This quick reference guide presents the following step-by-step flows for quickly closing timing, based on the recommendations in the UltraFast Design Methodology Guide for Xilinx FPGAs and SoCs (UG949):

- **Initial Design Checks**: Review utilization, logic levels, and timing constraints before implementing the design.
- **Timing Baseline**: Identify root cause of setup or hold violations and close timing after routing.
- **Timing Violation Resolution**: Review and address timing violations after each implementation step to help close timing after routing.

**Failfast and QoR Assessment Reports**

You can use the failfast and quality of results (QoR) assessment reports interchangeably to quickly review your design. Both reports compare key design and constraints metrics against guideline limits. Metrics that do not comply with guidelines are marked as REVIEW. The reports include the following sections:

- **Design characteristics**
- **Methodology checks**
- **Conservative logic-level assessments based on a target Fmax**

In the Vivado® tools, you can run these reports as follows:

```bash
v++ --interactive
```

**QoR Suggestions Report**

In the Vivado™ environment, `report_failfast` is called during the implementation phase. This report analyzes the design, offers suggestions, and automatically applies the suggestions in some cases.

**Reports in the Vivis Environment**

In the Vivis™ environment, `report_failfast` is called during the compilation flow when using `v++ -R 1` or `v++ -R 2`. To generate QoR assessment and suggestions in the Vivado tools, use:

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**INTRODUCTION**

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- **Timing Baseline**: Review and address timing violations after each implementation step to help close timing after routing.
- **Timing Violation Resolution**: Identify root cause of setup or hold violations, and resolve the timing violations.

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```

**INITIAL DESIGN CHECKS FLOW**

1. Open the synthesized design checkpoint (DCP) or the post-opt_design.DCP (if available)
2. Review the detailed reports to identify the design characteristics or constraints to improve:
   - Estimated device and SLR Pblock resource utilization
   - Constraints preventing optimizations
   - Control signals and average fanout
   - Clock tree and clock domain crossing constraints
   - High logic levels given the target frequency
3. Create missing clock constraints to eliminate unconstrained internal endpoints and avoid timing loops
4. Fix methodology checks that impact timing closure (Fmax)
5. Proceed to design implementation (logic optimization, placement, routing)

**INITIAL DESIGN CHECKS DETAILS**

Although implementing a design on a Xilinx® device is a fairly automated task, achieving higher performance and resolving compilation issues due to timing or routing violations can be a complex and time-consuming activity. It can be difficult to identify the reason for a failure based on simple log messages or post-implementation timing reports generated by the tools. Therefore, it is essential to adopt a step-by-step design development and compilation methodology, including the review of intermediate results to ensure the design can proceed to the next implementation step.

The first step is to make sure all initial design checks are addressed. Review these checks at the following levels:

- Each kernel made of custom RTL or generated by Vivado HLS
  
  **Note**: Check that target clock frequency constraints are realistic.
- Each major hierarchy corresponding to a subsystem, such as a Vivado IP integrator block diagram with several kernels, IP blocks, and connectivity logic
- Complete design with all major functions and hierarchies, I/O interfaces, complete clocking circuitry, and physical and timing constraints

If the design uses floorplanning constraints, such as super logic region (SLR) assignments or logic assigned to Pblocks, review the estimated resource utilization for each physical constraint, and make sure that the utilization guidelines are met. See the default guidelines in the failfast report. To generate reports, use the following commands:

- `report_utilization -blocks <blockName>`
- `report_failfast -pblock <blockName>`
- `report_failfast [-slr SLRn | -by_slr]`

**TIP**: To automatically address most timing closure challenges during implementation, you can use an Intelligent Design Run (IDR), which is a special type of implementation run that leverages `report_qor_suggestions`, ML-based strategy predictions, and incremental compile. See UG949: Using Intelligent Design Runs.
The objective of timing baselining is to ensure that the design meets timing by analyzing and resolving timing challenges after each implementation step. Fixing the design and constraints issues earlier in the compilation flow ensures a broader impact and higher performance. Review and address timing violations before moving onto the next step by creating intermediate reports as follows:

**Reports in Vivado Project Mode**
- `report_timing_summary`
- `report_methodology`
- `report_failfast`

**Reports in the Vitis Software Platform**
- Use the `v++ -R 1` or `v++ -R 2` option to generate failfast reports, intermediate timing reports, and DCPs in the following directory:
  `<runDir>/_x/link/vivado/prj/prj.runs/impl_1`

**Pre-Placement (WNS < 0 ns)**
Before `place_design`, the timing report reflects the design performance assuming the best possible logic placement for each logic path. Setup violations must be addressed by adopting the Initial Checks recommendations.

**Pre-Routing (WNS < 0 ns)**
Before `route_design`, the timing report reflects the design performance assuming the best possible routing delays for each individual net with some fanout penalty and without considering hold fixing impact (net routing detours) or congestion. Setup violations are often due to sub-optimal placement caused by (1) high device or SLR utilization, (2) placement congestion due to complex logic connectivity, (3) many paths with many logic levels, and (4) high clock skew between unbalanced clocks or high clock uncertainty. Run `phys_opt_design` in Explore or AggressiveExplore mode to try improving the post-place_design QoR. If unsuccessful, focus on improving the placement QoR first.

**Pre-Routing (WHS < -0.5 ns)**
When the performance goal is not met after routing and worst negative slack (WNS) is positive before routing, try to reduce large estimated worst hold slack (WHS) violations. Fewer and smaller pre-route hold violations help `route_design` focus on Fmax rather than fixing hold time violations.

**Post-Routing (WNS < 0 ns or WHS < 0 ns)**
After `route_design`, first verify that the design is fully routed by reviewing the log files or running `report_route_status` on the post-route design checkpoint (DCP). Routing violations and large setup (WNS) or hold (WHS) violations are the result of high congestion. Use the Analyzing Setup Violations (page 3), Resolving Hold Violations (page 4), and Congestion Reduction Techniques (page 6) to identify and implement the resolution steps. Try running `phys_opt_design` after `route_design` to address small setup violations > -0.200 ns. When iterating the design, constraints, and compilation strategies, keep track of the QoR after each step, including the congestion information. Use the QoR table to compare run characteristics and determine what to focus on first when addressing the remaining timing violations.

<table>
<thead>
<tr>
<th>Impl. Run</th>
<th>opt_design</th>
<th>place_design</th>
<th>phys_opt_design</th>
<th>route_design</th>
</tr>
</thead>
<tbody>
<tr>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
</tr>
<tr>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
<td>WNS</td>
</tr>
<tr>
<td>Congestion</td>
<td>Congestion</td>
<td>Congestion</td>
<td>Congestion</td>
<td>Congestion</td>
</tr>
<tr>
<td>Run1</td>
<td>Explore/WithRemap</td>
<td>WDrivenBlockPlacement</td>
<td>-0.07</td>
<td>5-5-5-5</td>
</tr>
<tr>
<td>Run2</td>
<td>Explore</td>
<td>AltSpreadLogic_medium</td>
<td>-0.368</td>
<td>6-5-5-5</td>
</tr>
<tr>
<td>Run3</td>
<td>Default</td>
<td>AltSpreadLogic_high</td>
<td>-0.393</td>
<td>5-5-5-5</td>
</tr>
<tr>
<td>Run4</td>
<td>Default</td>
<td>ExtraTimingOpt</td>
<td>-0.41</td>
<td>5-5-5-5</td>
</tr>
</tbody>
</table>

**TIP:** Use `report_qor_suggestions` after `place_design` and after `route_design` to automatically identify design, constraints, and tool option changes that can help improve the QoR for new compilations.
Design performance is determined by the following:

- **Clock skew and clock uncertainty**: How efficiently the clocks are implemented
- **Logic delay**: Amount of logic traversed during a clock cycle
- **Net or route delay**: How efficiently Vivado implementation places and routes the design

Use the information in the timing path or design analysis reports to:

- Identify which of these factors contributes most to timing violations
- Determine how to iteratively improve the QoR

**TIP**: If needed, open the DCP after each step to generate additional reports.

In Vivado project mode, find setup timing path characteristics as follows:

1. In the Design Runs window, select the implementation run to analyze.
2. In the Implementation Run Properties window, select the **Reports** tab.
3. Open the timing summary report or design analysis report for the selected implementation step:
   - **Timing summary report**: `<runName>_flowStep>report_timing_summary (rpt for text or .rpx for the Vivado IDE)
   - **Design analysis report**: `<runName>_<flowStep>report_design_analysis`

In Vivado non-project mode or in the Vitis software platform, do either of the following:

- Open the reports in the implementation run directory.
- Open the implementation DCP in the Vivado IDE, and open the RPX version of the report.

**Note**: Using the Vivado IDE allows you to cross-probe between the reports, schematics, and Device window.

For each timing path, the logic delay, route delay, clock skew, and clock uncertainty characteristics are located in the header of the path:

**TIP**: In text mode, all columns of the Setup Path Characteristics column appear, making the table very wide. In the Vivado IDE, the same table shows a reduced number of columns to help with visualization. Right-click the table header to enable or disable columns as needed. For example, the DONT_TOUCH or MARK_DEBUG columns are not visible by default. Enable these columns to view important information skipped logic optimization analysis, which is difficult to identify otherwise.

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Avoiding Positive Hold Requirements

When using multicycle path constraints to relax setup checks, you must:

- Adjust hold checks on the same path so the same launch and capture edges are used in the hold time analysis. Failure to do so leads to a positive hold requirement (one or multiple clock periods) and impossible timing closure.
- Specify the endpoint pin instead of just the cell or clock. For example, the endpoint cell REGB has three input pins: C, EN, and D. Only the REGB/D pin should be constrained by the multicycle path exception, not the clock enable (EN) pin because the EN pin can change at every clock cycle. If the constraint is attached to a cell instead of a pin, all of the valid endpoint pins are considered for the constraints, including the EN pin.

Xilinx recommends that you always use the following syntax:

```
set_multicycle_path -from [get_pins REGA/C] -to [get_pins REGB/D] -setup 3
set_multicycle_path -from [get_pins REGA/C] -to [get_pins REGB/D] -hold 2
```

Reducing the WHS and THS Before Routing

Large estimated hold violations increase the routing challenge and cannot always be resolved by `route_design`. The post-placement `phys_opt_design` command provides several hold fixing options:

- The insertion of opposite-edge triggered registers between sequential elements splits a timing path into two half period paths and significantly reduces hold violations. This optimization is only performed if setup timing does not degrade. Use the following command:
  ```
  phys_opt_design -insert_negative_edge_ffs
  ```
- The insertion of LUT1 buffers delays the datapath to reduce hold violations without introducing setup violations. Use the following commands:
  ```
  phys_opt_design -hold_fix: Performs LUT1 insertion on paths with the largest WHS violations only.
  phys_opt_design -aggressive_hold_fix: Performs LUT1 insertion on more paths to significantly reduce the total hold slack (THS) at the expense of a noticeable LUT utilization increase and longer compile time. This option can be combined with any `phys_opt_design` directive.
  phys_opt_design -directive ExploreWithAggressiveHoldFix: Performs LUT1 insertion to fix hold in addition to all other physical optimizations designed to improve Fmax.

Following is an example of a hold timing path with high clock skew:

<table>
<thead>
<tr>
<th>Name</th>
<th>Path 259</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slack (Hold)</td>
<td>-1.122ns</td>
</tr>
<tr>
<td>Source</td>
<td>inst_109033/inst_381/inst_285870/inst_285870/inst_285584/inst_285584/inst_285584/inst_285584</td>
</tr>
<tr>
<td>Destination</td>
<td>inst_109033/inst_381/inst_285870/inst_285870/inst_285584/inst_285584/inst_285584/inst_285584</td>
</tr>
<tr>
<td>Path Group</td>
<td>appclk</td>
</tr>
<tr>
<td>Path Type</td>
<td>Hold (in at Slow Process Corner)</td>
</tr>
<tr>
<td>Requirement</td>
<td>0.000ns (setup, clk rise:0.000ns - launch, clk fall:31.3 rise:0.000ns)</td>
</tr>
<tr>
<td>Data Path Delay</td>
<td>0.180ns (logic:0.050ns (31.776%); recon:0.125ns (67.232%))</td>
</tr>
<tr>
<td>Clock Path Skew</td>
<td>0.287ns</td>
</tr>
</tbody>
</table>

See Improving Clock Skew (page 8)

See Avoiding Positive Hold Requirements (this page)

See Reducing the WHS and THS Before Routing (this page)

See Improving Clock Uncertainty (page 9)
Optimizing Regular Fabric Paths

Regular fabric paths are paths between registers (FD*) or shift registers (SRL*) that traverse a mix of LUTs, MUXFs, and CARRYs. If you encounter issues with regular fabric paths, Xilinx recommends the following. For more information, see the Vivado Design Suite User Guide: Synthesis (UG901) and Vivado Design Suite User Guide: Implementation (UG904).

- For high logic levels, paths can be identified with LUT/net budget checks using report_failfast or report_qor_assessment. Address high logic levels early in the design cycle through either recoding RTL or using retiming.  
  Recommended: Use synthesis -retiming globally. Use the block synthesis strategy BLOCK_SYNTH.RETIMING 1 to target a module or RETIMING_FORWARD/BACKWARD properties to target a specific cell.
- Small cascaded LUTs (LUT1-LUT4) can be merged into fewer LUTs unless prevented by the design hierarchy, by intermediate nets with some fanout (10 and higher), or by the use of KEEP, KEEP_HIERARCHY, DONT_TOUCH, or MARK_DEBUG properties.  
  Recommended: Remove the properties, and rerun starting from the synthesis step or from opt_design -remap.
- Single CARRY (non-cascaded) cells limit LUT optimizations and can make placement less optimal.  
  Recommended: Use the FewerCarryChains synthesis directive, or set the CARRY_REMAP property on the cells to be removed by opt_design.
- The shift register SRL* delay is higher than the register FD* delay, and SRL placement might be less optimal than FD placement.  
  Recommended: Pull a register from the input or output of the SRL using the SRL_STYLE attribute in RTL or the SRL_STAGES_TO_INPUT or SLR_STAGES_TO_OUTPUT property on the cell after synthesis. 
  Dynamic SRLs must be modified in the RTL.
- When the logic path ends with a LUT driving a clock enable (CE), synchronous set (S), or synchronous reset (R) pin of a fabric register (FD*), the routing delay is higher than register data pin (D), especially when the fanout of the last net of the path is greater than 1.  
  Recommended: If the path ending at the data pin (D) has a higher slack and fewer logic levels, set the EXTRACT_ENABLE or EXTRACT_RESET attribute to no on the signal in RTL. Alternatively, set the CONTROL_SET_REMAP property on the cell to trigger the same optimization during opt_design.

Optimizing Paths with Dedicated Blocks and Macro Primitives

Logic paths from/to between dedicated blocks and macro primitives (e.g., DSP, RAMB, URAM, FIFO, or GT_CHANNEL) are more difficult to place and have higher cell and routing delays. Therefore, adding extra pipelining around the macro primitives or reducing the logic levels on the macro primitive paths is critical for improving the overall design performance.

Before modifying the RTL, validate the QoR benefit of adding pipelining by enabling all optional DSP, RAMB, and URAM registers and rerunning implementation. Do not generate a bitstream when adopting this evaluation technique. For example:

```
set_property -dict {DOA_REG 1 DOB_REG 1} [get_cells xx/ramb18_inst]
```

Following is an example of a RAMB18 path that requires additional pipeline registers or logic level reduction (reported after route_design):

```
Path 5
Net Delay Logic Delay Slack Path Delay Logic Levels Net Delay Routes Path 5
RAMB18E2 LUT6 LUT6 LUT5 LUT5 LUT5 FORE 5 5 No DO_REG
```

1. Indicates automated resolution using report_qor_suggestions

Vivado implementation focuses on the most critical paths first. This means less difficult paths often become critical after placement or after routing. Xilinx recommends identifying and improving the longest paths after synthesis or after opt_design, because this has the biggest impact on QoR and usually dramatically reduces the number of place and route iterations to reach timing closure. Use the report_design_analysis command, and enable all columns of the Setup Path Characteristics table to identify the clock domains that require design improvements by weighing the logic level distribution against the requirement. The lower the requirement, the fewer logic levels are allowed. For example, in the following pre-placement logic level distribution report:

```
<table>
<thead>
<tr>
<th>Block</th>
<th>Requirement</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>app_clk</td>
<td></td>
<td>3.148m</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>135</td>
<td>16</td>
<td>17</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>txoutclk_out[0].4</td>
<td>2.238m</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>txoutclk_out[1].4</td>
<td>1.592m</td>
<td>2100</td>
<td>5029</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

Note: Cascaded CARRY or MUXF cells can artificially increase the logic level number and have a low impact on delay.

TIP: In the Vivado IDE report, click the logic level number to select the paths, and press F4 to generate the schematics and review the logic.
Global congestion impacts the design performance as follows:

- **Level 4 (16x16)**: Small QoR variability during route_design
- **Level 5 (32x32)**: Sub-optimal placement and noticeable QoR variations
- **Level 6 (64x64)**: Difficult placement and routing and long compilation time. Timing QoR is severely degraded unless the performance goal is low.
- **Level 7 (128x128) and above**: Impossible to place or route.

The route_design command outputs the Initial Estimated Congestion table in the log file for congestion Level 4 or above. To report both placer and router congestion information, use report_design_analysis -congestion.

**TIP:** Open the post-place or post-route DCP to create an interactive report_design_analysis window in the Vivado IDE. Highlight the congested areas and visualize the impact of congestion on individual logic path placement and routing by cross-probing. See UG949: Reducing Net Delay Caused by Congestion.

**Reducing Congestion**

To reduce congestion, Xilinx recommends using the following techniques in the order listed:

- When the overall resource utilization is above 70-80%, lower the device or SLR utilization by either removing some design functions or moving some modules or kernels to a different SLR. Avoid LUT and DSP/RAMB/URAM utilization that is above 80% at the same time. If the macro primitive utilization percentage must be high, try keeping LUT utilization below 60% to allow placement spreading in the congested area, without introducing complex floorplanning constraints. Use xilinx::designutils::report_failfast -by_slr to review the utilization per SLR after placement.
- Promote non-critical high fanout nets in the congested region to global clock routing as follows: 1
  ```
  set_property CLOCK_BUFFER_TYPE BUFG [get_nets <highFanoutNetName>]
  ```
- Reduce equivalent net overlap in the congested area by merging synthesis-replicated nets. Remove the MAX_FANOUT property from the RTL and synthesis XDC, or use set_property EQUIVALENT_DRIVER_OPT merge on target cells. 1
- Try several placer directives (e.g., AltSpreadLogic* or SSI_Spread*), the Congestion_* implementation run strategies, or ML strategies.
- Reduce MUXF* and LUT combining usage in the congested region. See the corresponding columns in the RDA congestion report. Set MUXF_REMAP to 1 and SOFT_HLUTNM to "" on the congested leaf cells. Use report_qor_suggestions for help. 1
- Use report_design_analysis -complexity -congestion to identify large, congested modules (> 15,000 cells) with high connectivity complexity (Rent Exponent > 0.65 or Average Fanout > 4). Use the congestion-oriented synthesis settings, which are added to the XDC file: set_property BLOCK_SYNTH.STRATEGY {ALTERNATE_ROUTABILITY} [get_cells <congestedHierCellName>]
- Reuse DSP, RAMB, and URAM placement constraints from previous implementation runs with low congestion. For example: read_checkpoint -incremental routed.dcp -reuse_objects [all_rams] -fix_objects [all_rams]

**Optimizing High Fanout Nets**

- Use hierarchy-based register replication explicitly in RTL or with the following logic optimization:
  ```
  opt_design -merge_equivalent_drivers -hier_fanout_limit 512
  ```
- Force replication on critical high fanout nets with more physical optimization steps before place: set_property FORCE_MAX_FANOUT

---

**UltraFast Design Methodology Timing Closure Quick Reference Guide (UG1292)**

**REDUCING CONGESTION TECHNIQUES**

**REDUCING NET DELAY FLOW 1**

Is the path overlapping a congested area?

Yes

No

See Reducing Net Delay (page 7)

Is the fanout < 10 for the critical nets?

Yes

No

See Optimizing High Fanout Nets (this page)

See Reducing Congestion (this page)

---

UG1292 (v2021.2) November 19, 2021
Fixing Setup Violations Due to Hold Detours

To ensure the design is functional in hardware, fixing hold violations has higher priority than fixing setup violations (or Fmax). The following example shows a path between two synchronous clocks with high skew with a tight setup requirement:

<table>
<thead>
<tr>
<th>Name</th>
<th>Slack</th>
<th>Requirement</th>
<th>Path Delay</th>
<th>Clock Skew</th>
<th>Hold Fix Detour</th>
<th>Logical Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path 1</td>
<td>-1.438</td>
<td>1.592</td>
<td>3.244</td>
<td>0.655</td>
<td>[11B1]</td>
<td>FORE LUT4 FORE</td>
</tr>
</tbody>
</table>

Note: The Hold Fix Detour is in picoseconds. To address the hold detour impact on Fmax, see Resolving Hold Violations Techniques (page 4).

Reviewing and Correcting Physical Constraints

All designs include physical constraints. Although I/O locations cannot usually be changed, Pblock and location constraints must be carefully validated and reviewed when making design changes. Changes can move the logic farther apart and introduce long net delays. Review the paths with more than 1 Pblock (PBlocks column) and with location constraints (Fixed Loc column).

Improving the SLR Crossing Performance

When targeting stacked silicon interconnect (SSI) technology devices, making the following early design considerations helps to improve the performance:

- Add pipeline registers at the boundary of major design hierarchies or kernels to help long distance and SLR crossing routing.
- Verify that each SLR utilization is within the guidelines (use report_failfast -by_slr).
- Use USER_SLR_ASSIGNMENT constraints to guide the implementation tools. See UG949: Using Soft SLR Floorplan Constraints.
- Use SLR Pblock placement constraints if the soft constraints do not work.
- Use phys_opt_design -slr_crossing_opt after placement or after routing.

Reducing Control Sets

Try reducing the number of control sets when their number is over the guideline (7.5%), either for the entire device or per SLR:

- Remove MAX_FANOUT attributes on clock enable, set, or reset signals in RTL. 1
- Increase the minimum synthesis control signal fanout (e.g., synth_design –control_set_opt_threshold 16). 1
- Merge the replicated control signals with opt_design –control_set_merge or –merge_equivalent_drivers.
- Remap low fanout control signals to LUTs by setting the CONTROL_SET_REMAP property on CLB register cells. 1

Trying Alternative Implementation Flows

The default compilation flow provides a quick way to obtain a baseline of the design and start analyzing the design if timing is not met. If timing is not met after initial implementation, try some of the other recommended flows:

- Try several place_design directives (up to 10), and several phys_opt_design iterations (Aggressive*, Alternate* directives).
- Overconstrain the most critical clocks (up to 0.500 ns) during place_design/phys_opt_design using set_clock_uncertainty.
- Increase the timing QoR priority on timing clocks that must meet timing using group_path –weight.
- Run the top 3 implementation ML strategies for your design generated by report_qor_suggestions.

1. Indicates automated resolution using report_qor_suggestions
Adding Timing Exceptions Between Asynchronous Clocks

Timing paths in which the source and destination clocks originate from different primary clocks or have no common node must be treated as asynchronous clocks. In this case, the skew can be extremely high, making it impossible to close timing. Add set_clock_groups, set_false_path and set_max_delay -datapath_only constraints as needed. For details, see UG949: Adding Timing Exceptions Between Asynchronous Clocks.

Cleaning Up the Logic Used in Clock Trees

The opt_design command automatically cleans up clock trees unless DONT_TOUCH constraints are used on the clocking logic. Select the timing path, enable the Clock Path Visualization toolbar button, and open the schematic (F4) to review the clock logic.

- Avoid timing paths between cascaded clock buffers by eliminating unnecessary buffers or connecting them in parallel. For example:
  - Combine parallel clock buffers into a single clock buffer unless the clocks are not equivalent.
  - Remove LUTs or any combinatorial logic in clock paths, which can make clock delays and clock skew unpredictable.

Matching Clock Routing

Use the CLOCK_DELAY_GROUP to improve clock routing delay matching between critical synchronous clocks, even when the two clock nets already have the same CLOCK_ROOT. The following example shows two synchronous clocks without the CLOCK_DELAY_GROUP:

Constraining the Clock Loads Placement Next to the Related I/O Bank

For clocks between I/O logic and fabric cells with less than 2,000 loads, set the CLOCK_LOW_FANOUT property on the clock net to automatically place all the loads in the same clock region as the clock buffer (BUFG*), and keep insertion delay and skew low. 1

Constraining the Clock Loads Placement to a Smaller Area

You can use Pblocks to force the placement of clock net loads in a smaller area (e.g., 1 SLR) to reduce insertion delay and skew or to avoid crossing special columns, such as I/O columns that introduce a skew penalty.

Reducing the Clock Net Delay by Moving the Physical Source

Use a location constraint to move the source mixed-mode clock manager (MMCM) or phase-locked loop (PLL) to the center of the clock loads to reduce the maximum clock insertion delay, which results in lower clock pessimism and skew. For details, see UG949: Improving Skew in UltraScale and UltraScale+ Devices.

1. Indicates automated resolution using report_qor_suggestions
Clock uncertainty is the amount of input jitter, system jitter, discrete jitter, phase error, or user-added uncertainty, which is added to the ideal clock edges to model the hardware operating conditions accurately. Clock uncertainty impacts both setup and hold timing paths and varies based on the resources used in the clock trees.

Reducing Clock Uncertainty by Using Parallel BUFGCE_DIV Clock Buffers

For synchronous clocks with a period ratio of 2, 4, or 8 generated by the same MMCM or PLL and driven by several clock outputs, use only 1 MMCM or PLL output and connect it to parallel BUFGCE_DIV clock buffers (UltraScale™ and UltraScale+™ devices only). This clock topology eliminates the MMCM or PLL phase error that results in 0.120 ns clock uncertainty in most cases.

Reducing Clock Uncertainty by Changing the MMCM or PLL Settings

Clock modifying blocks, such as the MMCM and PLL, contribute to clock uncertainty in the form of discrete jitter and phase error. 1

- In the Clocking Wizard or using the `set_property` command, increase the voltage-controlled oscillator (VCO) frequency by modifying the M (multiplier) and D (divider) values. For example, MMCM (VCO=1 GHz) introduces 167 ps jitter and 384 ps phase error versus 128 ps and 123 ps for MMCM (VCO=1.43 GHz).

Limiting Synchronous Clock Domain Crossing Paths

Timing paths between synchronous clocks that are driven by separate clock buffers exhibit higher skew, because the common clock tree node is located before the clock buffers, resulting in higher pessimism in the timing analysis. As a result, it is more challenging to meet both setup and hold requirements at the same time on these paths, especially for high frequency clocks (over 500 MHz). To identify the number of paths between two clocks, use `report_timing_summary` (Inter-Clock Paths section) or `report_clock_interaction`. The following example shows a design that contains many paths between two high speed clocks (requirement = 1.592 ns). 30% of these paths fail timing, which indicates that they are particularly difficult to implement.

Review the logic involved in the clock domain crossings and remove unnecessary logic paths, or try the following modifications:

- Add multicycle path constraints on the paths controlled by clock enable, because new data are not transferred every cycle.
- Replace the crossing logic with asynchronous crossing circuitry and appropriate timing exceptions at the expense of extra latency. For example, use asynchronous FIFOs or XPM_CDC parameterized macros. For details, see the UltraScale Architecture Libraries Guide (UG974).

1. Indicates automated resolution using `report_qor_suggestions`
In the failfast report, address the checks marked as REVIEW to improve implementation and timing closure. Following are the different sections of the failfast report:

1. **Design Characteristics**: The default utilization guidelines are based on SSI technology devices and can be relaxed for non-SSI technology devices. Designs with one or more REVIEW checks are feasible but are difficult to implement.

2. **Clocking Checks**: These checks are critical and must be addressed.

3. **LUT and Net Budgeting**: Use a conservative method to better predict which logic paths are unlikely to meet timing after placement with high device utilization.

**Pblock-Based and SLR-Based Analysis**

The `report_failfast` script reports the utilization of the specified physical area or SLR as follows:

- **Before placement**: Use `-pblock <pblockName>` to report on floorplanning constraints. This is especially important for reviewing SLR placement constraints early in the design cycle when SLR Pblocks exist.

- **After placement**: Use `-slr <slrName>` or `-by_slr` to report utilization metrics for each SLR.

**Floorplanning What-If Analysis**

Use `-top` or `-cell <hierCellName>` with `-pblock <pblockName>` to report utilization metrics and identify good floorplanning constraints without changing the cells to the Pblock.

**Failfast Report Checks Marked as REVIEW Analysis**

When you use the `-detailed_report <prefix>` option, `report_failfast` generates additional detailed reports for each check that does not meet the guideline (except for resource utilization checks). Review each of the following reports:

- `<prefix>.TIMING.rpt`: Detailed Methodology TIMING-* violations
- `<prefix>.AVGFO.rpt`: Average Fanout for modules bigger than 100,000
- `<prefix>.HFN.rpt`: Non-FD high fanout net (HFN) driving more than 10,000 loads
- `<prefix>.DONT_TOUCH.rpt`: List of cells/nets with DONT_TOUCH property set
- `<prefix>.timing_budget_LUT.rpt`: Detailed timing paths failing the LUT budgeting
- `<prefix>.timing_budget_LUT.rpx`: Detailed timing paths failing the LUT budgeting (Vivado IDE interactive report)
- `<prefix>.timing_budget_Net.rpt`: Detailed timing paths failing the net budgeting
- `<prefix>.timing_budget_Net.rpx`: Detailed timing paths failing the net budgeting (Vivado IDE interactive report)

**Kernel-Level or Module-Level Analysis**

Synthesize each kernel or major design hierarchy in an out-of-context mode. Then, verify that timing is met with estimated delays and with a realistic clock constraint:

- Review the timing reports and address any failing paths.
- Review the logic level budgeting section of `report_failfast` to identify the paths that are more likely to fail timing after placement. Optimize the paths flagged by this analysis by modifying your design.

**Pre-Implementation Design Analysis**

After all kernels, sub-modules, and the top-level design are assembled and synthesized, review and address all checks flagged as REVIEW.

**Pre-Implementation Floorplan Constraints Analysis**

For large designs and for Vitis software platform designs, verify that the design architecture and hierarchies fit the device floorplan appropriately.

**Post-Placement SLR Utilization Analysis**

Use `report_failfast -by_slr` to verify that the resource utilization in each SLR is within the recommended guidelines.

**TIP**: In Project Mode, add the failfast report with the following Tcl hook:

```
set_property STEPS.OPT_DESIGN.TCL.POST <path>/postopt_failfast.tcl [get_runs impl_*]
```

Following is an example of `postopt_failfast.tcl`:

```
xilinx::designutils::report_failfast -file failfast_postopt.rpt -detailed_reports postopt
```
The QoR assessment report comprises the following sections:

1. **Overall Assessment Summary**: Provides the QoR assessment score and recommendations for improving QoR.

2. **QoR Assessment Details**: Shows the QoR information for each item. For items with a score of less than 5, REVIEW appears in the Status column.

   **TIP**: To assess the risk of items marked with REVIEW status, compare the data in the Threshold (Thresh.) and Actual columns. The Threshold is automatically adjusted for the design and for the targeted device. To see items that passed the check, use the -full_assessment_details option.

3. **Methodology Check Details**: Shows items that failed, which are related to methodology and impact QoR.

4. **ML Strategy Availability**: Lists the directives required in the training run to generate ML Strategies (details not shown).

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### QoR Assessment Score

The QoR Assessment Score estimates the likelihood of a design meeting timing goals as follows:

- **1**: Design will not complete implementation.
- **2**: Design will complete implementation but will not meet timing.
- **3**: Design will likely not meet timing.
- **4**: Design will likely meet timing.
- **5**: Design will meet timing.

### QoR Assessment Score Accuracy at Different Design Stages

Xilinx recommends using the QoR Assessment Score earlier in the flow, because the potential compile time savings are greatest at this point. However, there are different levels of accuracy in the analysis at different stages in the flow. The `report_qor_assessment` command automatically adjusts the analysis depending on the current state of the design, which takes into consideration possible optimizations later in the flow. Following is the analysis conducted at each design state:

- **Unplaced**: Analysis of cell utilization, higher clock skew thresholds, and LUT/net budget checks. No congestion analysis.
- **Placed**: Congestion analysis and analysis of tighter clock skew thresholds. No LUT/net budget checks.
- **Routed**: Fully accurate analysis and threshold.

**Note**: The score is based on the best metrics available within approximately +/-1 accuracy.

### Improving the QoR Assessment Score

Run `report_qor_suggestions` after `report_qor_assessment` to get suggestions on how to fix or reduce the compilation failure risk. If a suggestion exists, items with a low assessment score (marked with REVIEW status in the QoR assessment report) are automatically prioritized to the top of the QoR suggestion report.

### SLR and Pblock Analysis

SLR and Pblock analysis is conducted automatically. Only items with a score of less than 5 are reported.

### Running Further Analysis

Use the `-csv_output_dir` option to output the following CSV files that can be used for further analysis:

- `qor_timing_<design_stage>.csv`: Details timing paths that fail net and LUT budget checks.
- `qor_dont_touch_<design_stage>.csv`: Lists leaf/hierarchical cells as well as nets with DON'T_TOUCH properties.

**TIP**: In Project Mode, add the assessment report with the following Tcl command:

```tcl
set_property STEPS.OPT_DESIGN.TCL.POST <path>/postopt.tcl [get_runs impl_*]
```

Following is an example of:

```tcl
postopt.tcl:
report_qor_assessment -file postopt_qra.rpt -csv_output_dir ./rqa
```