

DESIGN VERIFICATION OF POWER MANAGEMENT UNIT AND CLOCK GENERATION BLOCK OF Wi-Fi SoC

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Abstract

It is all about the importance of the system on chip and the typical intellectual property design verification flow that is followed in the industry, motivation behind this project and the time plan that was followed in the execution of project.

The term “system on a chip”, or SOC really implies two things, the product itself and the methodology used to design it. A SOC product integrates several sub-systems, many or all of which would’ve been separate discrete chips in the past into a single chip. Depending on how tightly you restrict the definition, a SOC may be only a single silicon die, or possibly many dies inside a single package. Either way, a SOC is rarely the entire system on that single chip, but it usually encompasses the computing functions of the device.

Index Terms : System on chip(SOC),Silicon die.

Introduction

System On a Chip (SOC) is an implementation technology and may have many transformations and many different

variants during this execution flow. A typical SOC may contains the cores like a processor or processor sub-system, a processor bus, a peripheral bus, a bridge between the two buses, and many peripheral devices such as data transformation engines, data ports (e.g. UARTs, MACs) and controllers (e.g., DMA). The sub-systems included in a specific SOC depend on the intended device and a series of tradeoffs and requirements, such as cost, form factor, power, performance, and functionality.

The verification methodology of an SOC flow includes the stimulation of design by providing input stimuli through Testbench setup and verify that it functioning as per intended specifications and this input stimulus exercises through a comprehensive set of test cases which includes all scenarios those verifies the designed module for both functionality and timing behavior.

The primary focus in SOC verification is on checking the integration between the various components. The underlying assumption is that each component was already checked by itself. The combined complexity of the multiple sub-systems can be huge, and there are

many seemingly independent activities that need to be closely correlated. As a result, we need a way to define complicated test scenarios as well as measure how well we exercise such scenarios and corner cases.

The reuse of many hardware IP blocks in a mix-and-match style suggests reuse of the verification components as well. Many companies treat their verification IP as a valuable asset, sometimes valued even more than the hardware IP. Typically, there are independent groups working on the subsystems, thus both the challenges and the possible benefits of creating reusable verification components are magnified.

1.1 TYPICAL SOC VERIFIATION FLOW

The SOC verification undergoes many stages of verification during the cycle of design. A typical flow of verification starting from the specifications to design sign off is shown in Figure 1.1.

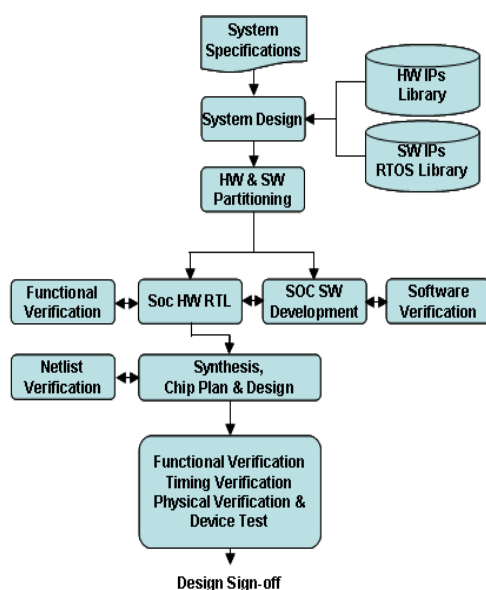


Figure 1.1 SoC Verification Flow

As shown in the design flow hardware part and software part will be segregated and they are developed in parallel. Design engineers will develop RTL models from specifications and also write test bench for their blocks. Verification engineers setup the verification environment like tool integration, scripts, etc.

Typical design verification flow consists of following steps as design goes from design entry to tapeout.

1. Functional Verification
2. Timing Verification
3. Physical Verification

1.1.1 Functional Verification

In functional verification, engineers check correctness of all features specified in design and this is carried out by RTL simulations of design. In RTL simulations, set comprehensive test cases are driven through Testbench setup and these test cases include the sequences that are required to verify the scenarios. After this the functionally verified design with error free is fed to synthesizer and this will generate gate level netlist for specified design technology.

1.1.2 Timing Verification

RTL simulations are run without timing information and it is not capable of finding potential design issues due to timing violations. Timing verification is carried out on synthesized netlist and called gate level simulations with timing information files for different corner cases called SDF. The netlist is nothing but gate

level description of the design. False paths (FP) and multi-cycle-paths (MCP) are timing exceptions that present a particularly difficult problem when trying to achieve the timing closure for high-performance designs. Typically these exceptions (as well as all timing constraints) are considered late in the design cycle and are specified in response to timing problems during verification. For optimum timing results, all timing exceptions must be guaranteed to be correct. So any potential timing violations those were not caught in STA can be caught in gate level simulations during netlist verification.

1.1.3 Physical Verification

Layout vs. Schematics (LVS), Design Rule Checking(DRC), Signal integrity, etc. is covered in physical verification. In DRC all physical measurements are verifies as per specified design technology (e.g. TSMC 180nm, UMC 65nm Technology, etc.). In LVS the developed layout is compared with required schematic and their connections with power supplies and interconnection between the cells. Finally designed RTL models are sent to fabrication and successive validation/testing will be carried out on raw chip to investigate the indeed functionality before sending them to customer.

1.2 MOTIVATION

As today SOC design technologies becomes more and more complex design with more cores present on a single chip

operating at higher speeds, the design has to be verify thoroughly for its completeness and indeed functionality. So it requires robust verification environment i.e. Testbench which need to be organize to suit for most of the similar design i.e. developing more generic environment gives the industry to produce more products in less time.

The objective of work included:

1. In a system-on-chip (SOC) design flow, the designed behavioral model i.e. register transfer level (RTL) code undergoes several transformations before it goes to synthesis. During each transformation, the design logical behavior needs to be verified for it's indeed functionality.
2. The typical complex SoC contains several components/blocks, that are having interconnection with each other and also those will be used for the host interface. So the functionality of these modules should be verified.
3. Perform gate level simulations with SDFs to verify any timing violations, functional aspects of synthesized design.
4. Run the regressions periodically to know percentage of verification coverage for design.

Deliverables included:

1. Development of comprehensive test scenarios for module level and chip level to achieve zero bugs in design.

2. The developed test cases must cover/verify all the features specified in design requirement.
3. The test cases should ensure less debugging efforts with maximum reusability for future IPs.

Key tools to be used:

1. Software: Linux, Cadence Ncsim simulator, Synopsys Novas debug Platform.
2. Languages: Perl, TCL, Verilog and VHDL.

1.4 ORGANIZATION OF REPORT

This report is organized in to 5 chapters.

Chapter 1 gives a brief introduction about the importance of the system on chip and the typical intellectual property design verification flow that is followed in the industry, motivation behind this project and the time plan that was followed in the execution of project.

Chapter 2 gives a brief description about Wi-Fi Technology and also gives brief introduction about 802.11 protocol standards and its classification. It also describes the typical architecture of a Wi-Fi SOC at chip level and briefly explains about the components present in this chip.

Chapter 3 describe about the Testbench environment that was set up for verification and flow of testcase generation. It gives brief introduction to

functional aspects of block and also it introduces the gate level simulation methodology with SDF.

Chapter 4 illustrates the basic functional behavior of PMU and Clock Generation Block through obtained waveforms. The timing violations that were caught during GLS are also explained though waveforms and the final regression status also presented in this chapter.

Chapter 5 talks about the future scope of the project and also the conclusions drawn from the results.

BACKGROUND THEORY

This chapter gives a brief description about Wi-Fi Technology and also gives brief introduction about 802.11 protocol standards and its classification. It also describes the typical architecture of a Wi-Fi SOC at chip level and briefly explains about the components present in this chip like MAC hardware, PHY core, JTAG, PMU, etc.

Wi-Fi, known as a popular wireless networking technology uses radio waves to provide high-speed Internet connections. The Wi-Fi provides wireless connectivity by allowing the users to communicate in the band of 2.4GHz and 5GHz. The wireless adapter will translate the data sent by the user, into a radio signal which is then sent, via an antenna, to a decoder popularly known as the router. After decode, the data will then be sent to the

Internet through a wired Ethernet connection. As the wireless network functions as a duplex system, the data received through the Internet will get passed on to the router, and then it gets coded into a radio signal which will be received by the wireless adapter. The wireless networks uses radio frequency (RF) technology, when this radio frequency current is supplied to an antenna, an EM field is created which will then propagate through space.

2.1 SPECIFICATION REVIEW

IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5, and 60 GHz frequency bands. They are created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802).

Table 2.1: 802.11 Protocol Network Standards

802.11 protocol	year	Frequency(GHz)	Bandwidth(MHZ)	Max. Data Rate(Mbit/s)	MIMO	Indoor Range (m)	Outdoor Range(m)
802.11	1997	2.4	22	2	No	20	100
A	1999	5/3.7	20	54	No	35	120
B	1999	2.4	22	11	No	35	140
G	2003	2.4	20	54	No	38	140
N	2009	2.4/5	20,40	65,135	4	70	250
Ac	2013	5	20,40,80,160	86,180,390,780	8	35	250

The base version of the standard was released in 1997, and has had subsequent amendments. The standard and amendments provide the basis for wireless network products using the Wi-Fi brand. While each amendment is officially revoked when it is incorporated in the latest version of the standard, the corporate world tends to market to the revisions because they concisely denote capabilities of their products. As a result, in the market place, each revision tends to become its own standard. Table 2.1 gives different protocols defined after first 802.11 protocol and their operating frequency, bandwidth, possible maximum data rate, MIMO support and range.

2.2 TYPICAL ARCHITECTURE OF WLAN SoC

The typical architecture of wireless local area network (WLAN) SoC with all integrated modules is shown in Figure 2.2. It includes protocol driver system which is having MAC, PHY and RF modules, host interface modules like PCIE or SDIO,

power management unit, PLL unit which drives the clock signal to each module present in SoC.

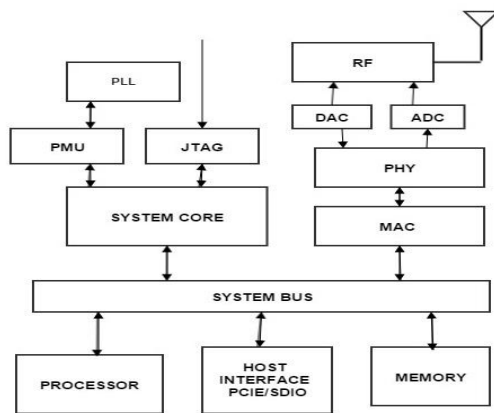


Figure 2.1: Typical Architecture of Wi-Fi Soc

The architecture of Wi-Fi SOC can be broadly divided as follows.

1. Protocol Driver

This set of hardware basically implemented as per protocol defined like 802.11n/ac.

- i. Medium access Controller hardware
- ii. PHY hardware including ADC, DAC
- iii. RF module

2. System Core

This set of hardware is responsible for system initialization, reset and debugging. It also contains PLL block which is primary source of clock though out the chip.

- i. PMU
- ii. JTAG
- iii. PLL

3. Host interface

This interface actually communicate with external world like Wi-Fi enabled laptop, Setup box or Wi-Fi routers. PCIe and SDIO are two major interfaces are used as host interfaces in industry.

4. On chip processor and memories

On chip processor is used to system boot up and instruction execution issued by MAC hardware. All these processors will have associated memories and also external memories present for software/firmware load purpose while system is waking up.

Major functionalities of MAC hardware:

1. Addressing of destination stations (both as individual stations and as groups of stations)
2. Conveyance of source-station addressing information.
3. Protection against errors, generally by means of generating and checking frame check sequences
4. Control of access to the physical transmission medium.
5. Discard malformed frames.

METHODOLOGY

This chapter gives a brief description about the methodology that was followed in the project. It describe about the Testbench environment that was set up for verification and flow of testcase generation. It gives brief introduction to functional aspects of block and also it

introduces the gate level simulation methodology with SDF.

3.1 TEST BENCH SETUP

A test bench or testing workbench is a virtual environment used to verify the correctness or soundness of a design or model. Test bench refers to an environment in which the product under development is tested with the aid of software and hardware tools.

3.1.1 TEST BENCH ARCHITECTURE

The test bench architecture which is used for current SoC is shown in Figure 3.1. It mainly contains input stimuli, test bench and device under test (DUT). A directed TCL script is the input stimuli for test bench which have default settings and set of scenarios to be verified. A typical SoC have host interfaces PCIE, SDIO, etc. and JTAG interface.

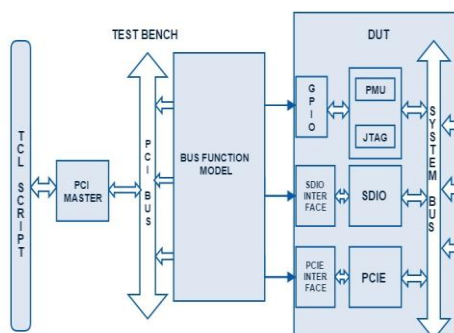


Figure 3.1: Test Bench Architecture

PCIE and SDIO can be access through the PCIE interface and SDIO interface respectively of DUT. JTAG can be access through the GPIO (general purpose input/output) pins. PCI master will drive applied input stimulus to target module like PCIE, SDIO or JTAG through PCI

BUS. We need to specify in our test case on which interface test case needs to run. All testcases can be run though any interface by providing interface command and the script will take care of handling of choosing interfaces.

3.1.2 TEST CASE GENERATION AND VERIFICATION

The flow of generating test case and its verification is shown in Figure 3.2.

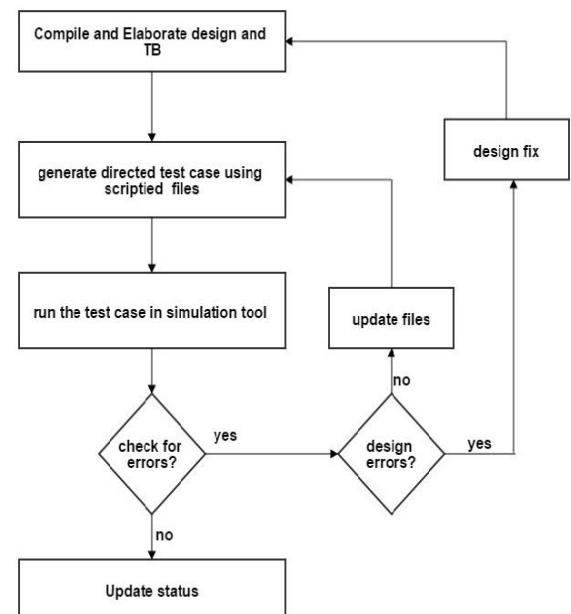


Figure 3.2: Test Case Generation and Verification Flow

As shown in figure, the design modules and respective test bench modules are compiled and elaborated using simulation tool. Using SoC specific scripting file generate directed test case which contains all the initial settings, interface (jtag, pcie, sdio, etc) to run the test case and input file having set of scenarios to be verified. Now this directed test case run on simulation tool. Check for any errors which might be

due to input directed test files or debug any design issues using debugging tools. If test is failing due to scrip errors update then and re run the test case and update. If test case failing due to design issues report bugs to respective designers and after design fix compile and elaborate again and run the test case. The above steps needs to be follow till test case pass and then update the status.

3.2 FUNCTIONAL DESCRIPTION OF MODULES

3.2.1 Power Management Unit

In low power design a set of methods are used to reduce power consumption of SoC. Out of all methods Power management unit especially plays crucial role in low power consumption. So in almost all the SoC, power management is being integrated. Power management Unit (PMU) is the most important core which manages clock/reset and power resources for the entire chip. The functioning of PMU is given high priority as many cores function on the clocks driven by it from the Phase Locked Loop (PLL).

PMU dynamically selects clocks to be operated, based on request from one or more cores and availability of resources. The PMU manages the power and clock resources for the entire chip, including Clock/Reset Management, Dynamic Clock control of Throughput clock, Low Power Clock and Ideal Mode Clock for all the modules of SoC. Driving clocks from PLL and their management. Generation of

power island-specific resets, extended Power On Reset (POR). Power Management like Controlling LPO clock frequency. Power Island on/off control that makes some resources off depending on the necessity .Strapping options to control power-up mode

The Power Management Unit (PMU) controls the oscillators and clocks with the capability of enabling or disabling the clock to the different peripherals individually in addition to enabling or disabling and configuring the available oscillators. This allows for minimizing energy consumption by disabling the clock for unused peripherals or having them run at lower frequencies.

Resource Management:

Resource management contains the information about resource power up/down sequence to be follow for all the states. Each state has the dependency on other states which must be powered up/down before the present state powered up/down. It also contains the power up/down time for each resource in sequence.

3.2.2 Clock Selection Module

PMU clock select module will decides output clock to be selected, based on clock request from one or more cores as well as on resource availability status. Any core request Throughput clock its checks whether resource current state is throughput avail, if state is throughput avail then its selects throughput as system

clock. If one core requests throughput clock and another core request Low power clock, then its gives the priority to throughput clock if throughput clock is available or it selects Low power clock as system clock. Clock select block follows the below priority in selecting output clocks.

Throughput clock > Low power clock >
Ideal mode clock

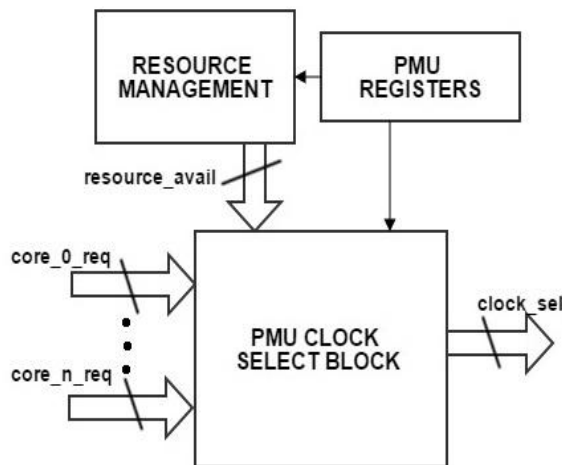


Figure 3.3: Clock Select Module

3.2.3 Clock Generation Block and PLL

The clock generation block is shown in Figure 3.4. Clock divider block gives the wide range of frequency signals which goes to different cores present on SoC. In clock divider block VCO frequency is divided by frequency dividers for accomplishing all cores wide range of clock frequency requirements. Finally these frequencies are given to clock select logic block and output clocks can be select using `clock_sel` signal and request from

individual cores which is output from PMU block.

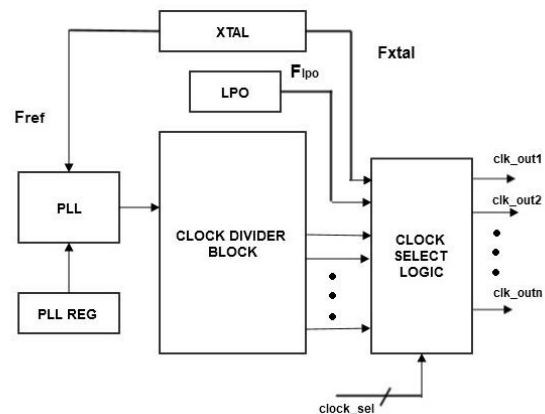


Figure 3.4: Clock Generation Block

Phased- Locked Loop:

Phase Locked Loop (PLL) is a fundamental part of radio, wireless and telecommunication

Technology. The PLL circuit performs frequency multiplication, via a negative feedback mechanism, to generate the output frequency F_{vco} , in terms of the phase detector comparison frequency, F_r . The phase-locked loop allows stable high frequencies to be generated from a low-frequency reference. Any system that requires stable high frequency tuning can benefit from the PLL technique.

Registers (PMU and PLL):

The default control values for PMU core and PLL block present in these registers. Resource management and clock requests done through the PMU registers. PLL registers have default divider integer and fractional values. Clocks request from MAC and PHY and clock gating can be done through PLL registers.

3.2.4 Clock Gating

Clock gating is a popular technique used in many synchronous circuits for reducing dynamic power dissipation. Clock gating saves power by adding more logic to a circuit to prune the clock tree. Pruning the clock disables portions of the circuitry so that the flip-flops in them do not have to switch states. Switching states consumes power. When not being switched, the switching power consumption goes to zero, and only leakage currents are incurred.

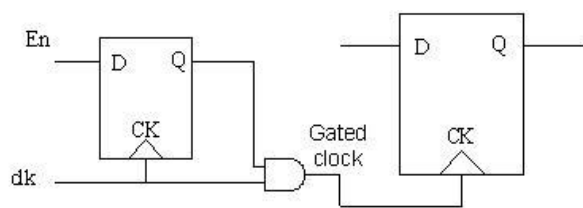


Figure 3.5: Latch Based Clock Gating

Clock gating works by taking the enable conditions attached to registers, and uses them to gate the clocks. Therefore it is imperative that a design must contain these enable conditions in order to use and benefit from clock gating. This clock gating process can also save significant die area as well as power, since it removes large numbers of muxes and replaces them with clock gating logic. This clock gating logic is generally in the form of "Integrated clock gating" (ICG) cells. However, note that the clock gating logic will change the clock tree structure, since the clock gating logic will sit in the clock tree.

Clock gating logic can be added into a design in a variety of ways:

1. Coded into the RTL code as enable conditions that can be automatically translated into clock gating logic by synthesis tools (fine grain clock gating).
2. Inserted into the design manually by the RTL designers (typically as module level clock gating) by instantiating library specific ICG (Integrated Clock Gating) cells to gate the clocks of specific modules or registers.
3. Semi-automatically inserted into the RTL by automated clock gating tools. These tools either insert ICG cells into the RTL, or add enable conditions into the RTL code. These typically also offer sequential clock gating optimizations.

Any RTL modifications to improve clock gating will result in functional changes to the design (since the registers will now hold different values) which need to be verified. Sequential clock gating is the process of extracting/propagating the enable conditions to the upstream/downstream sequential elements, so that additional registers can be clock gated.

3.3 METHODOLOGY OF GATE LEVEL SIMULATIONS EXECUTION

3.3.1 Introduction to Timing Analysis

Timing and delay information and analysis are very important and parallel flow in the ASIC design process because it brings higher level degree of realism to be implemented into the circuit model. Typically this timing information does not include in Hardware description model and the outputs of these modules are instantaneously got resolved. This strips the designer of important details such as propagation delay, pulse width, setup and hold times. The setup and hold violations could very easily lead to incorrect state transitions from the design which is not intended as per the functional requirements.

Timing characterization of entire design is tedious and time consuming endeavor and it is often ignored process in a design. So this allows most designers to be primarily concerned with the functional correctness of a circuit. In the past, this approach may have been adequate for lower speed designs. However, as technology continues to mature, meeting timing constraints for designs becomes just as important as functional correctness.

Design Flow with No Timing:

A typical Design entry which is implemented in HDL to layout design flow for ASICs is shown in figure. Essentially this HDL model is the design which is to be implemented. RTL simulations will run

on this model for verifying functional aspects of intended behavior. The synthesis tool generates gate level netlist for a given HDL modeled design using standard digital cell library respective to manufacturing technology. After this, gate level netlist go under several design flows including floor planning and an automatic place and route tool to generate the layout for the design.

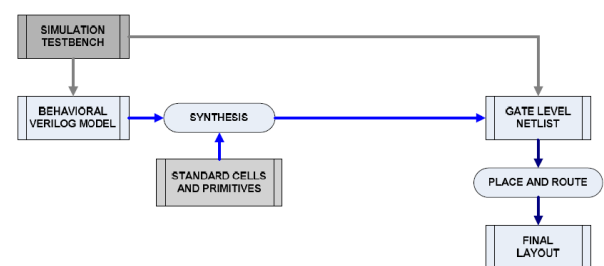


Figure 3.6: Design Flow with No Timing

At this point the design is well on its way to being finished. The design could be simulated and it could also be functionally verified to be correct. However, up to this point, no timing information has been included. There is no knowledge about whether or not setup and hold times can be met. There is no knowledge that propagation delays are appropriate. The design may be functionally correct, but after getting the chip back from fabrication, it still might fail. The reason would be that no timing information was included in the verification process and critical paths were not properly identified.

Design Flow with Timing

Additional timing characterization has to be done on the design in order to prove that it will not fail. The design flow

should be changed to include delay extraction and back annotation.

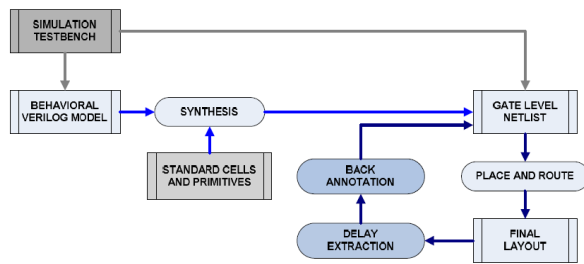


Figure 3.7: Design Flow with Timing using Back Annotation

Delay extraction will allow us to get delays from the placed and routed design. Back annotation will then take this delay information and place it back into the gate level Verilog model. Gate level simulations will carry out on this netlist for verifying design after place and route to ensure indeed functionality. At this point, the design can be simulated with timing information to ensure both functional and timing correctness.

3.3.2 Motivation for running gate level simulations

RTL simulation is the basic requirement to signoff design cycle, but as operating frequencies of SOC tremendously increased whole design need to properly verify functionally as well as for timing requirements. This is accomplishing by carry out static timing analysis and Dynamic timing analysis. Static timing analysis does not depend on any data or logic inputs, applied at the input pins. The input to an STA tool is the routed netlist, clock definitions (or clock frequency) and external environment

definitions. The STA will validate whether the design could operate at the rated clock frequency, without any timing violations. Limitations of STA lead to increasing trend in the industry to run gate level simulations (GLS) before going into the last stage of chip manufacturing. Improvements in static verification tools like Static timing analysis (STA) and Equivalence Checking (EC) have leveraged GLS to some extent but so far none of the tools have been able to completely remove it. GLS still remains a significant step of the verification cycle footprint.

The main reasons for running GLS are as follows:

1. To verify the power up and reset operation of the design and also to check that the design does not have any unintentional dependencies on initial conditions.
2. To give confidence in verification of low power structures, absent in RTL and added during synthesis.
3. It is a probable method to catch multi cycle paths if tests exercising them are available.
4. Power estimation is done on netlist for the power numbers.
5. To verify DFT structures absent in RTL and added during or after synthesis. Scan chains are generally inserted after the gate level netlist has been created. Hence, gate level

- simulations are often used to determine whether scan chains are correct. GLS is also required to simulate ATPG patterns.
6. Tester patterns (patterns to screen parts for functional or structural defects on tester) simulations are done on gate level netlist.
 7. To help reveal glitches on edge sensitive signals due to combination logic. Using both worst and best-case timing may be necessary.
 8. It is a probable method to check the critical timing paths of asynchronous designs that are skipped by STA.
 9. To avoid simulation artifacts that can mask bugs at RTL level (because of no delays at RTL level).
 10. Could give insight to constructs that can cause simulation-synthesis mismatch and can cause issues at the netlist level.
 11. To check special logic circuits and design topology that may include feedback and/or initial state considerations, or circuit tricks. If a designer is concerned about some logic then this is good candidate for gate simulation. Typically, it is a good idea to check reset circuits in gate simulation. Also, to check if we have any uninitialized logic in the design which is not intended and can cause issues on silicon.

12. To check if design works at the desired frequency with actual delays in place.
13. It is a probable method to find out the need for synchronizers if absent in design. It will cause “x” propagation on timing violation on that flop.

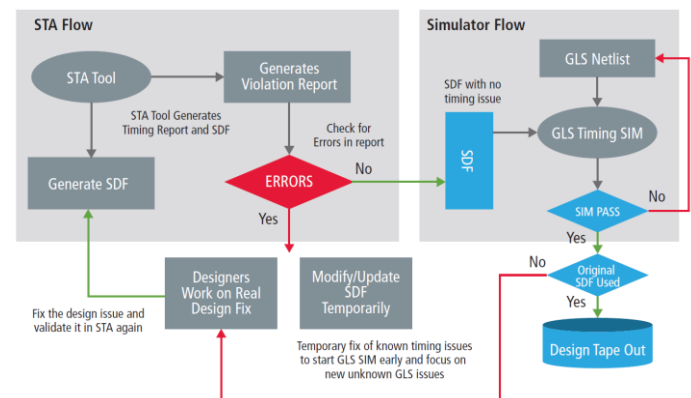


Figure 3.8: GLS Execution flow

Execution Strategy for GLS

1. Planning the test-suite wisely to be run in GLS

In highly integrated products it is not possible to run gate simulation for all the SoC tests due to the simulation and debug time required. Therefore, the list of vectors which are to be run in GLS has been selected judiciously. The possible candidates for this list are

- i. Testcases involving initialization, boot up.
- ii. All the blocks of the design must have at least one testcase for GLS.
- iii. Testcases checking clock source switching.

- iv. Cases checking clock frequency scaling.
- v. Asynchronous paths in the design.
- vi. Testcases which check entry/exit from different modes of the design.
- vii. Dedicated tests for timing exceptions in the STA.
- viii. Patterns covering multi clock domain paths in the design
- ix. Multi reset patterns are a good candidate for GLS

It must also be made sure that the test cases selected to be run in GLS are targeting the maximum desired operating frequency of the design. Should there be no time constraints, all tests run in RTL simulations can be rerun in GLS. Also, if there are no tests fulfilling the criteria mentioned above, then they should be coded.

2. Test bench updates for GLS

A list of all the synchronizer flops is generated using CDC tools. Also, other known asynchronous paths where timing checks needs to be turned off are analyzed and complete list of such flops is prepared which also includes reset synchronizers. The timing checks are turned off on all such flops to avoid any redundant debugging, otherwise they will cause “x” corruption in GLS. This work should be ideally done before the SDF arrives .It may happen that the name of the synchronizers in RTL and the netlist are different. All such flops should be updated

as per netlist .Also, the correct standard cell libraries, correct models of analog blocks, etc. need to be picked for GLS.

3. Initialization of non-resettable flops in the design

One of the main challenges in GLS is the “x” propagation debug. X corruption may be caused by a number of reasons such as timing violations, uninitialized memory and non resettable flipflops. There are uninitialized flops in design which by architecture are guaranteed to not cause any problems (if they settle to any value at start). Thus, there is a need to find out all such flops in the design (which are reviewed with designers) and initialize them to some random value (either 0 or 1) so as to mimic silicon.

4. Unit delay GLS for Testbench cleanup

This step is not compulsory but is generally very fruitful if employed in the GLS execution. The setup is done for unit delay GLS (no SDF) and the testcases that are planned to be run on gate level are run with this setup to clean the testbench. This is done because the unit delay simulations are relatively faster (than those with SDF) and all the testbench/testcase related issues can be resolved here (for example - change probed logic hierarchy from rtl to gate, wrong flow of testcase, use of uninitialized variables in the test cases that can cause corruption when read via core, etc). Running the unit delay GLS is recommended because one can catch most

of the testbench/testcase issues before the arrival of SDF. After the SDF arrives, focus should be more on finding the real design/timing issues, so we need to make sure that the time does not get wasted in debugging the testcase related issues at that time.

5.Annotation warnings cleanup on SDF

When the SDF is delivered to verification team, then the simulations are run with the SDF/netlist. Specific tool switches need to be passed which picks up the SDF and tries to annotate the delays mentioned in the SDF to the corresponding instances/arcs in the netlist. This is known as back-annotation.

During this process, many annotation warnings are encountered which need to be analyzed and either sorted out or waived off by the design team. Most important warnings which need to be looked into are the ones which are due to non-existent paths i.e. the SDF has an arc but netlist does not have it. Also, there can be mismatch between the simulation model “specify” block and .lib of the IP.

5. Running GLS with SDF:

Early SDF (for initial debug) this step involves use of a SDF in which timing is met at a lower frequency than target and GLS can be run at that frequency. This helps in cleaning up the flow and finding certain issues before the final SDF arrives.

This step starts with the SDF in which timing is met at target frequency. The entire setup is done and the planned pattern-suite is run on this setup and failures needs to be debugged according to a priority list which should be made before hand. All the high priority patterns need to be debugged first.

Challenges faced during GLS setup

GLS with SDF delays annotated is usually very slow and time consuming. A lot of planning is needed to wisely select the patterns that need to be simulated on netlist. Run-time for these tests and memory requirements for dump and logs must also be considered. Identifying the optimal list of tests to efficiently utilize GLS in discovering functional or timing bugs is tough. These are to be decided with discussions with timing team and design team on which paths are timing critical/asynchronous and needs to be checked.

GLS is much more difficult than RTL simulations as delays of gates, interconnects comes into picture and RTL assumptions for arrival of data/clock may mismatch causing failures. During the initial stages of GLS, identifying the list of flops/latches that needs to be initialized (forced reset) is a big hurdle. The pessimism in simulations would cause “x” on the output of all such components without proper reset, bringing GLS to a standstill. If approved by design and architecture team, these initializations should be done to move forward.

During synthesis, the port/nets may get optimized or re-named to meet the timing on these paths. Monitors/Assertions hooked in Testbench during RTL simulations need to be revised for GLS to make sure the intended net is getting probed. Also, in netlist there can be inverters that can be inserted on that signal driver due to boundary optimization and can cause false failures (not having any design issues). This is really tough to figure out and debug.

If the gate level simulation with SDF is done without a complete synchronizer list, then failure debug to find such cases on gate level is quite cumbersome. Multiple debug iterations may happen in GLS to find out many such flops.

Debugging the netlist simulations is a big challenge. In GLS, models of the cells make the output “x” if there is a timing violation on that cell. Identifying the right source of the problem requires probing the waveforms at length which means huge dump files or rerunning simulations multiple times to get the right timing window for violations. The latest tools are offering “x” tracing techniques for quickly tracing the source of “x” propagation. Such tool features need to be explored. All said and done, it can be concluded that one requires a lot of patience while debugging the GLS waveforms.

In short, despite being a time consuming activity and having many challenges in setup and debug, GLS is a great confidence booster in the quality of the design. It can uncover certain hidden

issues which get missed out or difficult to find by RTL simulations. This is the reason many organizations prefer this activity before tape-out because it is more close to the actual silicon and gives a fairly good idea about how the design will behave in real. The probability of having sound sleep after tape out improves with GLS.

3.3.3 Standard Delay Format and Generation of SDF Files

This section is an overview of the Standard Delay Format (SDF). The best description of what the SDF is can be found in the opening paragraph of the IEEE Draft Standard.

“The Standard Delay Format (SDF) was designed to serve as a simple textual medium for communicating timing information and constraints between electronic design automation tools. The original version was designed by Rajit C. Chandra in 1990 while at Cadence Design Systems, and was intended as a means of communicating macrocell and interconnects delays from Gate Ensemble to Verilog-XL, Veritime and other stand-alone tools requiring timing data”

The SDF was designed from the ground up to be an easy way to convey timing information to a simulator. The SDF file can furthermore be utilized by other design tools. It can be leveraged to convey design constraints identified during timing analysis to layout tools (forward annotation) and it can also be used for post

layout timing analysis and simulation (back annotation).

The figure on the following page depicts the general flow of how to use SDF files in an ASIC design. The SDF files are most often generated by a delay calculator. This delay calculator uses information from a placed and routed design. After the SDF file is generated by the timing calculator, simulator will be used to back annotate this delay information into the design description. Timing characteristics of ASICs are strongly influenced by interconnect affects. This is why back annotation is most often done post layout. The SDF imposes no restrictions on the precision of the timing data being represented. This implies that the accuracy of the timing data is dependent on the accuracy of the timing calculator.

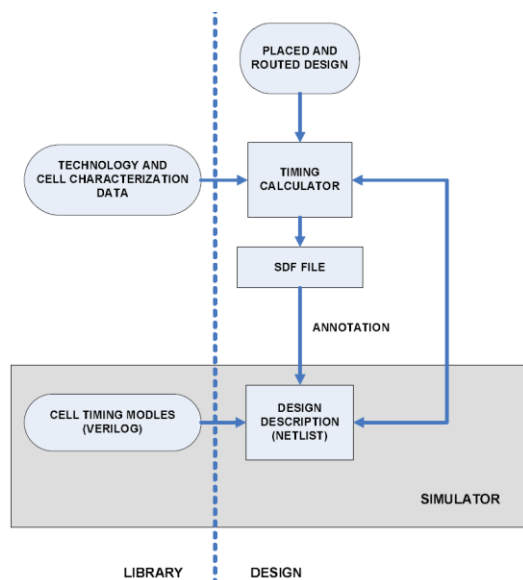


Figure 3.9: SDF Generation and Back Annotation

Timing Checks

The SDF has many different timing checks available. The important ones are the setup, hold, recovery and width timing checks. They will be discussed below. The format for the timing checks is a timing check definition followed by the appropriate delay information. This delay information varies for each timing check.

Setup Time: This is the setup timing check. It is defined as the time before a clock that the signal must remain stable in order for that signal to successfully be stored into the device. The format is the keyword SETUP followed by an input port specification followed by an output port specification followed by the delay values.

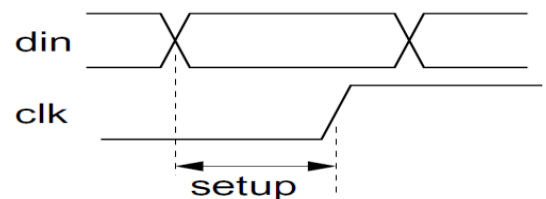


Figure 3.10: Setup Time

Example: (INSTANCE x.a)
(TIMINGCHECK
(SETUP din (posedge clk)

(12))

)

Hold Time: This is the hold timing check. It is defined as the time after a clock edge in which a signal must remain stable. The format is the keyword HOL followed by an input port specification followed by an output port specification followed by the delay values.

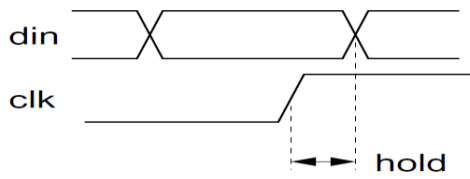


Figure 3.11: Hold Time

```
Example: (INSTANCE x.a)
(TIMINGCHECK
 ( HOLD din (posedge clk)
```

(10))

```
-----
-----
)
```

Setup and Hold Combined: This is a combination of setup and hold. Its format is the keyword SETUPHOLD followed by input port followed by output port followed by setup delay values followed by hold delay values.

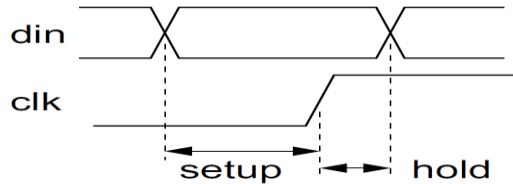


Figure 3.12: Setup and Hold Time

```
Example: (INSTANCE x.a)
(TIMINGCHECK
 (SETUPHOLD din
 (posedge clk) (12) (9.5) (CCOND ~reset))
```

```
-----
-----
)
```

Recovery Time: The recovery time is defined as the limit of the time between the release of an asynchronous control signal from the active state and the next active clock edge. The format is the keyword RECOVERY followed by an

input port followed by an output port followed by the delay values.

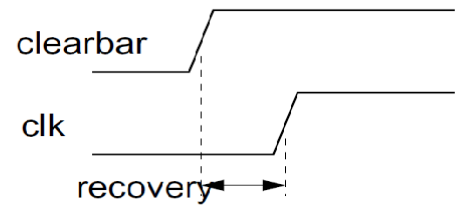


Figure 3.13: Recovery Time

```
Example: (INSTANCE x.b)
(TIMINGCHECK
 ( RECOVERY (posedge clk) (10.5))
 clearbar) (posedge clk) (10.5))
```

```
-----
-----
)
```

Removal Time: The removal shall specify limit values for removal timing checks. A removal timing check is a limit of the time between an active clock edge and the release of an asynchronous control signal from the active state, for example between the clock and the clearbar for a flip-flop. If the release of the clearbar occurs too soon after the active edge of the clock, the state of the flip-flop shall become uncertain it could be the value set by the clearbar, or it could be the value clocked into the flip-flop from the data input. In other respects, a removal check is similar to a hold check. The syntax for removal timing check is described in Syntax

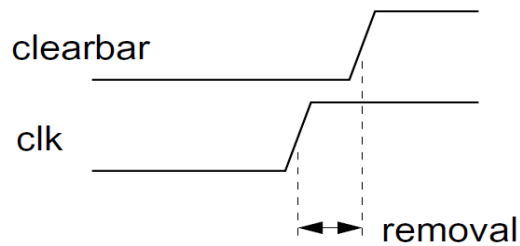


Figure 3.14: Removal Time

```
Example: (INSTANCE x.b)
         (TIMINGCHECK
          (REMOVAL (posedge
clearbar) (posedge clk) (10.5))
         -----
         -----
         )
```

Width: The width timing check specifies a limit for a minimum pulse width. If the signal has unequal phases, two pulse widths can be specified.

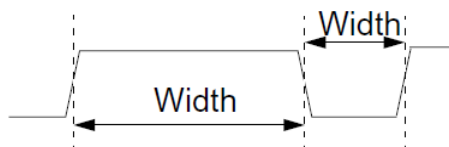


Figure 3.15: Width Timing Check

```
Example: (INSTANCE x.b)
         (TIMINGCHECK
          (WIDTH (posedge clk)
(30))
          (WIDTH (negedge clk)
(16.5))
         -----
         -----
         )
```

Verilog Back Annotation:

Back annotation is the process by which timing information is added into a design so that the design can be simulated with realistic delays. For this section back annotation requires that a SDF file has been generated for a design and that specify blocks with path delays have been defined for cells.

3.3.4 Importance of Corner case Simulations

The propagation delay varies significantly due to variations in transistor operating parameters over the environmental changes which include operating supply voltages and temperature variations and process changes. Process variations are due to variations in the manufacture conditions such as temperature, pressure and dopant concentrations.

- A higher voltage makes a cell faster and hence the propagation delay is reduced
- A higher temperature will decrease the threshold voltage
- Variations in the process parameter leads to transistors have different transistor lengths throughout the chip. This makes the propagation delay to be different.

These variations can be modelled under different corner case like fast (minimum delay) and slow (maximum delay) and these are shown in Table.

Table 3.1: Corner cases

Corner	Environmental Parameter		Process Parameter
	Voltage	Temperature	V_{th} Voltage
Fast	V_{nom}	$-40^{\circ}C$	V_{thnom} - ΔV_{th}
Slow	V_{nom}	$125^{\circ}C$	V_{thnom} - ΔV_{th}
Typical	V_{nom}	$27^{\circ}C$	V_{thnom} - ΔV_{th}

So apart from typical SDF generation we need generate SDF for maximum and minimum corners too using worst case conditions and finally using these SDF, carry out gate level simulations for verifying the design under corner conditions this eventually boost the confident on designed modules. Run slow corner simulations for delay analysis and fast corner simulations for power and race conditions like hold time analysis.

3.4 TOOLS USED IN PROJECT

3.4.1 Cadence Ncsim Simulator

Ncsim from Cadence is used as a solution for all simulation and verification environments. It provides engines for Coverage, constraint solver, Assertions to name a few. Ncsim provides many options to collect and analyze the simulation data effectively and debug them using waveform dumping. This tool is used for compilation and elaboration of both Verilog and VHDL model and commands

can be given from console or GUI provided by vendor.

3.4.2 NOVAS DEBUG PLATFORM (VERDI)

Novas Debussy debug system, Verdi automated debug system is used for the debugging and has the best interactive feature for debugging when we want to back trace a signal, it will be able to show all the drivers respective to that load, and also it has the facility for grouping of signals and this also comes into handy when analyzing the signals. The Verdi Automated Debug System is an advanced open platform for debugging digital designs with powerful technology that helps you comprehend complex and unfamiliar design behavior, automate difficult and tedious debug processes and unify diverse and complicated design environments.

nTrace: A source code viewer and analyzer that operates on the KDB to display the design hierarchy and source code for selected design blocks. It allows the tracing of signals across the design.

nWave: A state-of-the-art graphical waveform viewer and analyzer that is fully integrated with Verdi. It allows viewing the signals value and waveform. Figure 3.4.1 shows GUI interface for nTrace and nWave.

ANALYSIS

This chapter shows the results which illustrate basic functional behavior of PMU and Clock Generation Block through obtained waveforms. The timing violations that were caught during GLS are also explained through waveforms and the regression status while verifying these blocks at the end of the project.

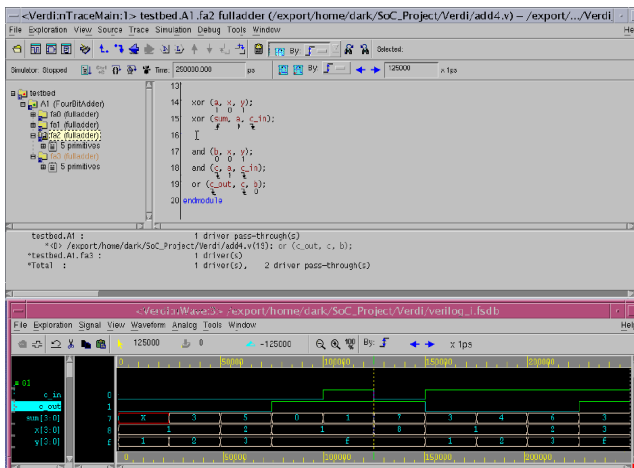


Figure 3.16: Verdin window for nTrace and nWave.

nSchema: As shown in figure 4.4.2 a schematic viewer and analyzer that generates interactive debug-specific logic diagrams showing the structure of selected portions of a design. Flexible schematics and block diagrams give you the ability to display logic and connectivity using familiar symbols.

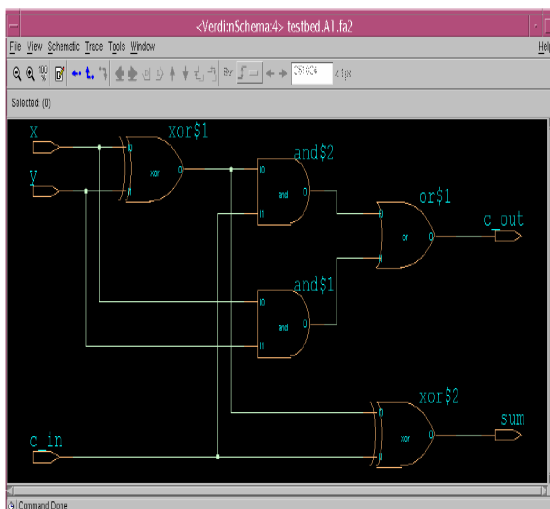


Figure 3.17: nSchema Window

4.1 OUTPUT WAVEFORM ANALYSIS

Figure 4.1 describes the basic Clock request from different cores and final PMU output for requests based on availability of resources that are required for current state requirement. In the present SOC, there are total six cores present and each core has separate clock request depending on system requirement. Here before request for any clock, we must ensure the all the resources should be in 'ON' state and clock_avail signal should go active.

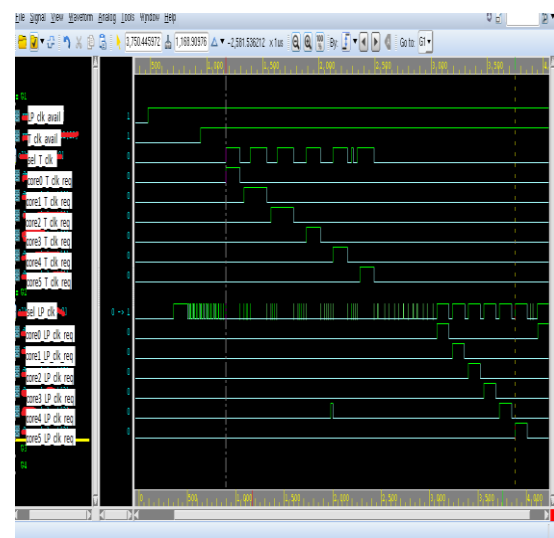


Figure 4.1: Output waveform shows Clock request from different cores and PMU output for requests.

Figure 4.2 describes how exactly PMU determines the priority over the request and availability of resources. Here it explains PMU final clock select for a single core with multiple clock requests. Initially all clocks (H_clk, LP_clk and IM_clk) are available and there is request for H_clk so T_clk is selected as final clock to be run. After some time T_clk turned off, now PMU look for next available clock and LP_clk is available so PMU select LP_clk as final clock even though there is a request for T_clk. Similarly same priority is followed for LP_clk over IM_clk.

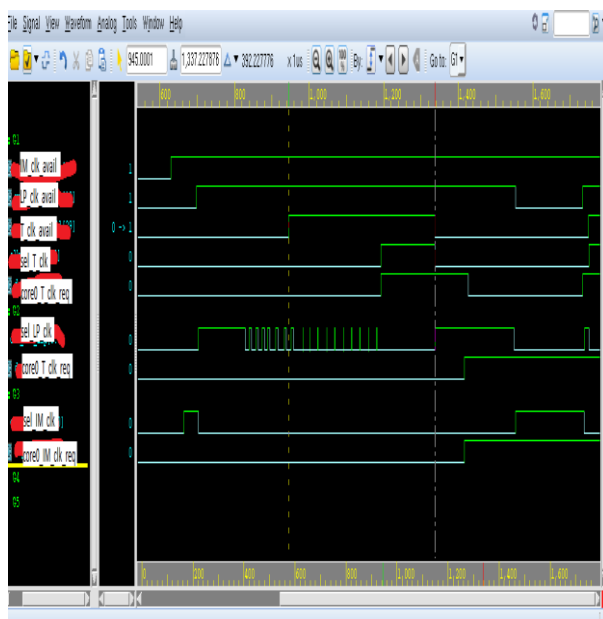


Figure 4.2: Output waveform shows PMU priority over request and availability of resource

Figure 4.3 explains programming of PLL dividers and respective output frequency on PLL VCO output. Here PLL is

provided with set registers which can be program as per require of

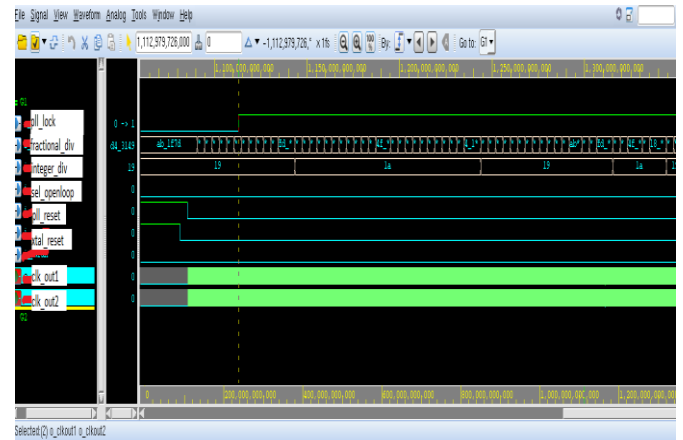


Figure 4.3: Output waveform shows programming of PLL dividers and respective frequency

clock frequency. There are two parts in divider registers first part is integer divider and fractional part for fine tune of signal frequency. In this the reset sequence of PLL has been shown and PLL is in close loop and it must not lost its lock during small step change of frequencies which can be observed in this waveform.

Figure 4.4 describes clock gating implementation which is a low power technique. Here clock gating block generates output signal based on clock enable during which gives output as input and rest of the skips the pulses. The number of pulses need to be skip and number of pulses need to pass can be program through registers and using these values internal timers will toggle clock enable signal. In following example total seven pulses have been skipped and only three pulses are present on output signal and this repeats for every ten pulses.

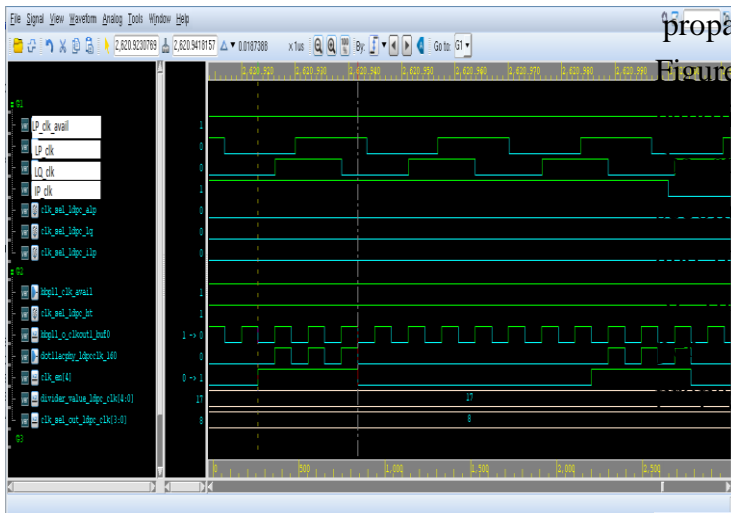


Figure 4.4: Output waveform shows Clock Gating Implementation.

Figure 4.5 shows ‘X’ propagation due to non resettable flipflop. Here a 4-bit register outputs are initially ‘X’ and when there is a first rising edge of clock with rst_n, clr are being at ‘0’, all flip flop should get reset. But second flipflop is not resettable and this cause ‘X’ propagation. After releasing reset also second flipflop is sampling the input as ‘X’ at the output.

Figure 4.5: Output waveform shows ‘X’ propagation due to non resettable flipflop.

Figure 4.6 shows one possible way of handling ‘X’ propagation problem. Here at the starting of simulation the output of second flipflop is deposited to logic ‘0’ and this make sure that output is at logic ‘0’ till next assignment for this output as per logic. So this eliminates ‘X’ propagation due to non resettable flipflop.

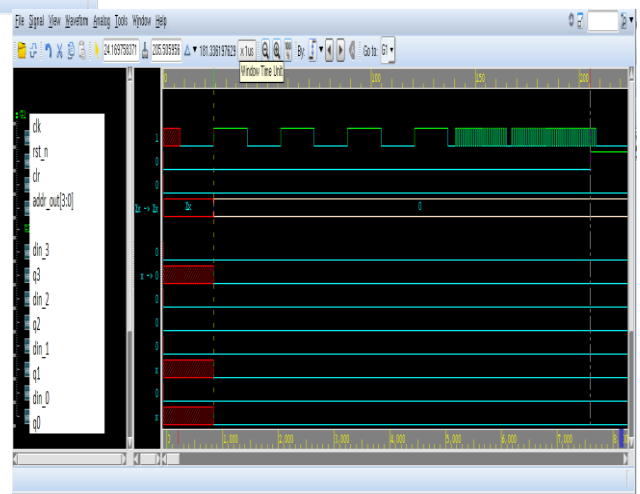


Figure 4.6: Output waveform shows depositing ‘0’ on non resettable flipflop output

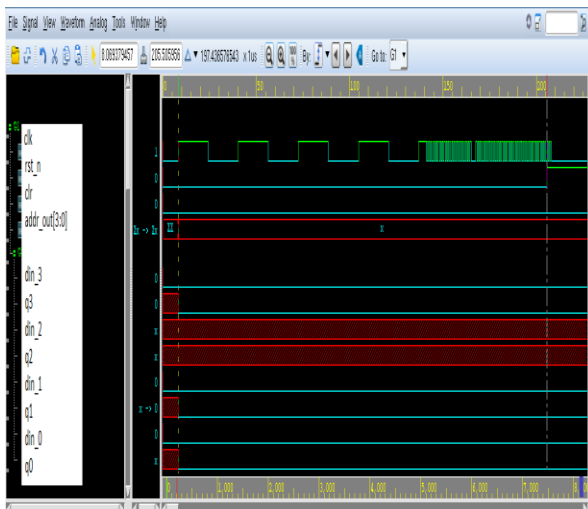


Figure 4.7 shows another possible way of handling ‘X’ propagation problem. Here at the starting of simulation the output of second flipflop is deposited to logic ‘1’ and this make sure that output is at logic ‘1’ till next assignment for this output as per logic. So this eliminates ‘X’ propagation due to non resettable flipflop.

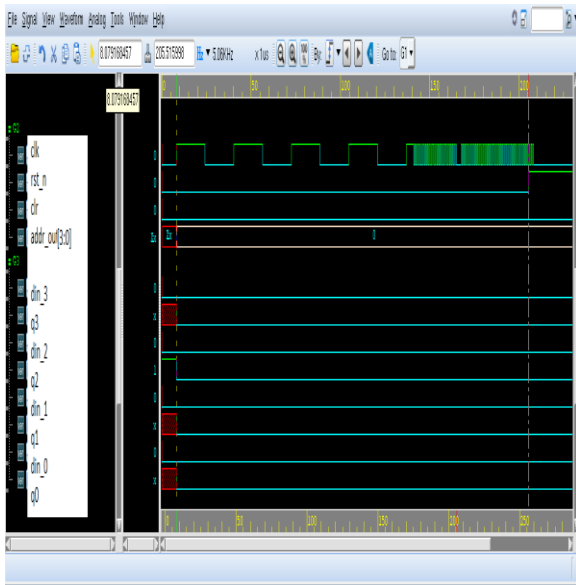


Figure 4.7: Output waveform shows depositing ‘1’ on non resettable flipflop output.

Figure 4.8 shows setup time violation. Here enabled signal and resetb of flipflop are at logic ‘1’ so input value is sampled at output at rising edge of clock. But as shown in figure the minimum amount of time during which data at input is not stable before clock edge which leads to metastability state of flipflop and this makes flipflop output as ‘X’

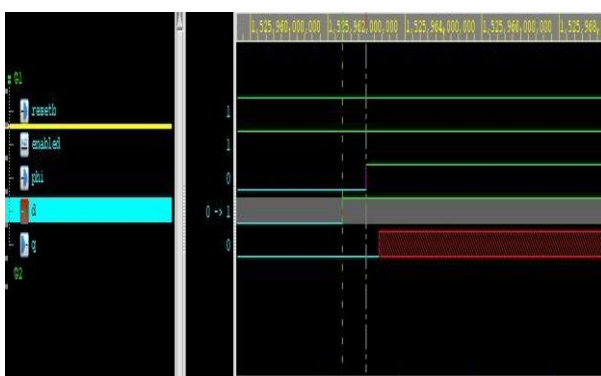


Figure 4.8: Output waveform shows setup time violation

4.2 REGRESSION STATUS RESULTS

To know the amount of verification completed we run the regressions periodically or/and after any design changes in RTL. Here these regressions have been run for both RTL simulations and gate level simulations throughout the projects. The following tables give regression status for RTL and GLS simulations of Chip1 and Chip2.

Table 4.1: Regression status for RTL simulations of Chip1

Module	Total no of Testcases	No. of testcases passed at starting of project	No. of testcases passed at end of project
PMU	36	9	36
CGB	29	12	29

Table 4.2: Regression status for Gate Level Simulations of Chip1

Module	Total no of Testcases	No. of testcases passed at starting of project	No. of testcases passed at end of project
PMU	13	5	13
CGB	15	4	15

Table 4.3: Regression status for RTL simulations of Chip2

module	Total no of Testcases	No. of testcases passed at starting of project	No. of testcases passed at end of project
PMU	43	8	43
CGB	37	15	37

Table 4.4: Regression status for Gate Level Simulations of Chip2

Module	Total no of Testcases	No. of testcases passed at starting of project	No. of testcases passed at end of project
PMU	15	4	15
CGB	19	7	19

CONCLUSION AND FUTURE SCOPE OF WORK

This chapter gives a quick overview about the summary of the work done during the project and also the conclusions of the project work and the challenges that were faced in the execution of the project alongside the future scope of it.

5.1 WORK SUMMARY

The main objective of the project design verification of PMU and clock generation block through RTL and gate level simulations. As design progress RTL would go several transformations and at each such case designed model must ensure error free. In order to achieve complete and robust design, first models of PMU and clock generation block are functionally verified through RTL simulation with comprehensive testcases. Functional verification does not satisfy complete verification so for timing verification which vital gate level simulations have been run with sub set of testcases those involves reset sequence and at clock domain crossing. Regressions have been run periodically to know the status of design verification.

5.2 CONCLUSIONS

The work concludes that the design verification of Power management unit and clock generation block has completed successfully for two target chips. There were many design change with respect to first chip in both specification wise and manufacturing technology wise. The functionality of these blocks thoroughly verified with help of RTL and gate level simulations and 100% regression status has achieved before the tapeout of two chips. During cycle of verification several bugs were found and out of them some are very critical and they were reported to respective design owners. Similarly during gate level simulations many timing violation have caught and reported to

backend team and this cycle repeated till end of project.

5.3 FUTURE SCOPE OF WORK

The developed scripts for verifying scenarios were made as generic which permits future chips can adopt these testcases with less efforts which intern reduce design cycle. All register read or writes have made generic to all other chips which are design phase or architecture phase in which by giving base address only we run all testcases as register set index is fixed for all core registers and this can be easily understood by designers and help them to reduce debugging efforts.

The developed test bench setup and set comprehensive testcases can easily migrate to system verilog platform which is popular language for verification in industry which provides more feasible constructs. The existing sequences in TCL language can directly port to System verilog platform and there is a scope of increase in automation in new platform.

The next step after the verification is followed by the backend flow, and any issues that they come across during this process will be brought to the notice of front end designers if they are related to functional issues and once they are fixed the models are delivered to the SOC team and it goes through one more verification flow and after successful fabrication comes as a product in next generation Wi-Fi SOC.

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