

# Block Level Physical Design of Interfacing Module in RISC Core

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**Abstract**— *The physical design plays a major role in implementing the circuit and logic cells physically, because physical devices and interconnecting materials will have its own parasitic resistances and capacitances. Placement and Routing (PNR) flow involves proper placement and routing the interfacing module including majorly PCI and SDRAM. In this project work digital cells called standard cells and macro are placed with minimum congestion of 3% in a block. And routing is done by keeping in mind the manufacturability by utilizing non default rule (NDR) design rules. The clock tree network is built by using the H-Tree network topology. The power network is synthesized with higher metal layers available in technology node. This project is implemented in TSMC 120nm technology, which has 7 metal layers but as this project is block level so 6 metal layers are used for routing. The clock frequency of block system is 250MHz is used as the main clock, peripheral clocks and generated clock of 133MHz. The GDSII format of layout is generated with no violations.*

## I. INTRODUCTION

The chip design is a complex process which has to be handled in hierarchy block level. The entire design is partitioned into sub-blocks depending on the logical connectivity and level of hierarchy. Typically standard cells have a constant height that allows them to be lined up in rows on the integrated circuit. So the physical design is directly related to the technology nodes, irrespective of coding technique. So this ASIC physical design is hot domain in VLSI industry.

This project is carried out with the help of Synopsys IC Compiler tool by preparing Milky-Way database.

The chip will consist of a very large number of rows (with power and ground running next to each row) with each row filled with the various cells making up the actual design. Placers obey certain rules: each cell is assigned a unique (exclusive) location on the die map. A given gate is placed once, and may not occupy or overlap the location of any other gate. Using the placement netlist and the layout view of the standard cells, the router adds both signal connect lines and power supply lines. The fully routed (physical) netlist contains the listing of cells (from synthesis), the placement of each cell (from placement), and the drawn interconnects (from routing).

In 1958 IC has been invented, at that time only few numbers of transistors are placed per unit area. In 1965 it is

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observed that the integration of transistor devices on a same unit area is increased by more than double. From this observation Gordon E Moore stated that the transistor integration will increase by double every 18 months [1].

Block level physical design involves the designing the layout without considering the pin pads. Block level has peripheral interconnecting in the form of ports. Usually the complex chip design starts with the block level physical design. Each block consists of different number of standard cells and macro's. While designing a chip, in block level half cell concept is used for abutting with the neighboring blocks.

Chip level physical design includes the combination of the block levels. Chip level design is top level integration of blocks. At the periphery IO pads and IO pins are included for external world connection. For IO pads ESD (electrostatic discharge) protection circuits also need to be implemented. ESD is a huge topic of research, so this desertion work will not be covering about this.

The complex digital systems are designed with hardware modules which interact by transferring information and synchronizing their inputs and outputs. In this project the interfacing modules like PCI (peripheral component interface) and SDRAM (Synchronous Dynamic Random Access Memory). The ORCA (Optimized Reconfigurable Cell Array) is considered as a reference for implementing the interfacing module in a RISC core processor. The details regarding RISC (Reduced Instruction Set Computer) is out of scope of this project work. A RISC is computer architecture that reduces chip complexity by using simpler instructions.

VLSI physical design includes the tasks like floor-planning and partition of logical groups and power required. Power planning involves the power network synthesis and analysis. Clock tree synthesis involves distribution of clock signal in the block by inserting required number and strength of cells. Routing involves the rule based and non default rule based routing metals for interconnection. Routing includes power, clock and signal routing. The final stage is to generate a GDSII from the DRC violation free and violation free timing.

## II. OVERVIEW OF THE ASIC PHYSICAL DESIGN

The physical design is implementing the digital chip from the synthesized gate level netlist. ASIC implementation is divided mainly 3 types as Front end (RTL design and Verification), DFT (Scan insertion) and Back end (Physical design) Digital circuits are interconnected sets of logical gates that perform operations varying from very simple such as AND, OR, NOR, XOR to very complex such as programmable general purpose processors, image processing, graphics processing.

In semiconductor design, standard cell methodology is the way of designing Application Specific Integrated Circuits (ASICs). Standard cell methodology is an example of design abstraction, whereby a layout view of a logic function is encapsulated into an abstract logic representation (such as a NAND gate). Cell-based methodology (the general class that standard-cell belongs to) makes it possible for one designer to focus on the high-level (logical function) aspect of digital-design, while another designer focused on the implementation (physical) aspect. The library along with a logic level design netlist (list of connections) is the basis for exchanging design information between different phases of the SPR (Standard Cell Place and Route) process[3].

The few of the important algorithms helps to do PNR (placement and routing) of the cells. Placement algorithms includes, simulated annealing, simulated evolution, force directed placement, Breuer's algorithm, cluster growth algorithm [2].

### III. PHYSICAL DESIGN FLOW

The physical design involves the portioning, floor-planning, placement, Clock Tree Synthesis, Routing, compaction, extraction and verification. In figure 4.1 circuit design and fabrication is out of scope of this project. The following flow diagram shows the brief overview of digital back end design flow.

#### A. Partitioning:

Partitioning is the process where the entire design block is sub-divided into many sub-blocks depending on either hierarchy or criticality of the blocks. Block means the logical circuit which is sub part of the main logical circuit.

#### B. Floor-planning and Placement:

This step involves deciding the area which will be sufficient to place and route the design without any congestion and manufacturability issues. Placement involves the placement of the critical blocks which are sensitive at to the noise or any third order effects. Automated cell placement for VLSI circuits has always been a key factor for achieving designs with optimized area usage and timing behavior [4]. There are essentially two types of placement that the IC Compiler allows the designer to do, which is Timing-Driven placement and Congestion-Driven placement. Besides these, other types of placement include Block level placement and Hierarchical placement. After placement timing analysis is done by considering the virtual routing lines.

#### C. CTS and Routing:

Once the timing and size of the design if frozen then the clock tree synthesis is created where the clock tree buffers or inverters are inserted to balance the load and skew between the blocks. Routing is critical stage in PNR, which is done with 2 stages as global routing and detailed routing. The routing of metals includes the parasitic resistance and capacitance in the design. If the routing feels too complex then the re floor-planning and placement is carried else the compaction is done.

#### D. Compaction:

Compaction is the process where the redundant metals are removed and extraction of the parasitic is done for actual timing analysis.

#### E. Timing Verification:

In this step the parasitic resistance, capacitance are extracted with the help of wire load models. Wire load models are developed by the chip manufacturing units by rigorous development and testing. Extraction is done in the file format SPEF. This extracted data is used for the final timing analysis. If the timing is met with the specified specification then the GDSII is extracted and sent to the fabrication unit for manufacturing the chip. Sometimes if the timing is not met then it should be rerouted the some blocks or whole block and then checked for timing. Even then the rerouting will not satisfy the timing window, need to go back to the placement stage, where whether timing and sizing is sufficient or more than sufficient is analysed and timing analysis is done. Finally in worst case even placement does not solves the issues then portioning is done once more. From above discussion it shows that the timing and cross verification at each step will keeps the project flow clear and successful.

The flow diagram shown in figure 3.1 is one type of flow. The basic idea like floor-planning, partitioning, power planning, clock tree synthesis, routing flow will be maintained. The way to perform it might from designer to designer. The timing is checked at every step for the flow of the physical design.

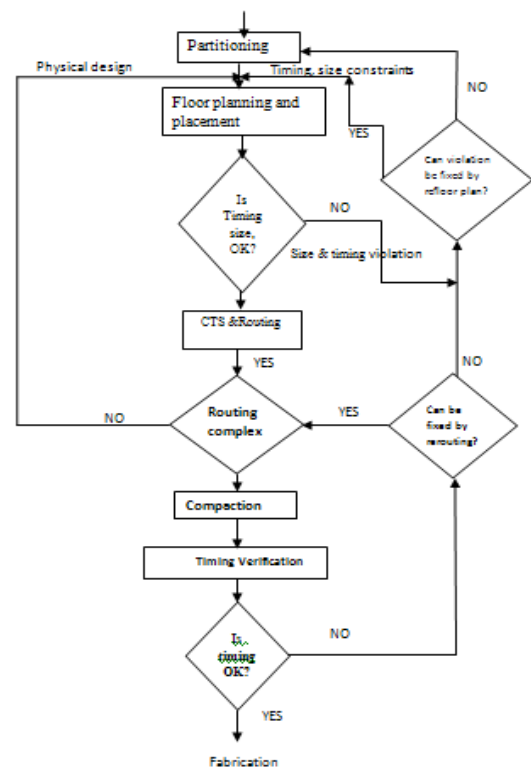


Figure 3.1: Physical design flow diagram [5].

### IV. IMPLEMENTATION

#### A. Data Setup

The library or data set-up preparation is done initially before proceeding into the implementing the physical process of block. It involves sourcing the required data's, files into the home directory. The following are important files needed and setting the parameters as per the design.



1. Design Input data: synthesised gate level net list. Gives the logical connectivity of the cells.
2. Constraints File: Synopsys Design Constraint  
In this file timing specifications are specified for the design.
3. Libraries,
  - i) model file
  - ii) Physical libraries:
  - iii) technology libraries
  - iv) Logical Library
4. Technology File  
In this fabrication related information like metal conductivity, width, spacing and layer name is specified.
5. TLU Plus  
In this file the R and C values are specified.

The following process flow in figure 4.1 shown is used for the implementing this project. In each process step there will be many or few steps to finish the process. The input for the data set up flow is verilog, technology files, physical and logical libraries. And output is GDSII in the form of layout.

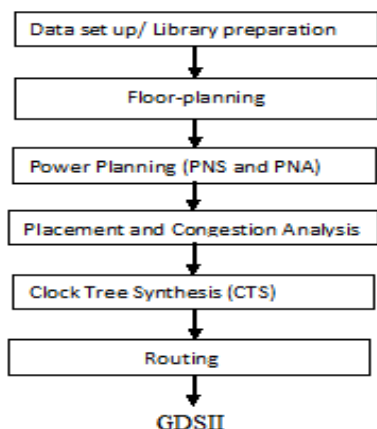


Figure 4.1: Flow diagram of physical design of block

The above diagram in figure 4.1 shows the complete flow of the physical design. Some steps can be altered as and when applicable. Analysis step is followed every stage for accuracy.

### B. Floorplanning

Floor-plan involves the area decision for block and chip, this is very critical stage in chip design. This is done by applying the floor-plan constraints like aspect ratio, core utilization, IO utilization. Floor-plan could be changed if it is not fitting into the given area. Sometimes floorplan aspect ratio might change to accommodate the all the standard cells and macros. The core, macro and IO utilization should be retained same for to maintain the logical functionalities of the design.

In this design aspect ratio is 1, which means the block should be square including the core, IO clearance and IO ports. As this design is block level physical design, which does not considers the IO pins/pads (special ESD issue should be taken care). Each cell inside the block has its own pins for interconnecting between block cells. The block boundary has the ports which will be connecting to another block ports or sometimes IO pads too. The report related to floor-plan is given in the following table,

TABLE OF FLOORPLAN

NUMBER OF MACRO CELLS	12
NO. OF STANDARD CELLS	10865
NO. OF PINS	65514
NO. OF IOPINS	144
NO. OF CELL ROWS	192
ASPECT RATIO	1
CORE CELL UTILISATION	77.02%

Table 4.2.1: Floor-plan information before pre-CTS

The floor-plan is specified as the aspect ratio, core utilization, core to IO distance at top, bottom, left, right, boundary area. The table 4.2.1 shows the floor-planning constraint.

Specifications:

Aspect Ratio: 1 (width=1, length=1)

Core Size: width 710um, Height 710um

Block Size: width 750um, height 750 um

Clock frequency: 250MHz (main system clock) and 133MHz(generated clock)

Power consumption acceptable: 50Mw

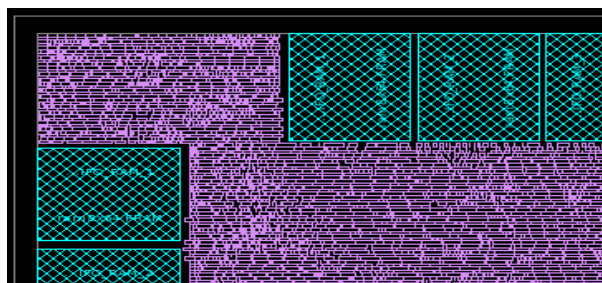


Figure 4.2: placement view of standard cells and macros in ICC tool.

The partial placement view of the design is shown in figure 4.2. The pink colored portion is standard cells and green layer is macro cells. The macro is hard IP, where physical designer will not have chance to change the functionality.

### C. Power Planning

Power planning is also called as the PG (power/ground) planning. This step involves making the connections via net to the pin VDD and VSS. Next need to create the power mesh for proper distribution of powers to each cell in the core. The mesh is like a square shape which is specified as the start and end location with the direction as horizontal or vertical with the metal used for power and ground route with the width specified.

The power planning involves the power network synthesis, in this power routes are laid with required width of the metals. The power routing metals are done by the highest metal layers available.

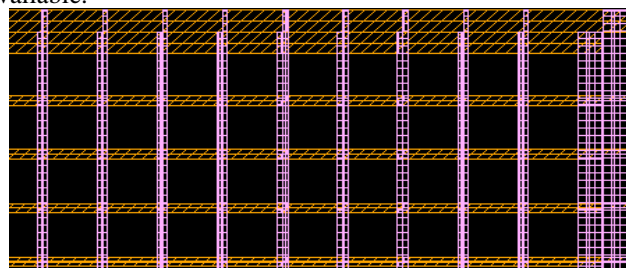


Figure 4.3: power metal routes for power supply in core area.



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The figure 4.3 shows the horizontal power line is metal 5 and vertical power line is metal 6. This is used because the power supply lines should not have more power dissipation.

The power network analysis involves the calculating the power consumed by the metal layers of the power routes.

### D. Placement

Placement of the standard cells and macros are carried out depending on rule specified and floor-planned design. The following flow diagram shows the placement steps as,

Placement involves the iteration process, initially all cells are placed randomly called coarse placement and then the cells are placed according to timing driven or congestion driven or rout-ability driven requirements. After one level of placement is done the placement is legalized and saved in database in db format for further steps of physical design analysis and implementation.

- i) Timing-driven placement tries to place cells along timing-critical paths close together to reduce net RCs and meet setup timing.
- ii) Congestion driven placement sees the number of metals routes could be routed in the specified channel. So the congestion driven placement spreads apart the cells that contribute to high congestion.
- iii) Addition and modification of blockages is added to the cells usually for macros. Blockage may be hard or soft. The blockage means the keep out of the cells from one macro to another or to the boundary.

Congestion is calculated by,

Congestion = [number of nets crossing the global routing/  
number of available routing tracks]

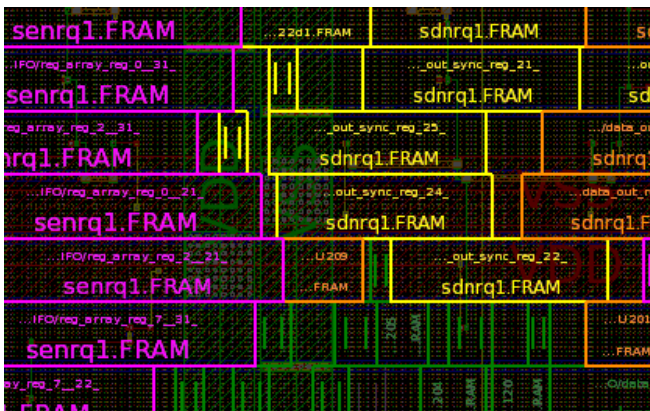


Figure 4.4: placement view of standard cell and filler cells

The figure 4.4 shows the partial placement of the cells. In this project the functionality is achieved with mostly basic standard cells.

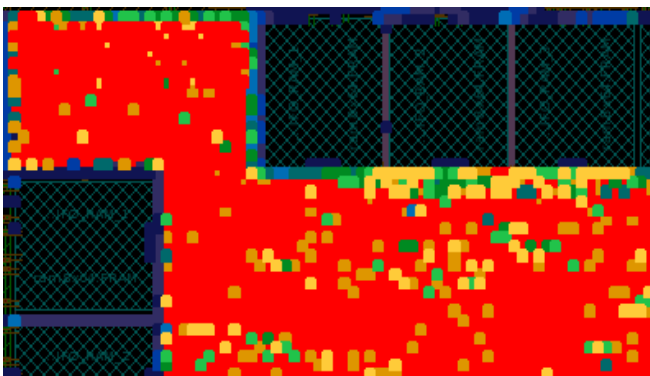


Figure 4.5: Initial congestion map in design

The congestion analysis is done after placement of the cells. The congestion is defined as the acquired routing channels to the required channels. The above figure 4.5 shows most congested places with the red color.

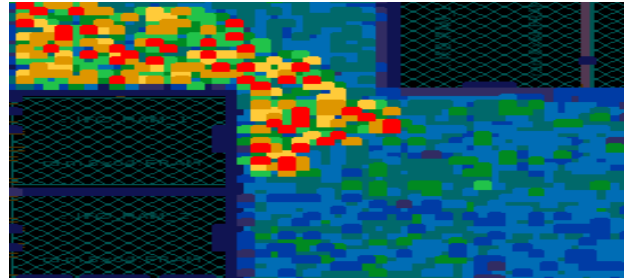


Figure 4.6: Second iteration of congestion map

The main intension of the physical design is to reduce the congestion by proper placement of the blocks. The green and blue spots shown in figure 4.6 are low congestion.

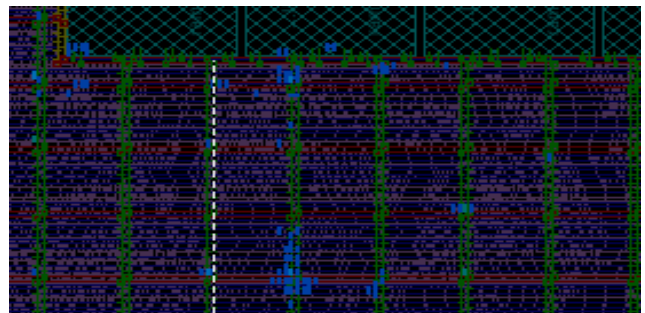


Figure 4.7: Final stage of congestion map.

The figure 4.7 shows the congestion map with the least congested spot. The dark blue line is showed lowest congestion value. When doing congestion analysis, the threshold value is set for up to which there will not be any congestion and above the threshold there will be congestion.

### E. Clock Tree Synthesis (CTS)

Clock tree synthesis is a process of generating the clock network in the design for clock distribution. In this project clock network is built using the H-tree topology. The following figure 4.8 shows the clock signal connection from the clock source to target sequential cells. Pre clock tree synthesis is just the connection of the clock paths without considering the inclusion of clock tree buffers and inverters for balancing and optimization of clock tree . It assumes the zero skew, latency and transition. The following figure 4.8 shows the pre-CTS circuit. Post CTS includes the clock tree buffers in the path of the clock routes.

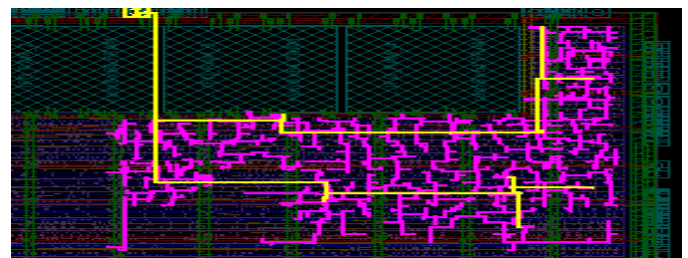


Figure 4.8: Clock generation and connection to the sink ports

The clock tree buffer insertion diagram is not shown instead the report generated is given in table. So the CTS insert the clock tree buffers and/or inverters to balance the loads and to meet the skew, latency and transition goals of the design. The insertion and optimization of the clock tree buffers are done using the specially designed buffers with different driving strengths.

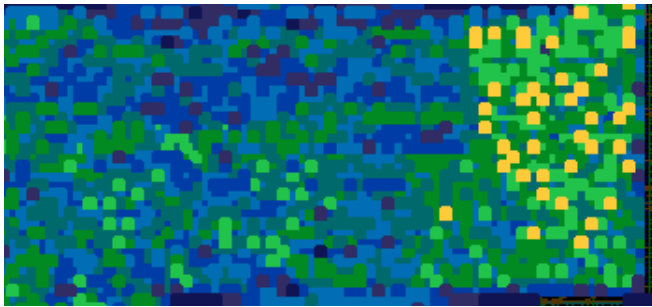


Figure 4.9: Congestion map after clock tree buffers insertion

The figure 4.9 shows the congestion map after clock tree synthesis, where clock tree synthesis cells are inserted. From figure 4.7 and 4.9 congestion value will be differed because of cell counts.

**Clock Tree Summary**

Clock Source	Sinks	Clk Cells	Skew	Longest Path	Total Drc	Buffer Area
PCI_CLK	201	0	0.0	0.231	0	0
SYS_CLK	902	0	0.0	0.527	0	0
SYS_2X_CLK	254	0	0.0	0.237	0	0
SDRAM_CLK(G)	643	0	0.0	0.293	0	0
SD_DDR_CLK	0	0	0.0	0	0	0

Table 4.1: Clock tree network before cell insertion with DRC

Clock Source	Sinks	Clk Cells	Skew	Longest Path	Total Drc	Buffer Area
PCI_CLK	201	0	0.0	0.231	246	0
SYS_CLK	902	0	0.0	0.527	897	0
SYS_2X_CLK	254	0	0.0	0.237	562	0
SDRAM_CLK(G)	643	0	0.0	0.293	242	0
SD_DDR_CLK	0	0	0.0	0	148	0

Table 4.2: Clock tree network summary after cell insertion with DRC

Clock Source	Sinks	Clk Cells	Skew	Longest Path	Total Drc	Buffer Area
PCI_CLK	201	4	0.03	0.231	0	74.132
SYS_CLK	902	25	0.068	0.527	0	319.222
SYS_2X_CLK	254	6	0.022	0.237	0	107.416
SDRAM_CLK(G)	643	15	0.029	0.293	0	301.067
SD_DDR_CLK	0	0	0	0	0	0

TABLE 4.3: CTS summary showing the number of CT cells inserted with DRC clean

The table 4.1 shows the virtual clock tree network, where no clock tree cells are inserted. It assumes that clock path is ideal no DRC violations also it has target points in the column sinks. The table 4.2 shows the summary of clock tree network, where clock path is laid with the higher level metals. It has

some DRC errors so it need to be resolved for proper functioning of chip. So in table 4.3 shows the final CTS network where no DRC and the additional area acquired by the clock tree cells.

**F. Routing**

The routing goal is to physically interconnect all the clocks, signal pins through metal interconnect and meet the set-up and hold timing and clock skew requirement. Also metal traces must meet physical DRC requirement.

The Routing flow involves as follows

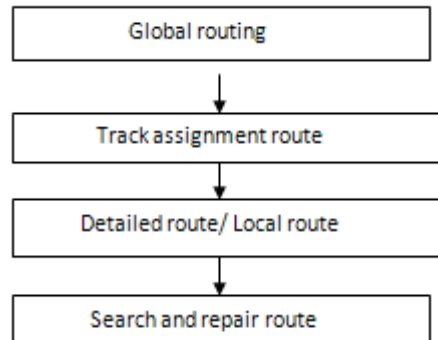


Figure 4.10: Routing flow diagram

The figure 4.10 shows the flow of the routing of the block, which involves global routing, track assignment routing, local or detailed routing and search and repair route for accurate check.

**Global Routing:** Global routing is done while placement of cells (both standard cells and macros). Usually this is done with higher metal layers. Global routing is used for power and clock routing for less IR drop and flexible long routing on cells.

**Track Assignment:** It assigns each net to a specific track and lays down the actual metal traces. It tries to make long and straight traces also tries to reduce the number of via usage. In this stage some DRC will occur like notch violation, which will be resolved in later stage.

**Detailed Routing:** Detailed routing is routing inside the block with lower metals than the global routing metals. There would be many more net lengths inside the blocks. Detailed route attempts to clear DRC violations using fixed size PrBoundary.

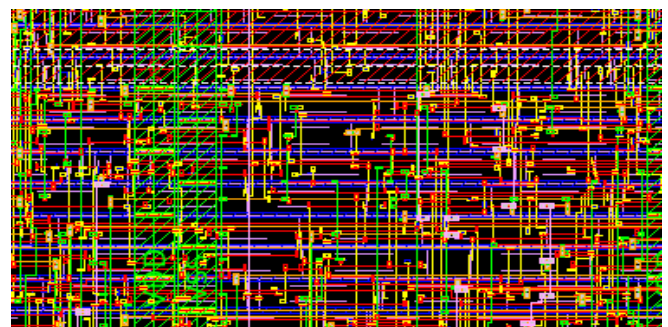


Figure 4.11: Global and Local Routing view.

The global and detailed route is done with the all metals. The power and clock route should be done with higher metals, in this design it is with M4 and M5. The clock routing is very critical and important, so shielding is utilized whenever clock is critical.



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**Search and Route:** Search and route divides chip into SBox (standard box) and work through each SBox sequentially and fixes the DRC violation by rerouting within the confined box. In this stage involves insertion of redundant vias for proper manufacturability. The figure 4.11 shows the final routing view.

### V. RESULTS AND DISCUSSIONS

#### A. Area Report Before CTS

The table 5.1 shows the summary report of area before clock tree synthesis where clock tree cells were not inserted. The core utilization is taken as 77% to place only standard cells and macros. The pins are associated with each cells and ports are interface to another block in the chip. The core area is partitioned into 192 rows with height 2.5um and standard width of tile 4.5um.

CORE SIZE	711.35X708.48 um
BLOCK SIZE	751.76X748.48 um
CORE UTILISATION	77.02%
NUMBER OF MACROS	12
NUMBER OF STD CELLS	10865
NUMBER OF PINS	65514
NUMBER OF PORTS	144
NUMBER OF CELL ROWS	192

**Table 5.1: Area report of design before CTS**

#### B. Area Report After Cts

The table 5.2 shows the summary of area of block after clock tree synthesis step, where some standard cells like buffers and inverters are inserted in the path of clock route for balancing the load and skew. From comparison of table 5.1 and table 5.2 shows that utilization, standard cell count and pin numbers increased. This increase is because of the clock tree cells have been inserted.

CORE SIZE	711.35X708.48
BLOCK SIZE	751.76X748.48
CORE UTILISATION	80.22%
NUMBER OF MACROS	12
NUMBER OF STD CELLS	26287
NUMBER OF PINS	96250
NUMBER OF PORTS	160
NUMBER OF CELL ROWS	192

**Table 5.2: Area report after CTS**

### VI. CONCLUSION

Ever increasing complexity of the semiconductor devices (IC) in the industry depending on the need of the consumers in the form of the portable electronic gadgets, the need for integration of multimillion gates need to be placed and interconnected depending on the functionality. So this project is initial step towards the multimillion gate integration.

The physical design of interfacing module of PCI and SDRAM in the RISC core is critical and requires the accurate timing, clocking and DRC free module. So in this project the accurate timing at placement and routing is achieved. In this project approximately achieved a lowest congestion of 2% at

the placement stage and 3% after clock tree insertion. The area utilization for around 27000 standard cells, i.e approximately about 60,000 of MOS devices has been placed in the area assigned of size 751.76X748.48 um<sup>2</sup>. The power consumption about 51mW is achieved including the dynamic and static power. The entire design flow is carried out with the help of Synopsys IC Compiler Galaxy family tool.

The physical analysis of DRC is also carried out successfully without any violations. The DRC rules will be provided by the TSMC 120nm Design Rule Manual (DRM). And for routing critical clock and reducing IR drop at critical places Non Default Rule (NDR) of DRC is used for achieving low power and congestion free design.

### VII. ACKNOWLEDGE

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