

Virginia Tech
ECE 2504: Introduction to Computer Engineering
Spring 2003

Design Project 2
Design and Implementation of a Simple 4-bit “Computer”

Project Objective: The objective of this project is to design, build, and demonstrate a simple 4-bit computer processor that is capable of performing a number of arithmetic operations. To construct this project, you may only use the ICs included in your chip set purchased at the University Bookstore.

Preparation:

Read and consult the following documents in preparing your solution to this lab assignment:

- Course text, Mano Chapters 2 and 4. Be sure you understand the use of the MSI components of Chapter 2 and the use and implementation of RTL in Chapter 4.
- Logic Works 4 text
- Course Lab Manual, available on the 2504 CEL web page

Equipment for this lab includes:

- LD-1 “Pencil Box” logic design trainer kit
- Course digital logic parts assortment (sold at the bookstore)

Project Description: The computer processor is built around a 4-bit register, w (with bits w_3 , w_2 , w_1 , and w_0), and includes the necessary logic to perform several operations (computer instructions) on the contents of w and, possibly, external input data. The external 4-bit data is called l (for “literal”) (with bits l_3 , l_2 , l_1 , and l_0). The operation performed during a given clock cycle is specified by 3 control signal inputs (an “instruction word”), X_2 , X_1 , and X_0 . **2’s complement data representation and math are to be used.** The processor must perform the following operations (instructions):

Instruction (Description)	Mnemonic	Notation
Add l to w (store in w)	ADDLW	$w \leftarrow w + l$
Subtract l from w (store in w)	SUBLW	$w \leftarrow w - l$
Increment w (store in w)	INCW	$w \leftarrow w + 1$
Arithmetic right shift w (store in w)	ASHRW	$w \leftarrow \text{ashr of } w$
Clear w	CLRW	$w \leftarrow 0$
Load l into w	MOVL	$w \leftarrow l$

In constructing your processor, use dip switches S_3 , S_2 , S_1 , and S_0 for external inputs l_3 , l_2 , l_1 , and l_0 , respectively. Use switches S_7 , S_6 , and S_5 for control signals X_2 , X_1 , and X_0 , respectively. LEDs L_3 , L_2 , L_1 , and L_0 should be used to display the corresponding bits of register w . Use LEDs L_7 , L_6 , L_5 , and L_4 to display the external inputs l_3 , l_2 , l_1 , and l_0 . Note that w_0 and l_0 are the LEAST significant bits of the two quantities. Use push button PB_1 as the (manual) clock. Each time that PB_1 is pressed and released, the instruction specified by the current settings of X_2 , X_1 , and X_0 is executed.

Design Approach: In designing your processor, first determine the register-level building blocks that are required as well as their interconnections. Determine the control signals needed by each block and determine how these signals can be derived from the X2, X1, and X0 values. As part of the design process, **you must assign specific 3-bit values for X2, X1, and X0 to each of the 6 instructions.** A "good" assignment will result in simpler logic used to generate the control signals. To ease trouble shooting, implement and test individual building blocks in isolation from other building blocks. Next, interconnect the individual building blocks (testing as you go) to form the overall circuit. Make sure that all inputs to gates/flip-flops, etc. are NOT LEFT "FLOATING!" The flip-flops in particular will not work as desired if their "asynchronous clear" inputs are left floating! **The asynchronous clear inputs on the D flip-flops and the strobe lines on the multiplexers are not to be used to perform/implement the specified instructions.**

Simulation in Logic Works: Use Logic Works (LW4) to simulate your design before actually building it. Use the following components in your schematic.

IC type	LW4 Component
7400	7400-Actual
7404	7404-Actual
74153	74_153
74175	74175-Actual
74283	Adder-4

Use LW4 to draw a circuit schematic. Label each chip so that you can use your schematic as a wiring diagram. The components labeled "74xx-Actual" in the table above are available in the 7400Actual.clf file that can be downloaded from the CEL Web page. Use these parts in lieu of the standard "74_xx" parts to avoid problems in pin/label errors. Download and unzip the 7400Actual.zip file from the CEL web page, extract the 7400Actual.clf file, and then copy it to LW4 program's library subdirectory, LIBS.

Apply values to the inputs of the circuit (literal data ℓ , control signals X, and the manual clock) and verify that your circuit is working correctly. A printout of the schematic should be turned in as part of your report.

Create a timing data input file that includes columns for all input values (ℓ , X, "manual" clock). The data in this file should cause the simulator to perform the same sequence of instructions that you will perform on the actual hardware you construct for your validation (see Validation section below). The manual clock should be pulsed slow enough as to allow any instruction adequate time to fully execute (see Timing Delay section). **Turn in a printout of the timing window that is displayed upon executing this sequence of instructions. On the printout, clearly mark or highlight the different instructions that are being performed (i.e., if you perform an addition, show where (vs. the time axis) the addition is being performed) and the results that are computed. Include in the timing diagram, all input bits, X; all input bits, ℓ ; all register bits, w; and the the clock.**

Time Delay: Determine the worst-case time delay of your circuit for the execution of each of the 6 instructions. In your delay calculations, assume the individual gate delays are as follows:

IC type	Delay (ns)
7400	10
7404	10
74153	22
74175	15
74283	16

You may neglect any “external delays” such as the time for someone to change the DIP switch settings – assume this takes zero time.

Validation and GTA Help: Derive a sequence of instructions (an RTL-level computer program!) that will compute a result for the following expression: $(2x - y + z + 1)/2$. Your instruction sequence **MUST** use each of the 6 instructions at least **once**. **The first instruction mnemonic MUST BE "CLRW."** Register w should hold the result of the computation once the program has been executed. You do not have to consider overflow or underflow error conditions. To evaluate the expression, the values of x, y, and z must be input to the processor via the external data input, ℓ . Evaluate the expression for $x=3$, $y=2$, and $z=-2$. The result of your calculation should be 1 (integer math is being performed!).

Once you have constructed your circuit and are satisfied with its operation, take your kit to the CEL and have a GTA on duty validate your circuits’ operation by completing the attached validation form. The form must be completed in ink! GTA hours are posted outside the CEL and can also be found on the CEL web page. Validate early! The waiting lines in the CEL can be very long as the due date approaches!

- You **MUST** bring a copy of your Logic Works design (on diskette or equivalent) as well as a printout of your Logic Works circuit diagram with you when seeking troubleshooting help from a GTA. Without these, the GTAs’ ability to help you is limited.
- You **MUST** bring a current copy of your Logic Works circuit diagram with you when seeking validation from a GTA.

Report:

- After you have validated your project, you will submit a written lab report that presents a detailed discussion of project, the design procedures followed, the final design you implement, the simulation, the completed validation sheet, and the evaluation of the implementation.
- The report should be prepared on your word processor. Hand written submissions will not be accepted. Use your spelling and grammar checkers! Proof read your report before turning it in.
- Your report should be divided up into logical sections and **MUST** have appropriately labeled introductory and conclusion sections. Use other, intermediary sections as needed.
- Each student will prepare an individual report – group work is a violation of the Honor System.
- Print out and use the attached cover and grading sheet as the first page of your report (You may fill in its “blanks” by hand).
- Securely staple your report together in the top left corner. **DO NOT** put your report in a binder or folder.

Honor System Reminders:

- All work is to be done ON YOUR OWN. You should NOT discuss your solution or approach with any other student. GTA Jesse Hunter is available at jeh@vt.edu and at the CEL.
- Copying or using another student's design or any portions of the design is a breach of the Honor System.
- You may discuss general features of Logic Works, the trainer kits, the chips, and questions about interpretation of design requirements.

Grading: The design project will be graded on a 100 point basis, as shown below:

- Manner of Presentation (25 points)
 - Completed cover sheet with name, SSAN, recitation day, and signed pledge (3 points)
 - Report organization: clear concise presentation of information, use of sections (introduction, body, summary, etc.) (15 points)
 - Mechanics: spelling, grammar, etc. (7 points)
- Technical Merit (75 points)
 - Design procedure discussion (10 points)
 - Supporting figures, circuit diagrams, Karnaugh maps, etc. (10 points)
 - Implementation: discussion of the operation of your processor, complete specification of processor operation for all 6 control input combinations, the circuit you implemented, and schematic diagram showing chip placement and wiring (from Logic Works) (15 points)
 - Logic Works simulation results (15 points)
 - Time delay analysis (5 points)
 - Validation Sheet (completed by GTA in CEL) (20 points)

Bradley Department of Electrical and Computer Engineering
ECE 2504: Introduction to Computer Engineering Spring 2003
Design Project 2 Validation Sheet

Fill out this form in INK!

Student Name: _____ SSAN: _____

Instructor's name: Prof. Tom Hou

Before Validation: In the table below, the student should fill in the columns labeled "Instruction Mnemonic," and "Switch Settings" such that by performing the specified instructions, the equation $(2x - y + z + 1)/2$, where $x=3$, $y=2$, and $z=-2$ will be evaluated. The displayed result should be +1.

GTA: **Do not validate this lab if the STUDENT has not filled in the first two columns of the table, below.** The X2, X1, X0 settings specify the desired instruction to be performed in the processor. Switches S3, S2, S1, and S0 are used to provide input data to the processor. For each operation listed below, please set the switches in the trainer, pulse the clock push button, and record the value of the resulting computation, as indicated on LEDs L3, L2, L1, and L0.

- **Review the student's Logic Works schematic. If no schematic, STOP. Have the student return with one before proceeding. Does the schematic match the layout and wiring of the student's pencil box?**

_____ Yes / no _____ Comments?

Instruction Mnemonic (Completed before validation)	Switch Settings (Completed before validation)		LED Outputs Register w w3 w2 w1 w0 L3 L2 L1 L0
	Ext. Input l $\beta \ 2 \ 1 \ 0$ S3 S2 S1 S0	Control Signals X2 X1 X0 S7 S6 S5	
	CLRW		

- Neatness: The students are expected to neatly wire the project. Evaluate the student's efforts based on 10-point scale in the 2504 lab manual.

Score: _____

- Comments: Please include why neatness was downgraded

Please have the student remove the wires from his or her kit while under your supervision. Do not sign this evaluation until the kit is "stripped."

GTA Printed Name and Signature and validation date: _____

Bradley Department of Electrical and Computer Engineering
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Student Name: _____

SSAN: _____

Instructor's name: Prof. Tom Hou

Pledge: I have neither given nor received unauthorized assistance on this assignment.

Signed: _____

Project Grading to be completed by GTA or Instructor:

Grading: The design project will be graded on a 100 point basis, as shown below:

- Manner of Presentation (25 points)
 - Completed cover sheet with name, SSAN, recitation day, and signed pledge (3 points)
 - Report organization: clear concise presentation of information, use of sections (introduction, body, summary, etc.) (15 points)
 - Mechanics: spelling, grammar, etc. (7 points)
- Technical Merit (75 points)
 - Design procedure discussion (10 points)
 - Supporting figures, circuit diagrams, Karnaugh maps, etc. (10 points)
 - Implementation: discussion of the operation of your processor, complete specification of processor operation for all 6 control input combinations, the circuit you implemented, and schematic diagram showing chip placement and wiring (from Logic Works) (15 points), time delay analysis, etc.
 - Logic Works simulation results (15 points)
 - Time delay analysis (5 points)
 - Validation Sheet (completed by GTA in CEL) (20 points)

Grade: _____