TSEK06
Transistor-Level Design Report

Group 5

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Version P1A

Status

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PROJECT IDENTITY

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Contents

Document history

Version	**Date**	**Changes**	**Performed by**
P1A	2016-02-19	First draft	Johan Isaksson

1 Introduction

This document describes the state of the 16-bit Kogge-Stone adder project in the course TSEK06 after finishing the transistor level design phase. The meaning of transistor level is that the every basic logic gate is implemented with CMOS transistors. The main reson for doing this is to be able to simulate all logic to make sure that everything works as intended. Updated block diagrams can be found in section 2, simulation results in section 3 and a small risk analysis in section 5. In appendix C the time plan for the next phase can be found.

2 Block Level Description

Much of the block level descriptions can be seen in the high level report, but the transistor view of the leaf-cells will be described in this chapter. To find good sizes for our gates we used a very simple sizing strategy. Start small, and if the signal is to weak to drive the components, we just size it up and if necessary, make a buffer for it. The transistor schematic of the basic blocks like AND, OR, DFF etc. are simple enough that we will not include any description for them.

In Fig. 1 an updated block diagram of the complete system can be seen.

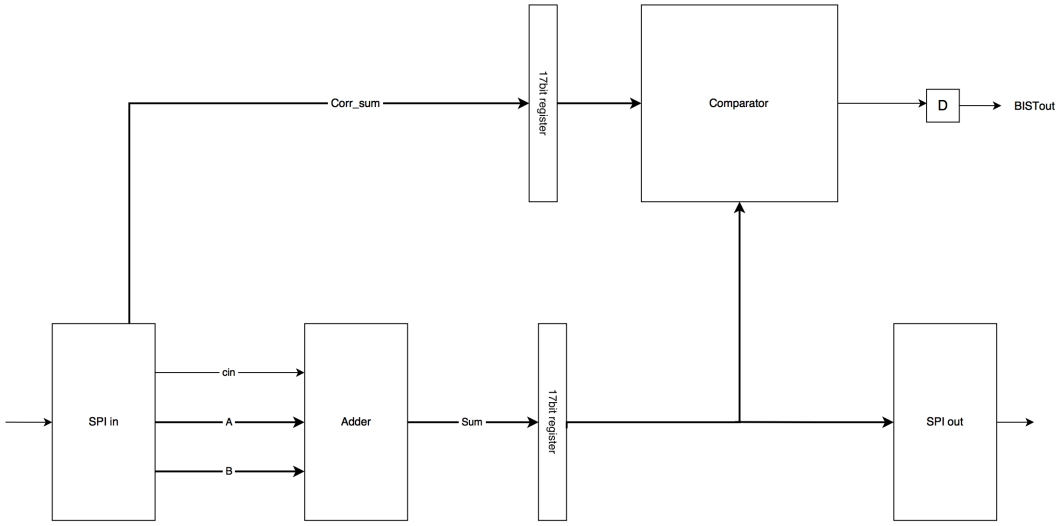


Figure 1 – Top level block diagram.

The updated diagram contains additional registers for synchronizing the signal before and after the comparator. This was done to provide more stable signals to the comparator and to have a more easily interpreted BISTout signal. The drawback is that the BISTout signal is available two clock cycles after the addition took place.

2.1 SPI-in/PRBS

This module only use basic leaf-cells at the transistor level, so this will be a quite small chapter. However, there are a few things worth noting regarding the sizing of these basic blocks. Some of the signals are connected to a large amount of devices (60+), which meant that the signal got really weak. This was solved by either just making the gates a bit bigger, or by using a buffer. SPI_en is using a 9x buffer, SPI_clk is using a 27x buffer and test_mode is using a 9x buffer. Clk_en is the result from an OR gate, and the NOR gate inside it is 6 times bigger and the inverter is 18 times bigger.

2.2 SPI out

This chapter will discuss the changes to the SPI output module.

2.2.1 Shift register

The output consist of a 68 bit shift register where each cell in the register contains one D flip-flop and one multiplexer. As we have transistor schematics for both the flip flop and the multiplexer nothing had to be changed to the individual cells, just change the configuration files to use schematics instead of the verilog code.

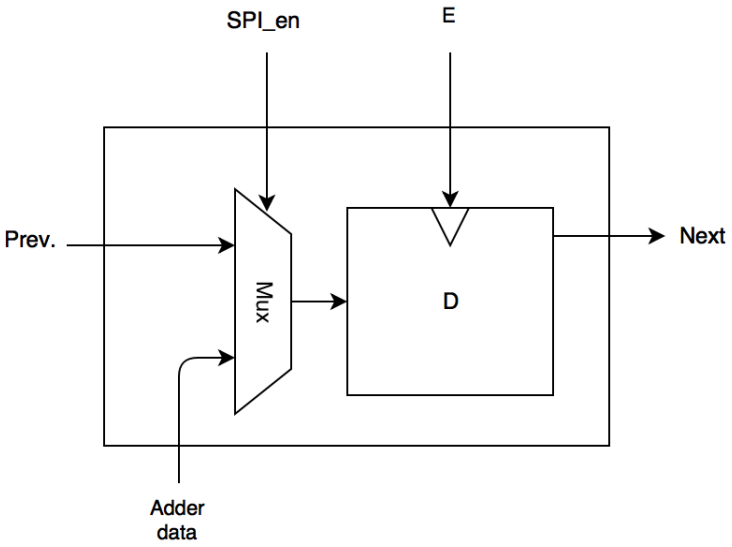


Figure 2 – Shift register cell

2.2.2 Control logic

As all verilog code were replaced by transistor schematics, the problem with this design got exposed. Each of the four enable signal has a large fan out as they are connected to 17 cells in the shift register.
The solution was to size the the multiplexer generating the control signals. The last internal block that includes this multiplexer can be seen in Fig. 3.

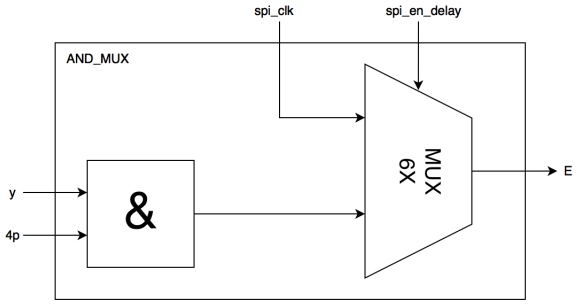


Figure 3 – Functional block containing an AND and a MUX.

By testing we found that a MUX that is approximately six times larger should be sufficient. In Fig. 4 the schematic of the sized multiplexer, implemented using NAND and an inverter, is shown.

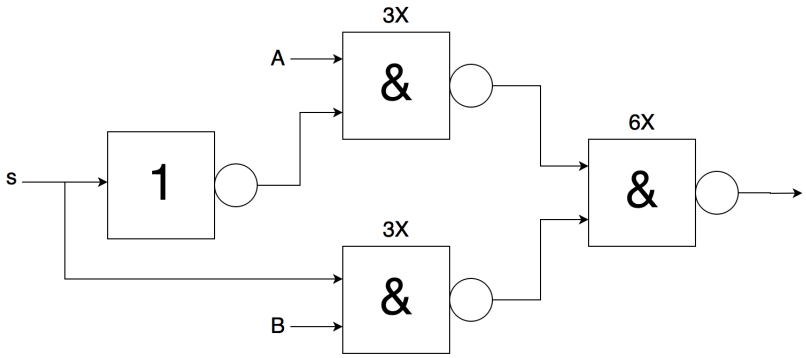


Figure 4 – Sized multiplexer.

2.2.3 Protocol

Due to a misunderstanding in the group, regarding if the SPI clock should be kept high or low during the high time of the SPI enable signal, the data on the spi output is now available for read already on the first falling edge of the SPI clock. This is possible as the group decided to keep the clock low during high time of SPI enable so that the data can be written to the output at the first rising edge as usual but the first falling edge will come afterwards instead.

2.3 16-bit Kogge-Stone Adder

The Kogge-Stone adder consists of several simple blocks connected in a complex way, as can be seen in appendix A. The adder has been significantly changed since the high-level design phase. The *yellow* block has been split into two blocks *yellow_inv_in* and *yellow_inv_out*, which can be seen in 5. The *yellow_inv_in* block takes inverted input signals and gives non-inverting output. The *yellow_inv_out* block takes non-inverted intputs and gives inverting output. This arrengement saves a lot of gates. The *yellow_carry* block has been split in the same way.

Because of the inverting signals from *yellow_inv_out* some *sum* blocks have been replaced with XNOR gates. A couple of inverters have also been added in some places.
All transistors in the adder are minimum sized since the gates have a low fan out.

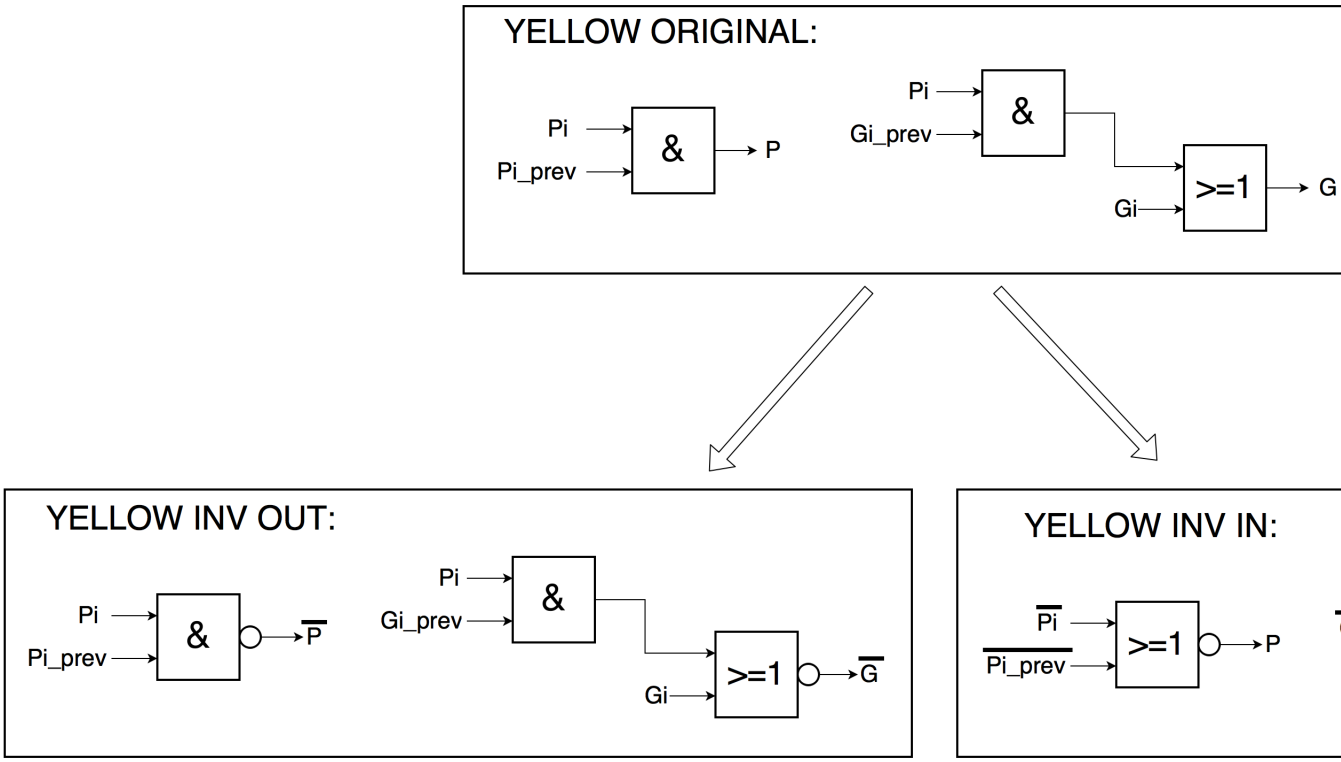


Figure 5 – The new yellow blocks.

Bild på generate gates osv

2.4 Comparator

The comparator consists of 17 2-input XNOR gates where one bit of each number is fed into each gate. The output from the XNOR gates are fed into a couple of AND gates which generates the final output. The comparator is 17 bits wide since it compares two 16 bit numbers plus their carry bits. The logic table of the XNOR gates is shown in table 1.

Table 1 – Logic table of XNOR block.

A_i	B_i	$Y = \overline{(A_i \oplus B_i)}$
0	0	1
0	1	0
1	0	0
1	1	1

3 Simulation Results

This section describes the high level simulation results. All files referenced to in this section can be found in the attached zip-file.

3.1 SPI In

The first thing to test in the system is where it all begins, at the input. The basics of it can be seen in test_spi_receive. As can be seen, as soon as the SPI_enable signal goes low and the SPI_clk starts we start to receive one bit on every positive edge. The data is then shifted trough all of the 16 registers. As the 16th bit is shifted in, the first load signal is triggered. Every 16 bits after that another load signal is triggered, and this can be seen in test_spi_load. One can also see that once the last load signal is triggered, SPI_enable goes high again.
The last thing in the SPI_in module to test is how the data travels out of the PRBS registers. This can be seen in test_spi_prbs. One important thing to note is that as soon as SPI_enable goes high, the registers are triggered on the system clock. As one can see in the figure, the first bit is ready for a long time, and as soon as the last bit is ready, we start to add at full speed. And after the four bits are done the system continues to add the pseudo random numbers.

3.2 Kogge-Stone Adder

The simulation of the adder can be seen in test_koggeadder and the input sequence is the same that were fed into the SPI. The most relevant part of the simulation is precisely after the topmost signal goes high. When this happens the data is already fed into the register in front of the adder and begins to shift into the adder on positive clock edge. The out, or to makes things more clear, the BISTout signal clearly shows that the two first addition yields the correct result but the thirds makes the same signal go low. This is a construction of the input from our side to test if the comparator can detect errors. After this the BISTout are low for a while before it goes high again which means that the fourth addition was successful.

3.3 Comparator

The simulation of the comparator is seen in test_corr. The same reasoning as in the section above applies here. The simulation is quite striped down due to readability but one can clearly see that out, which is BISTout, is high if and only if the corr-signals and sum signals match.

3.4 SPI Out

The critical parts of this module are the events after a transition on the spi enable signal.
In the image spi_out_control a simulation of the behaviour when the SPI enable goes high. The simulation shows that the buffering of the signals successfully achieved satisfying rise and fall times For the enable signals.
When spi enable goes low, the four enable signals are the same as the spi clock which can be seen in the image spi_out_control2.

3.5 Top Level

One can get a overall picture of the behaviour of the system by looking at at the simulations in the order spi_receive, spi_prbs, koggeadder, corr and last the spi_out. This is possible because all this simulations are part of a bigger one.

4 Pad Assignment and Early Test Plan

The following signals will be connected to external pins on the chip, where the first seven are inputs and the last five are outputs:

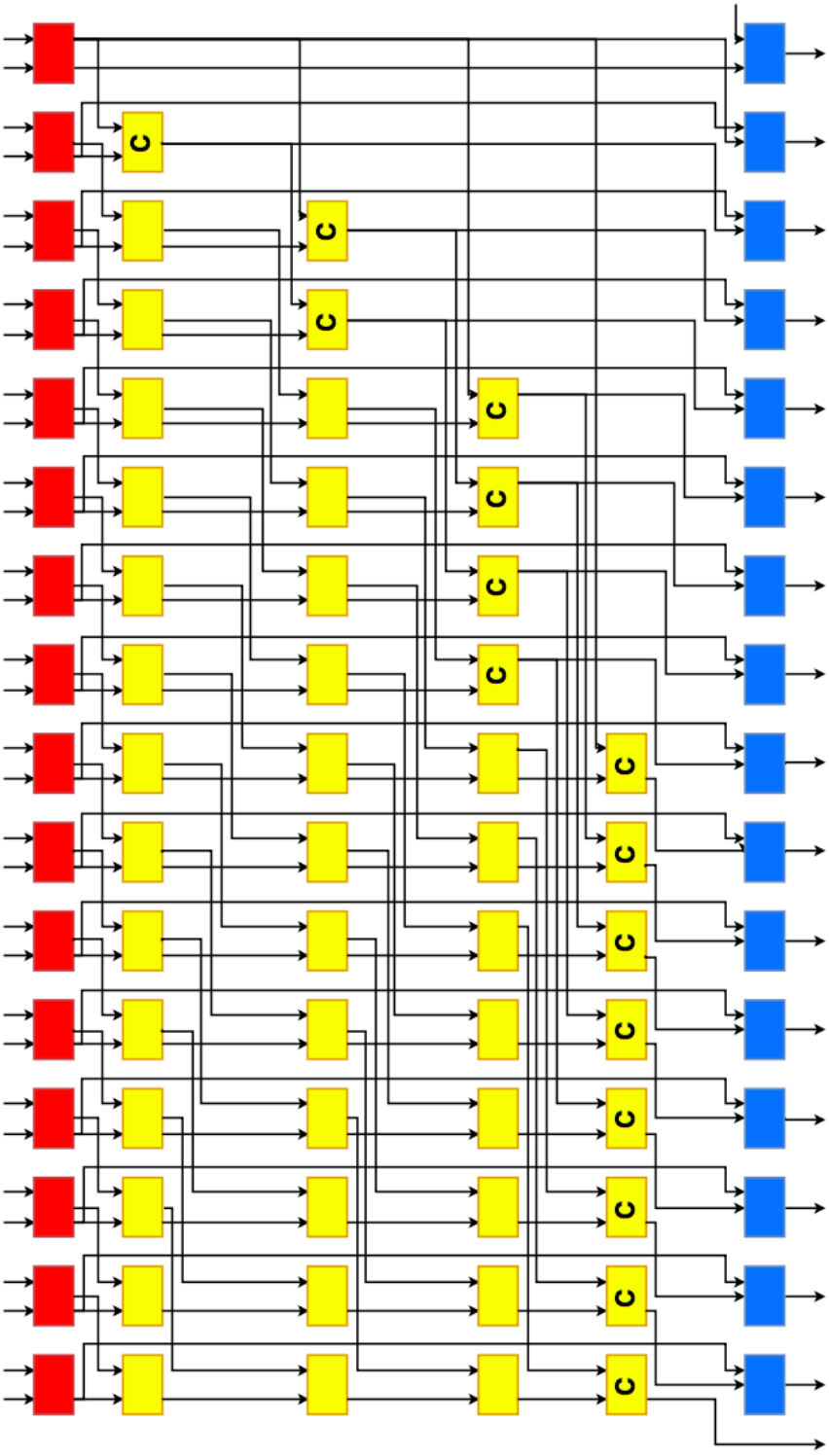
- Vdd1 - Will provide most of the system with power and will be a steady 3.3 V.
- Vdd2 - Will provide the adder with power and it might vary from 3.3 V downto below threshold-voltage

- GND - Ground
- Clk - This is the clock for the adder, some registers and control logic. Should have a frequency of at least 200 MHz at 3.3 V. Will be lower as we decrease the supply voltage.
- SPI_clk - This clock is used by the input and output unit and should be at least five times slower than the system clock. Should also be low if SPI_en is inactive.
- SPI_en - Active low. Should go high on the first negative flank of SPI_clk after the last value is read.
- SPI_in - Updates it's value as soon as SPI_en goes low, and should have it's value ready on the first positive flank of SPI_clk, as this is when we read the value. The value of SPI_in should then be updated on every negative flank of SPI_clk.
- SPI_out - The data is available for read on the first falling edge of SPI_clk after SPI_en has gone active.
- BIST_out - If the in-data is correct, this should be constant high after the first addition is done.
- Cin - Used to measure propagation delay.
- Cout - Used to measure propagation delay.
- Sum15 - Used to measure propagation delay.

5 Risks and Delays

During the transistor level design phase there hasn't been any condiderable risks or delays. The only thing that is an issue is that all members in the group has quite different schedules which sometimes can hinder cooperation. However the group has solved this by using good tools for project tracking (Trello) and communication (Slack). This has helped considerably with the delegation of tasks and keeping track of what needs to be done.
During the next phases of the project, cooperation will be more important since the tasks will be harder. We will need to plan ahead and schedule occasions where we all can meet and work together.

A Block diagram of the Kogge-Stone Adder



B Truth Tables for the Kogge-Stone Adder

Table 2 – Logic table of red block.

A_i	B_i	$P = A_i \oplus B_i$	$G = A_i \wedge B_i$
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Table 3 – Logic table of yellow block.

G_i	$G_{i,prev}$	P_i	$P_{i,prev}$	$P = P_i \wedge P_{i,prev}$	$G = (P_i \wedge G_{i,prev}) \vee G_i$
0	0	0	0	0	0
0	0	0	1	0	0
0	0	1	0	0	0
0	0	1	1	1	0
0	1	0	0	0	0
0	1	0	1	0	0
0	1	1	0	0	1
0	1	1	1	1	1
1	0	0	0	0	1
1	0	0	1	0	1
1	0	1	0	0	1
1	0	1	1	1	1
1	1	0	0	0	1
1	1	0	1	0	1
1	1	1	0	0	1
1	1	1	1	1	1

Table 4 – Logic table of yellow with carry block.

P_i	G_i	$G_{i,prev}$	$G = (P_i \wedge G_{i,prev}) \vee G_i$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Table 5 – Logic table of sum block.

P_i	C_{i-1}	$S_i = P_i \oplus C_{i-1}$
0	0	0
0	1	1
1	0	1
1	1	0

C Time Plan

Planning																										
Project: 16 bit Kogge-Stone ad																										
Project group: 5			**Date: 160310**												**Reviewed:**											
Customer: Martin Nielsen-Lön			**Version: P3A**												Johannes Klasson											
Course: TSEK06			**Author: JI**																							
ACTIVITIES		**TIME**	**WHO**	**TIME PLAN (week number)**																						
no	Description	hours	Initials	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21					
1	Define structure of the SPI unit	10	JI, JK		9,5			2,														−2				
2	Implement counters in Verilog-A	10	JI, JK		4																	6				
3	Implement control logic in Verilog-A	10	JI, JK			10																0				
4	Implement 1:4 decoder in Verilog-A	10	JI, JK			5,																4,5				
5	Integrate to high level design of SPI	10	JI, JK			17																−7				
6	Simulation and test of high level design (SPI)	5	JI, JK				13	6														−1				
7	Implement transistor level design of the SPI unit	30	JI, JK					6	1,													22,				
8	Simulation and test of transistor design (SPI)	20	JI, JK						12	0												7,5				
9	Implement layout level design of SPI unit	30	JI, JK										25	25	25	25						−7				
10	Simulation and test of layout (SPI)	20	JI, JK														20					0				
19	Define structure of the adder	10	JT, AY		3																	7				
20	Implement Generate calculation logic in Verilog-A	10	JT, AY		1																	9				
21	Implement Propagate calculation logic in Verilog-A	10	JT, AY		1																	9				
22	Implement Sum calculation logic in Verilog-A	10	JT, AY		1																	9				
23	Integrate to high level design of adder	20	JT, AY				17															3				
24	Simulation and test of high level design (adder)	20	JT, AY				3,			32												−1				
25	Implement transistor level design of the adder unit	40	JT, AY					12	7													21				
26	Simulation and test of the transistor design (adder)	20	JT, AY					3	12	0												5				
27	Implement layout level design of adder unit	40	JT, AY										25	20	20	20						−4				
28	Simulation and test of layout (adder)	20	JT, AY														20					0				
29	Define structure of the comparator	5	JT		0																	5				
30	Implement bit comparator in Verilog-A	5	JI			0																5				
31	Integrate to high level design of the comparator	10	JI			2																8				
32	Simulation and test of the high level design (comparator)	5	JI				2															3				
33	Implement transistor level design of the comparator unit	20	JT, AY					0	0													20				
34	Simulation and test of the transistor design (comparator)	10	JT, AY							0												10				
35	Implement layout level design of comparator unit	20	JT, AY										20	20								−2				
36	Simulation and test of layout (comparator)	10	JT, AY												10							0				
37	Off-chip hardware interface	30	JI, JH, JT, AY															15	15			0				
38	Documentation and presentation	60	JI, JH, JT, AY	28			35	14	2	19									10	20		−6				
39	Meetings	60	JI, JH, JT, AY		11	0	0	0	5,	4,5			4	4	4	4	4	4	4	4	4	3				
40	Buffer time	80	JI, JH, JT, AY					6					5	5	5	5	5	5	5	10	0	29				
41	High level integration (System)	15	JI, JH, JT, AY				14															1				
42	Transistor level integration	10																				10				
43	Layout level integration	15	JI, JH, JT, AY															30				−1				
44	Implementation of test bench for SPI	5	JH			0																5				
45	Implementation of test bench for generator	5	JI		0																	5				
46	Implementation of testbench for adder	10	AY		0			5														5				
47	Implementation of test bench for comparator	5	JT		0																	5				
48	Implementation of test bench for the complete system	20	JI, JH, JT, AY				15		7													−2				
	Sum, number of hours	755			30,5	34	99	55	47	55,	0	0	79	74	64	54	49	54	34	34	4	0				