National Cheng Kung University

Department of Electrical Engineering

Introduction to VLSI CAD (Spring 2024)

Lab Session 2

Design and Simulation of Carry-Lookahead Adder & Parallel-Prefix Adder & Multiplier

Name	Student ID	
劉冠妤	E24116152	
Practical Sections:	Points	Marks
Prob A	15	
Prob B	30	
Prob C	40	
Report	15	
Bonus	10	
Notes		

Due Date: 14:59, March 13, 2024 @ moodle

Deliverables

1) All Verilog codes including testbenches for each problem should be uploaded.
   NOTE: Please **DO NOT** include source code in the paper report!
2) All homework requirements should be uploaded in this file hierarchy or you will not get the full credit.
   NOTE: Please **DO NOT** upload waveforms!
3) Important! TA will use the command in Appendix A to check your design under SoC Lab environment, if your code can not be recompiled by TA successfully using the commands, you will not get the full credit.
4) If you upload a dead body which we can't even compile you will get **NO** credit!
5) All Verilog file should get at least 90% superLint Coverage.
6) File hierarchy should not be changed; it may cause your code can not be recompiled by TA successfully using the autograding commands

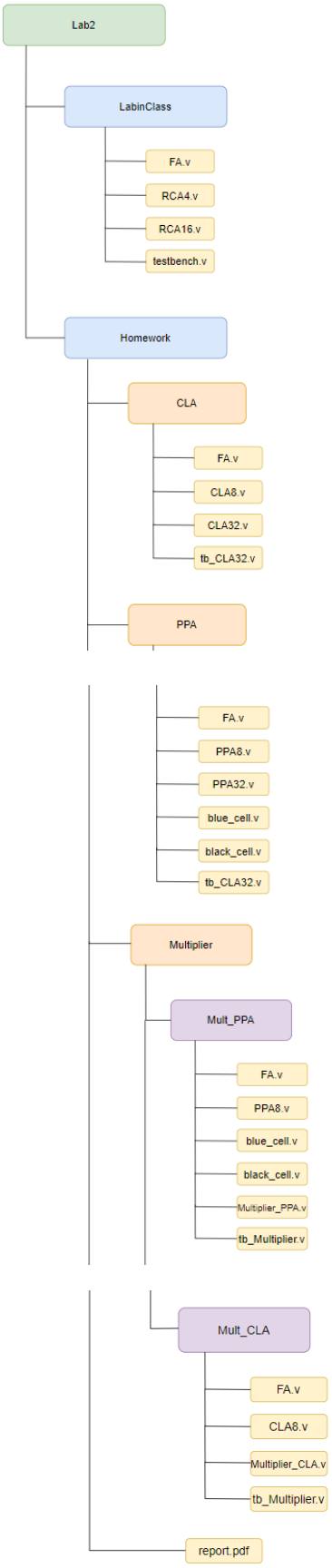

Fig.1 File hierarchy for Homework submission

Objectives:

Help students get familiar with the CAD tools (VCS & Verdi) for digital logic design. Introduce different adder architectures and the algorithms behind them. Please go through the hands-on exercise step-by-step.

Prob A: Design Steps & Carry-Lookahead Adder

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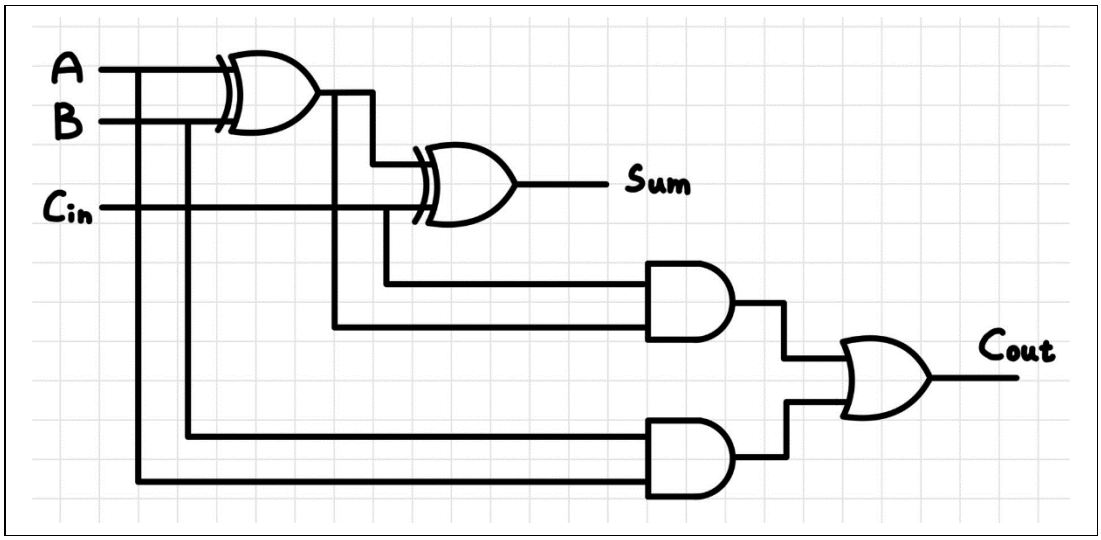
1) **An adder is a digital circuit that performs addition of number. Please design a full adder in gate level.**
2) **The truth table of full adder**

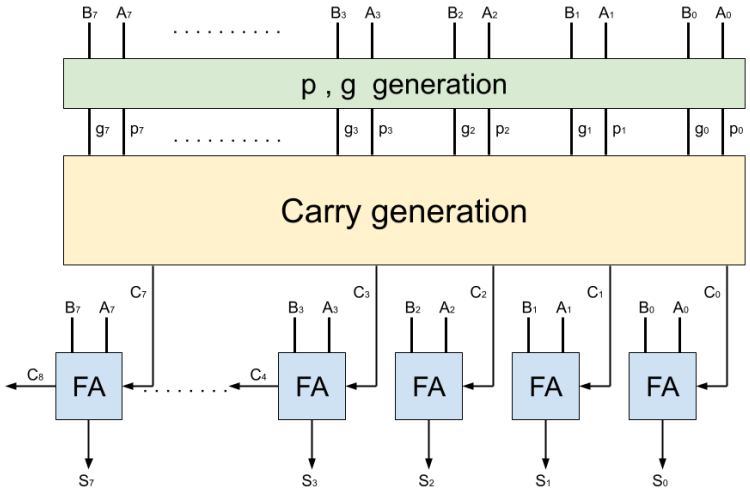
Inputs			Outputs	
A	B	C_{in}	C_{out}	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

3) **Draw a full adder in gate level.**



4) **Design a full adder in Structural coding (The module name should be FA. And the file you include should be FA.v)**
5) **Carry-lookahead-adder uses carry generator to alleviate the lengthy carry propagation procedure in ripple-carry-adder.**

6) **Derive the 8th carry bit C_8(ex. $C_2 = A_1B_1+(A_1+B_1)C_1 = g_1 + p_1C_1 = g_1 + p_1g_0 + p_1p_0C_0$)**

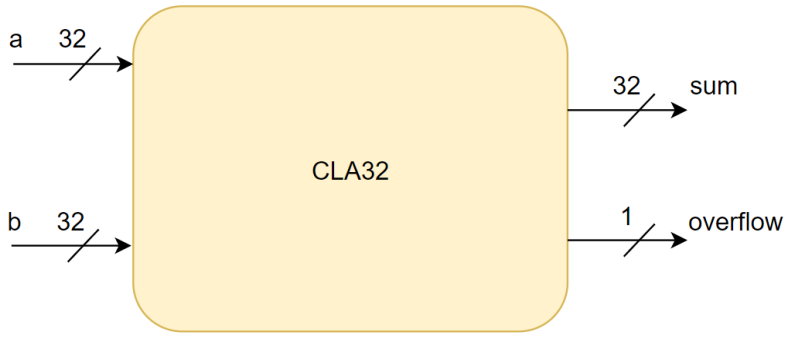


ex. $C_2 = A_1B_1+(A_1+B_1)C_1 = g_1 + p_1C_1 = g_1 + p_1g_0 + p_1p_0C_0$, $g_1 + p_1g_0 + p_1p_0C_0$ is the final result.

$C_8 = g_7 + p_7g_6 + p_7p_6g_5 + p_7p_6p_5g_4 + p_7p_6p_5p_4g_3 + p_7p_6p_5p_4p_3g_2 + p_7p_6p_5p_4p_3p_2g_1$
$+ p_7p_6p_5p_4p_3p_2p_1g_0 + p_7p_6p_5p_4p_3p_2p_1p_0C_0$

$$C_1 = g_0 + p_0C_0$$
$$C_2 = g_1 + p_1g_0 + p_1p_0C_0$$
$$C_3 = g_2 + p_2g_1 + p_2p_1g_0 + p_2p_1p_0C_0$$
$$\vdots$$
$$C_n = g_{n-1} + p_{n-1}g_{n-2} + p_{n-1}p_{n-2}g_{n-3} + \cdots + (p_{n-1}\cdots p_0C_0)$$
$$C_8 = g_7 + p_7g_6 + p_7p_6g_5 + p_7p_6p_5g_4 + p_7p_6p_5p_4g_3$$
$$+ p_7p_6p_5p_4p_3g_2 + p_7p_6p_5p_4p_3p_2g_1 + p_7p_6p_5p_4p_3p_2p_1g_0$$
$$+ p_7p_6p_5p_4p_3p_2p_1p_0C_0$$

7) **Design a 8-bit carry lookahead adder** in **Structural coding** (The module name should be CLA8. And the file you include should be CLA8.v)
8) **Design a 32-bit carry lookahead adder in hierarchical coding** using previously designed CLA8 module**.** (The module name should be CLA32. And the file should be CLA32.v)



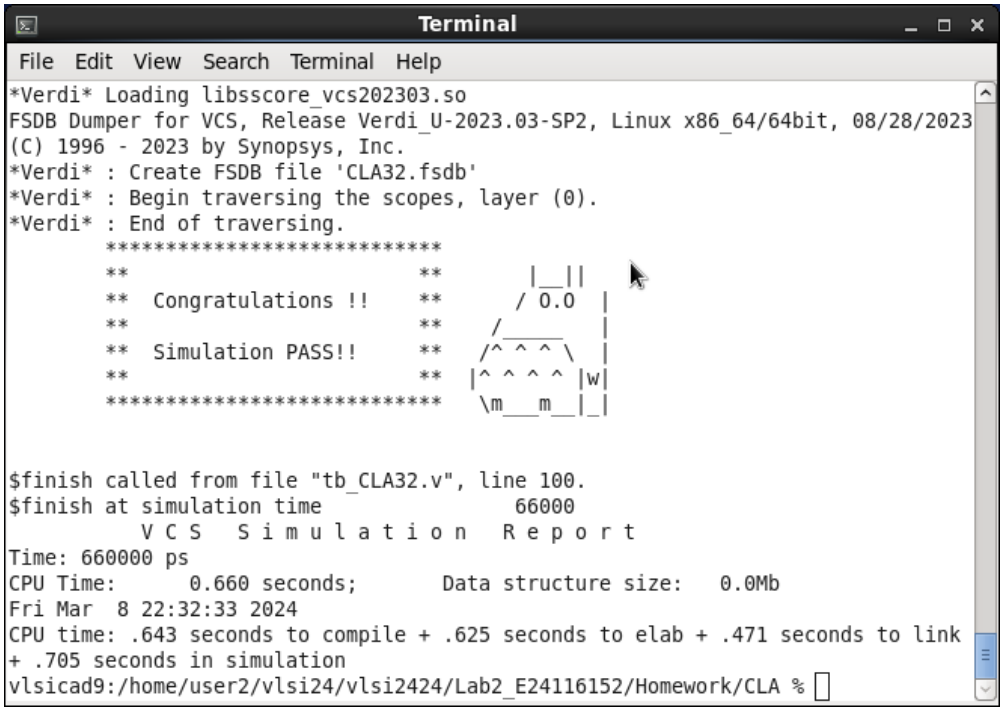
Signal	IO	Bits	Description
a	Input	32	Addend
b	Input	32	Augend
sum	Output	32	Result after calculating
overflow	Output	1	Overflow detection

9) Simulate your design with the following test pattern in sample testbench.
(Hint: The command for compiling is % vcs -R tb_CLA.32v -full64)
(Hint: The command for simulation is %vcs -R tb_CLA32.v -debug_access+all -full64 +define+FSDB)

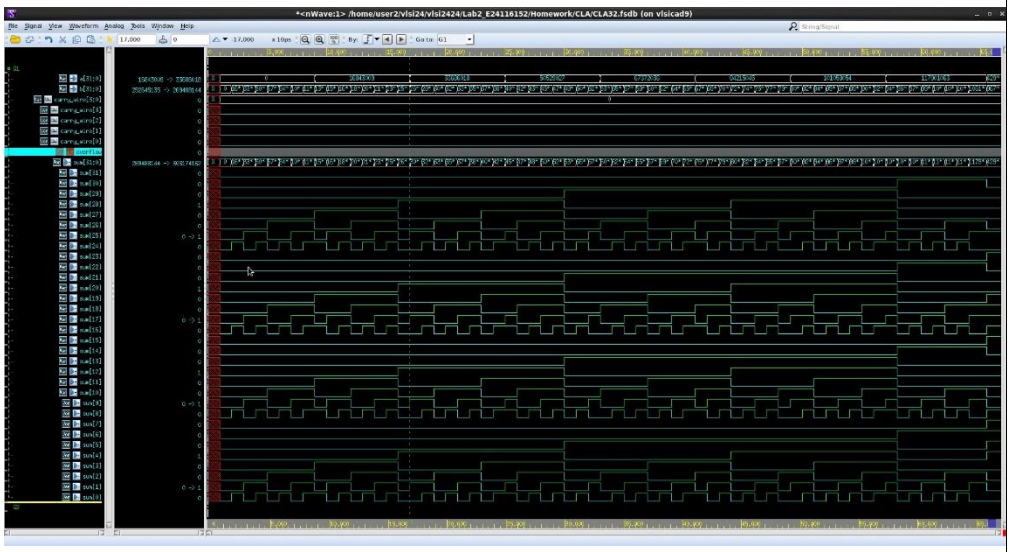
10) Verify your design by comparing the simulation results with the results you predicted. If the results are not the same, please go back to 2) and revise your code. If the simulation results are correct, please snapshot the simulation result on the terminal and the waveform you dumped and explain your waveform.
(Hint : The command to open nWave is %nWave &)
In addition, you should check your coding style, and make sure that there are no error messages and coverage with Superlint must > 90 %. Snapshot the result and *calculate Superlint coverage*. (Hint: The command to open Superlint is %jg -superlint superlint.tcl)

11) You only need to upload your v-code to moodle, **do not** paste your code here.

Your simulation result on the terminal.



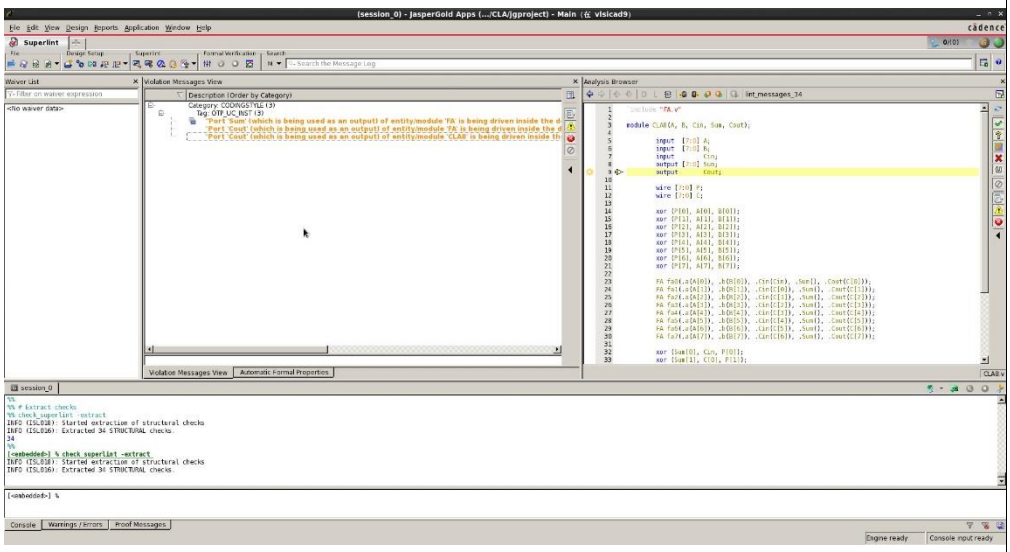
Your waveform :



Explanation of your waveform :

以圖中數據為例，$16843009_{10} = 00000001000000010000000100000001_2$，和 $252645135_{10} = 00001111000011110000111100001111_2$，兩者相加為 $269488144_{10} = 00010000000100000001000000010000_2$，而到下一個數據，$33686018_{10} = 00000010000000100000001000000010_2$ 與 $269488144_{10} = 00010000000100000001000000010000_2$ 相加時，得到 $303174162_{10} = 00010010000100100001001000010010_2$，可以觀察到兩個結果只有第 2、10、18、26 位不同，可從 Sum 的波型中看出，且兩個加法都沒有出現 overflow。

Superlint screenshot and coverage



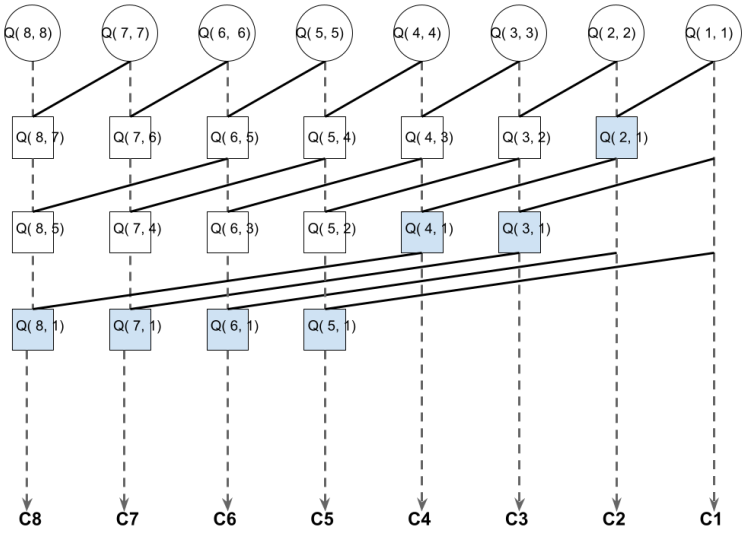
Superlint coverage = 90.3 %

Prob B: Parallel-Prefix Adder

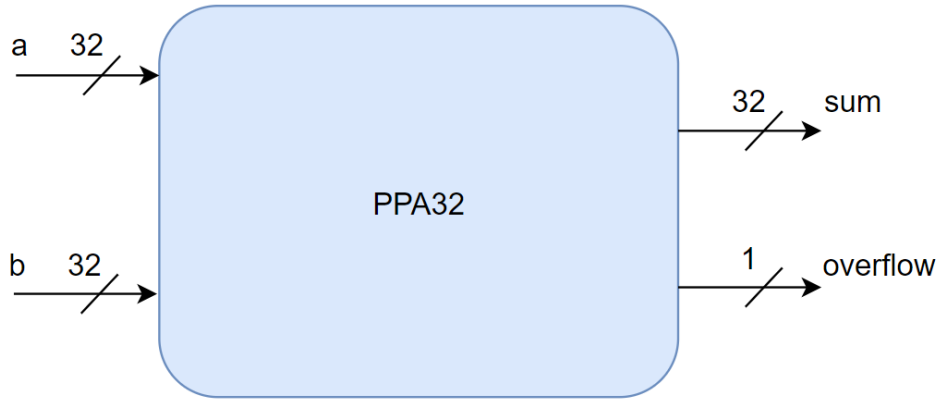
1) **Parallel-prefix-adder reduces the complexity of the carry generation circuitry in carry-lookahead-adder.**
2) **Recursive formulation of carry bits:**

$$Q(m, n) = \sum_{i=n}^{m}\left(\prod_{r=i+1}^{m} p_r\right) g_i$$

$C_0 = 0$	
$C_1 = A_1B_1+(A_1 \oplus B_1)C_0 = g_1 + p_1C_0 = g_1$	$= Q(1, 1)$
$C_2 = A_2B_2+(A_2 \oplus B_2)C_1 = g_2 + p_2C_1 = g_2 + p_2g_1$	$= Q(2, 1) = p_2Q(1, 1) + Q(2, 2)$
$C_3 = A_3B_3+(A_3 \oplus B_3)C_2 = g_3 + p_3C_2 = g_3 + p_3g_2 + p_3p_2g_1$	$= Q(3, 1) = p_3p_2Q(1, 1) + Q(3, 2)$
	$= p_3p_2Q(1, 1) + p_3Q(2, 2) + Q(3, 3)$
$C_4 = A_4B_4+(A_4 \oplus B_4)C_3 = g_4 + p_4C_3 = g_4 + p_4g_3 + p_4p_3g_2 + p_4p_3p_2g_1$	$= Q(4, 1) = p_4p_3Q(2, 1) + Q(4, 3)$



3) **Design a full adder in Structural coding (The module name should be FA. And the file you include should be FA.v)**
4) **Design black cell & blue cell in Structural coding** (The module name should be black_cell & blue_cell. And the file you include should be black_cell.v & blue_cell.v)
5) **Design a 8-bit parallel-prefix-adder** in **hierarchical coding using black cell & blue cell as basic unit** (The module name should be PPA8. And the file you include should be PPA8.v)
6) **Design a 32-bit parallel-prefix-adder in hierarchical coding** using previously designed PPA8 module**.** (The module name should be PPA32. And the file should be PPA32.v)



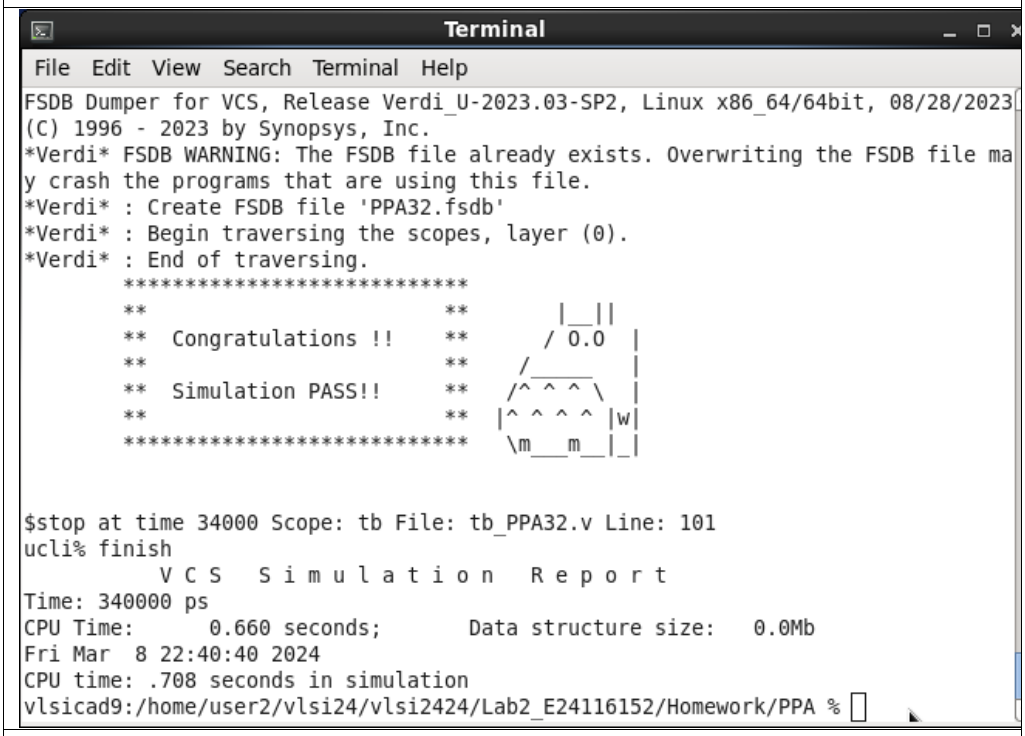
Signal	IO	Bits	Description
a	Input	32	Addend
b	Input	32	Augend
sum	Output	32	Result after calculating
overflow	Output	1	Overflow detection

7) **Simulate your design with the following test pattern in sample testbench.**
(Hint: The command for compiling is % vcs -R tb_PPA32.v -full64)
(Hint: The command for simulation is %vcs -R tb_PPA32.v -debug_access+all -full64 +define+FSDB)

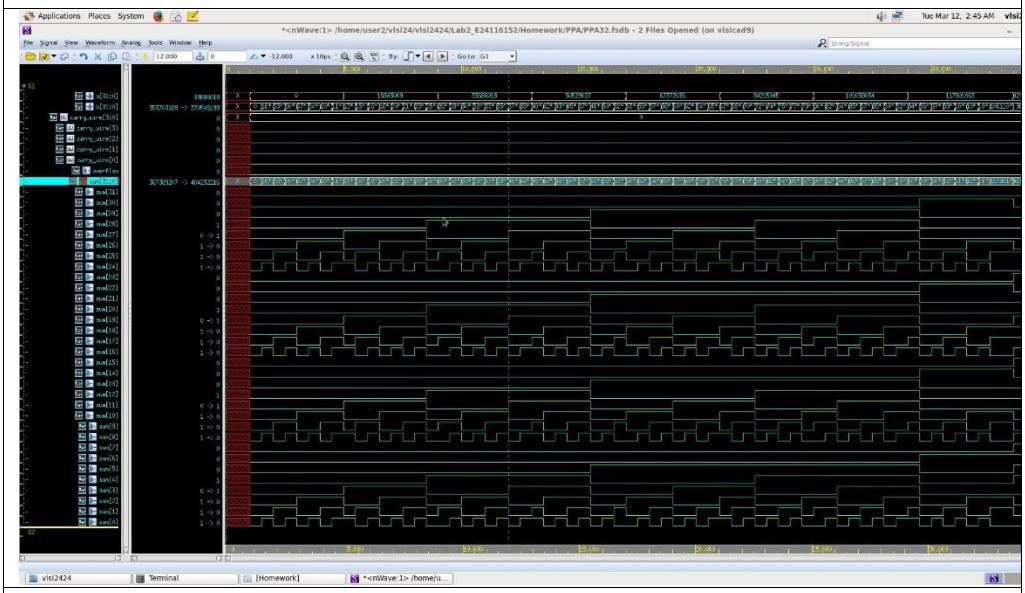
8) **Verify your design by comparing the simulation results with the results you predicted. If the results are not the same, please go back to 2) and revise your code. If the simulation results are correct, please snapshot the simulation result on the terminal and the waveform you dumped and explain your waveform.**
(Hint : The command to open nWave is %nWave &)
In addition, you should check your coding style, and make sure that there are no error messages and coverage with Superlint must > 90 %. Snapshot the result and *calculate Superlint coverage*. (Hint: The command to open Superlint is %jg -superlint superlint.tcl)

9) You only need to upload your v-code to moodle, **do not** paste your code here.

Your simulation result on the terminal.



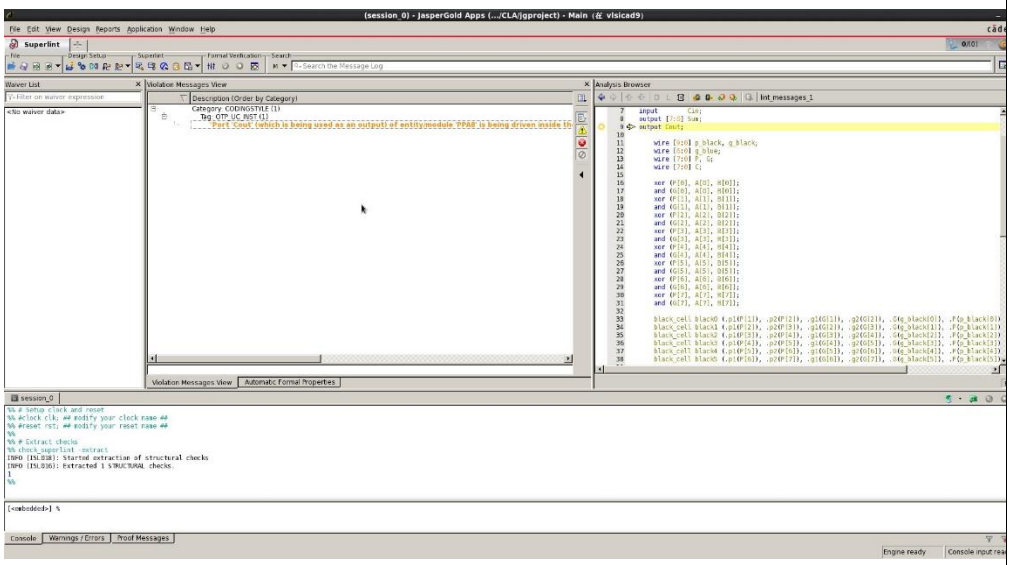
Your waveform :



Explanation of your waveform :

從波型圖可以觀察到 PPA 和 CLA 的 Sum 部分結果波型一致。但比較兩者的執行速度可以看出，PPA 的計算速度較快。

Superlint screenshot and coverage



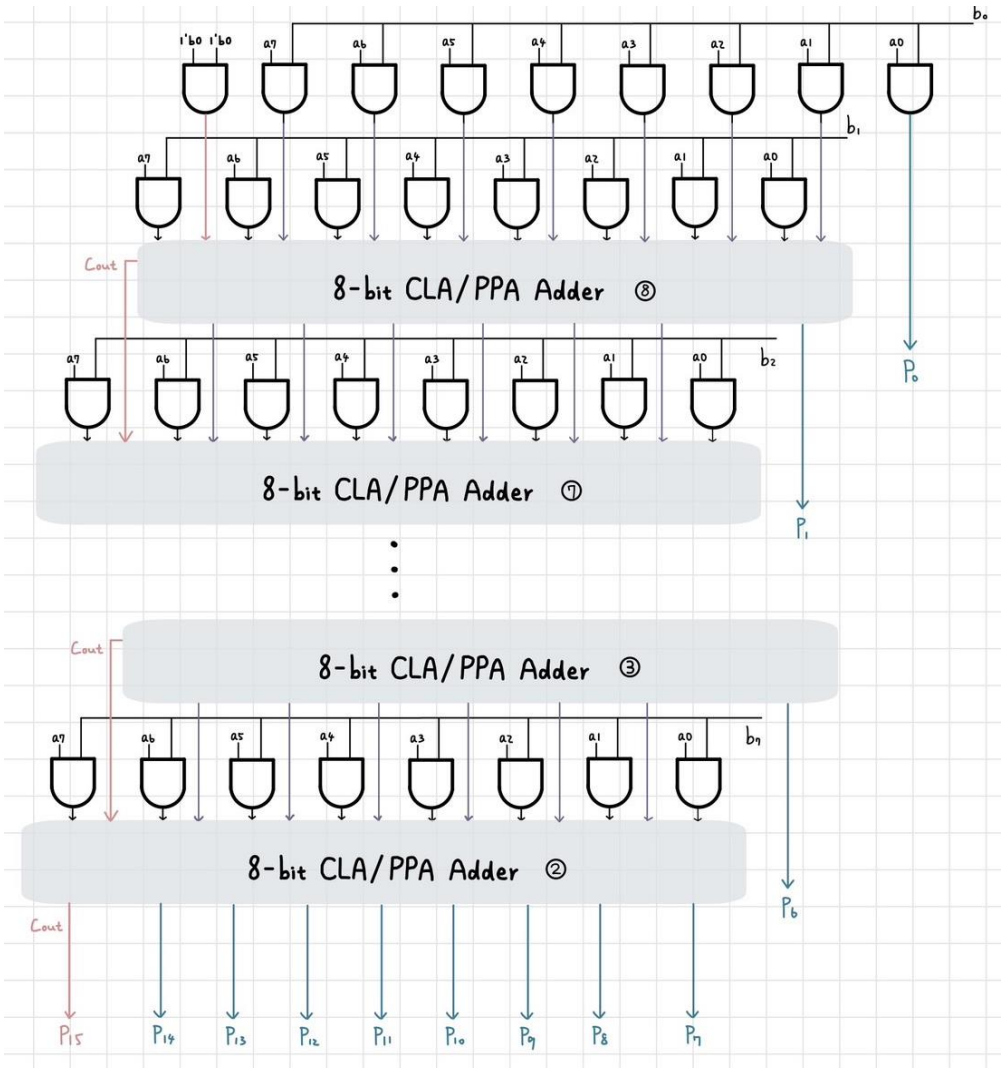
Superlint coverage = 95 %

Prob C: Application

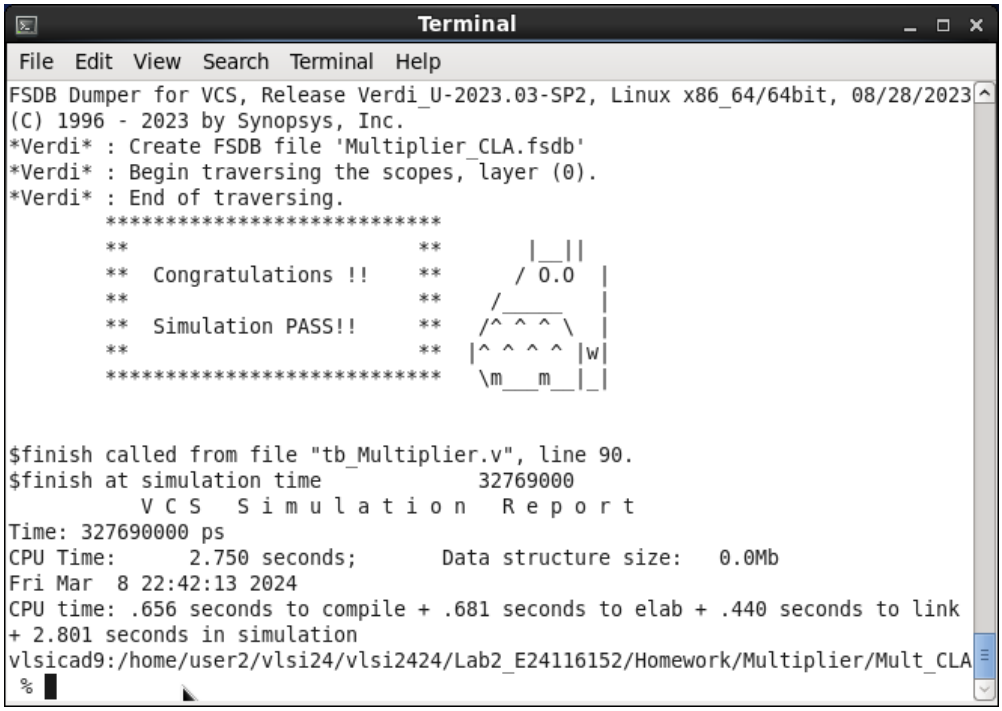
1) **Design a 8*8-bit multiplier**
   a. **Using CLAs of Prob A**
   b. **Using PPAs of Prob B**
   c. **Design in gate level rather than behavioural modelling. (The module name should be Multiplier_CLA & Multiplier_PPA. And the file you include should be Multiplier_CLA.v & Multiplier_PPA.v)**
2) **Draw your hieratical structure.**
3) **You only need to upload your v-code to moodle, do not paste your code here.**
4) **Simulate your design with the testbench which includes all case of input.**
   (Hint: The command for compiling is % vcs -R tb_Multiplier.v -full64)
   (Hint: The command for simulation is % vcs -R tb_Multiplier.v -debug_access+all -full64 +define+FSDB)

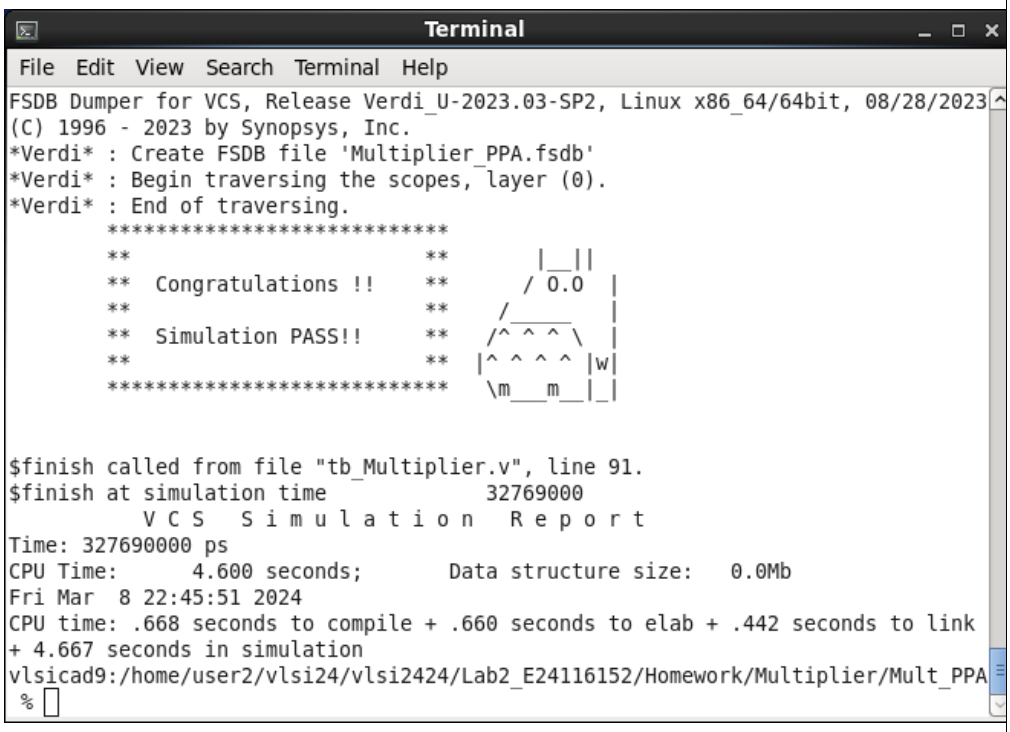
10) **Verify your design by comparing the simulation results with the results you predicted. If the results are not the same, please go back to 2) and revise your code. If the simulation results are correct, please snapshot the simulation result on the terminal and the waveform you dumped and explain your waveform.**
    (Hint : The command to open nWave is %nWave &)
    In addition, you should check your coding style, there are no error messages and over 90% coverage with Superlint. Snapshot the result and *calculate Superlint coverage*. (Hint: The command to open Superlint is %jg -superlint superlint.tcl)

Draw your hieratical structure.

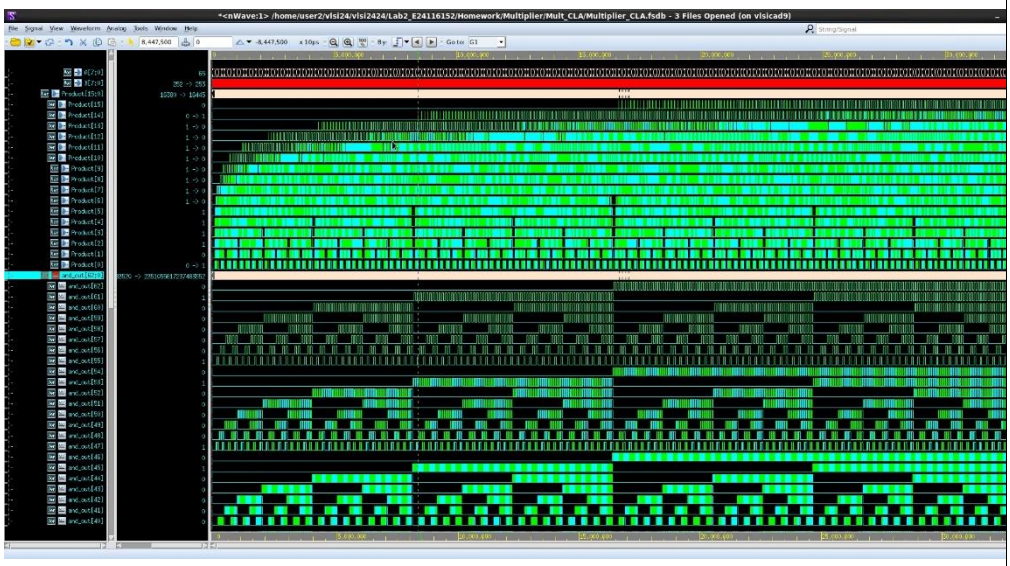


Your simulation result on the terminal.





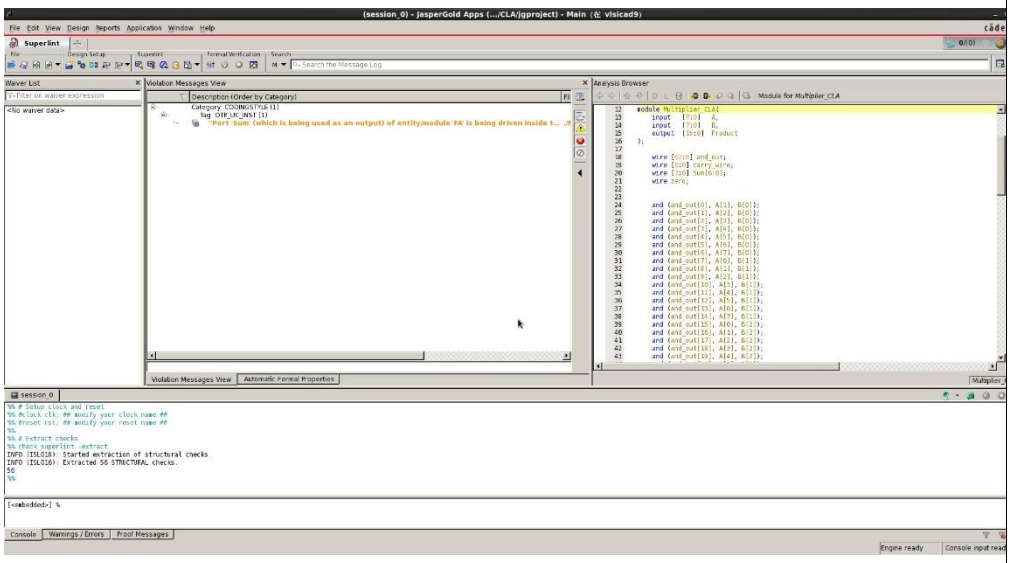
Your waveform :



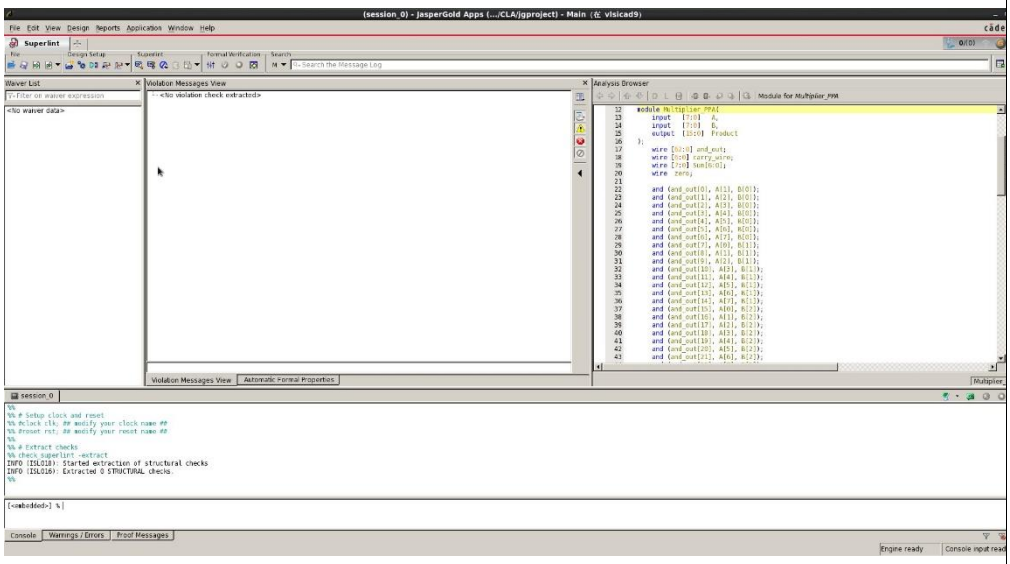
Explanation of your waveform :

從波型圖可以看出 4 個 8-bit 加法器組成乘法器的架構，而且是 unsigned，以圖中數據為例，$65_{10} = 01000001_2$ 和 $252_{10} = 11111100_2$ 相乘得到 $16380_{10} = 0011111111111100_2$，可以驗證。

Superlint screenshot and coverage



Superlint coverage = 99.2 %



Superlint coverage = 100%

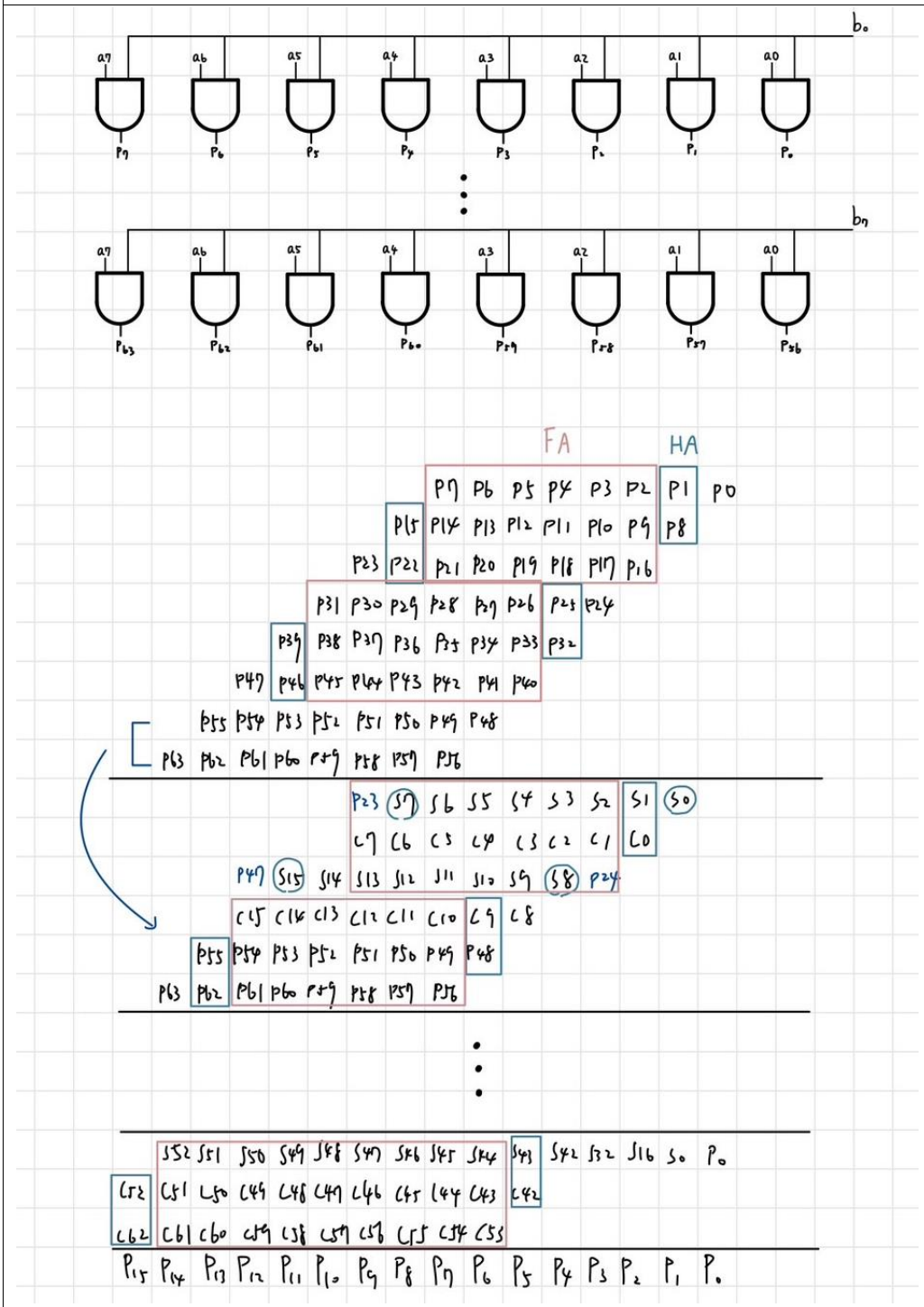
Different multiplier architectures - Wallace Tree Multiplier

使用一系列全加法器和半加法器來分階段對部分乘積求和，大致分為二步驟：

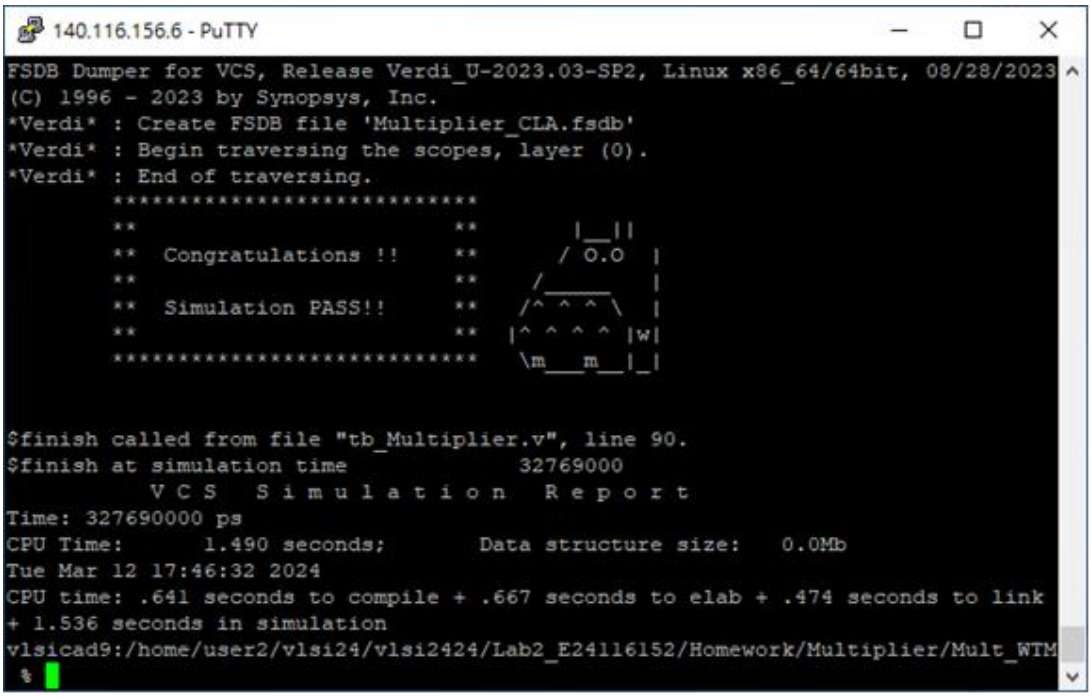
1. 將兩個輸入的 8 位元數字的每一個位元兩兩相乘。
2. 通過全加器和半加法器的層數將部分乘積的數量減少到兩個。

圖中最後一區的 C53~C62 為 S43 和 C42 到 S52 和 C51 的 Cout。

hieratical structure



Your simulation result on the terminal.



Appendix A : Commands we will use to check your homework

Problem		Commands
ProbA	Compile	% vcs -R tb_CLA32.v -full64
	Simulate	% vcs -R tb_CLA32.v -debug_access+all -full64 +define+FSDB
ProbB	Compile	% vcs -R tb_PPA32.v -full64
	Simulate	% vcs -R tb_PPA32.v -debug_access+all -full64 +define+FSDB
ProbC	Compile	% vcs -R tb_Multiplier.v -full64
	Simulate	% vcs -R tb_Multiplier.v -debug_access+all -full64 +define+FSDB