changes

With the addition of AXI4-Stream interfaces, the latency of the Divider Generator core v5.1 is different compared to v3.0 for AXI Blocking mode. Latency is the same as v3.0 in v5.1 for AXI Non-Blocking mode.

Importantly, when in Blocking Mode, the latency of the core is variable due to the FIFO nature of the AXI4-Stream protocol, so only the minimum possible latency can be determined. Relative to v3.0, with Blocking and output `tready` present, minimum latency is 3 cycles greater. With no output `tready`, minimum latency is increased by one cycle only.

### Instructions for Minimum Change Migration (v3.0 to v5.1)

To configure the Divider Generator core v5.1 to most closely mimic the behavior of v3.0 the translation is as follows:

#### Parameters

- Set FlowControl to NonBlocking.

All other new parameters default to FALSE and can be ignored.

#### Ports

- Rename and map signals as detailed in [Port Changes](#).
- Map ND to both `s_axis_dividend_tvalid` and `s_axis_divisor_tvalid`.
- Map RFD to `s_axis_dividend_tready` (`s_axis_divisor_tready` can be used equally).
- Map RDY to `m_axis_dout_tvalid`.

Performance and resource use is mostly unchanged compared with Divider Generator v3.0 other than small changes due to the use of a different version of the implementation tools.

## Functionality Changes

From v3.0 to v5.1, there are functional changes due to the adoption of AXI4-Stream Interfaces. See [Instructions for Minimum Change Migration \(v3.0 to v5.1\)](#) and [AXI4-Stream Considerations in Chapter 3](#).

## Simulation Changes

Starting with Divider Generator v5.1 behavioral simulation models have been replaced with IEEE Encrypted VHDL. The resulting model is bit and cycle accurate with the final netlist. For more information on simulation see the *Vivado Design Suite User Guide: Logic Simulation* (UG900) [\[Ref 6\]](#).

# Debugging

This appendix includes details about resources available on the Xilinx Support website and debugging tools.

---

## Finding Help on Xilinx.com

To help in the design and debug process when using the Divider Generator, the [Xilinx Support web page](#) contains key resources such as product documentation, release notes, answer records, information about known issues, and links for opening further product support.

### Documentation

This product guide is the main document associated with the Divider Generator. This guide, along with documentation related to all products that aid in the design process, can be found on the [Xilinx Support web page](#) or by using the Xilinx® Documentation Navigator.

Download the Xilinx Documentation Navigator from the [Downloads page](#). For more information about this tool and the features available, open the online help after installation.

### Answer Records

Answer Records include information about commonly encountered problems, helpful information on how to resolve these problems, and any known issues with a Xilinx product. Answer Records are created and maintained daily ensuring that users have access to the most accurate information available.

Answer Records for this core can be located by using the Search Support box on the main [Xilinx support web page](#). To maximize your search results, use keywords such as

- Product name
- Tool message(s)
- Summary of the issue encountered

A filter search is available after results are returned to further target the results.

Master Answer Record for the Divider Generator

AR: [54499](#)

## Technical Support

Xilinx provides technical support at the [Xilinx Support web page](#) for this LogiCORE™ IP product when used as described in the product documentation. Xilinx cannot guarantee timing, functionality, or support if you do any of the following:

- Implement the solution in devices that are not defined in the documentation.
- Customize the solution beyond that allowed in the product documentation.
- Change any section of the design labeled DO NOT MODIFY.

To contact Xilinx Technical Support, navigate to the [Xilinx Support web page](#).

---

## Debug Tools

There are many tools available to address Divider Generator design issues. It is important to know which tools are useful for debugging various situations.

### Vivado Design Suite Debug Feature

The Vivado® Design Suite debug feature inserts logic analyzer and virtual I/O cores directly into your design. The debug feature also allows you to set trigger conditions to capture application and integrated block port signals in hardware. Captured signals can then be analyzed. This feature in the Vivado IDE is used for logic debugging and validation of a design running in Xilinx devices.

The Vivado logic analyzer is used with the logic debug IP cores, including:

- ILA 2.0 (and later versions)
- VIO 2.0 (and later versions)

See the *Vivado Design Suite User Guide: Programming and Debugging* (UG908) [\[Ref 10\]](#).

### C Model Reference

See [Chapter 5, C Model](#) in this guide for tips and instructions for using the provided C Model files to debug your design.

# Simulation Debug

The simulation debug flow for Mentor Graphics Questa Simulator (QuestaSim) is illustrated in Figure B-1. A similar approach can be used with other simulators.

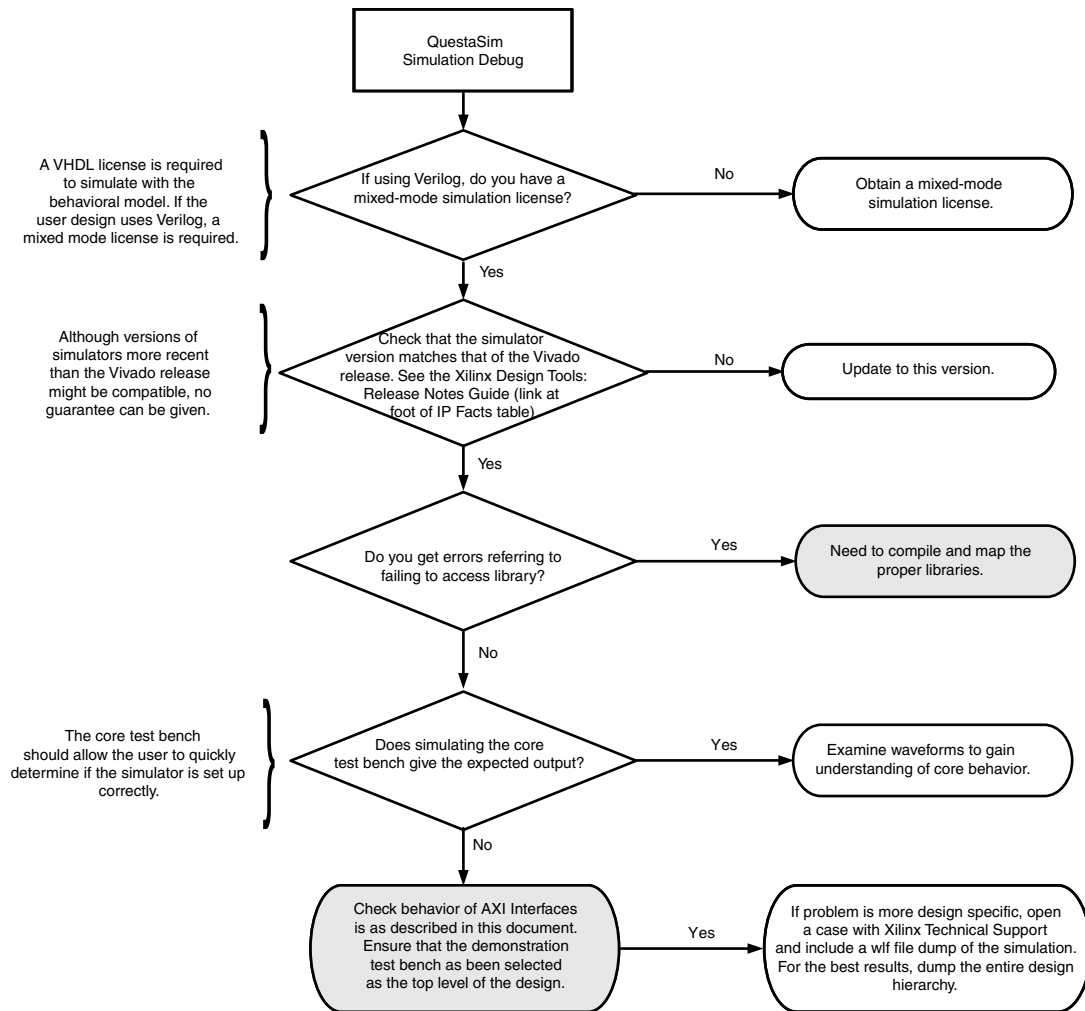


Figure B-1: QuestaSim Debug Flow Diagram

---

## AXI4-Stream Interface Debug

If data is not being transmitted or received, check the following conditions:

- If transmit `<interface_name>_tready` is stuck Low following the `<interface_name>_tvalid` input being asserted, the core cannot send data.
- If the receive `<interface_name>_tvalid` is stuck Low, the core is not receiving data.
- Check that the `ac1k` inputs are connected and toggling.
- Check that the AXI4-Stream waveforms are being followed as described in [AXI4-Stream Considerations in Chapter 3](#).
- Check core configuration.



# Additional Resources and Legal Notices and Legal Notices

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## Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see [Xilinx Support](#).

---

## References

These documents provide supplemental material useful with this product guide:

1. *Xilinx Vivado Design Suite AXI Reference Guide* ([UG1037](#))
2. *AMBA® AXI4-Stream Protocol Specification* ([ARM IHI 0051A](#))
3. *Vivado® Design Suite User Guide: Designing IP Subsystems using IP Integrator* ([UG994](#))
4. *Vivado Design Suite User Guide: Designing with IP* ([UG896](#))
5. *Vivado Design Suite User Guide: Getting Started* ([UG910](#))
6. *Vivado Design Suite User Guide: Logic Simulation* ([UG900](#))
7. The GNU Multiple Precision Arithmetic (GMP) Library [gmp.lib.org](#)
8. The GNU Multiple Precision Integers and Rationals (MPIR) library ([www.mpir.org](#))
9. *ISE® to Vivado Design Suite Migration Guide* ([UG911](#)).
10. *Vivado Design Suite User Guide: Programming and Debugging* ([UG908](#))
11. *Computer Arithmetic Algorithms and Hardware Designs*, Behrooz Parhami. Oxford Press, 2000.
12. *Proceedings 12th Symposium on Computer Arithmetic*, IEEE Computer Society Press, 1995.
13. *Synthesis and Simulation Design Guide* ([UG626](#))

## Revision History

The following table shows the revision history for this document.

Date	Version	Revision
10/05/2016	5.1	Latency description updated.
11/18/2015	5.1	UltraScale device support added.
06/24/2015	5.1	<ul style="list-style-type: none"> <li>Added MATLAB Interface to C Model chapter</li> <li>Radix-2 latency description updated</li> </ul>
04/02/2014	5.1	<ul style="list-style-type: none"> <li>Added link to resource utilization spreadsheet</li> <li>Added User Parameter table (Table 4-1).</li> </ul>
12/18/2013	5.1	Added UltraScale™ architecture support.
10/02/2013	5.1	<ul style="list-style-type: none"> <li>Revision number advanced to 5.1 to align with core version number.</li> <li>Addition of C model.</li> <li>Addition of LUTMult algorithm type</li> <li>Addition of configurable latency for Radix-2 when clocks_per_division = 1</li> <li>Addition of division_by_zero detection to Radix2.</li> </ul>
03/20/2013	1.0	Initial Xilinx as a product guide. Replaces DS819, LogiCORE IP Divider Generator Data Sheet.

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