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Revised Apr 2001, WDL with constructive feedback from Erik Laxdal.
INTRODUCTION TO THE LABS

Introduction

In this lab you will gain hands-on experience in the design, implementation and testing of digital circuits. The seven labs that you will perform support the theory covered in your textbook, the course notes and the lectures. The labs progress from rather simple labs that deal with digital instruments and components to the seventh lab that involves a rather complex digital system based upon a RAM memory chip. The mark for lab 7 is weighted twice that of the other labs.

These labs do not give you step-by-step instructions on how to do the lab. They require you to think carefully about what and how you are going to do things. For most of the labs you must do some preparation before you actually come to the lab. Some labs can actually be wired and pre-tested before you come to the lab.

You will do the labs with prototype boards and components that are signed out to you by the ECE Department. The kits must be returned at the end of the course.

Lab Requirements

- All labs are to be carried out with a partner.
- Each student is to maintain a lab notebook that contains the preparatory work and notes of the student.
- The write-up for lab #n must be submitted at the end of lab session # n+1 except for lab #7 which must be submitted on the last day of lectures.
- Each lab is to be demoed to the lab TA to confirm its operation. The TA will ask questions regarding the lab and sign that the lab has been demoed.
- Much of the lab work can be done outside of the scheduled lab time.
• The lab writeup should contain neat schematic diagrams, comments, explanations and answers to lab questions posed in the manual. See the 290 lab web page for additional guidance on the lab writeup.

**Fun and Games**

These labs should be fun to do. Every effort will be made to cover the lab material in class before the scheduled lab period. If the lectures do, however, lag behind the labs, please consult the text, the notes, the TA or the Prof for information you need.

**Additional Details**

Additional lab and lecture information is available through the ECE web page. The web site, www.onsemi.com, has data sheets for many electronic components. The CENG 290 web site has links to all data sheets used in the labs. Data books and data sheets are also provided in the labs.

The use of a schematic capture CAD program for drawing circuits is encouraged. LogicWorks and Xilinx CAD packages are provided in the lab and student versions can be purchased at a reasonable price. Shareware packages are also available. Use a logic template if circuits are drawn by hand.

The Lab is equipped with eight stations. Each station includes a PC workstation computer with schematic capture and simulation software, an ethernet link to the Unix system, a power supply, an oscilloscope, a multimeter and a function generator. The Lab also contains a printer and a logic analyzer.
## Components in Logic Kit

<table>
<thead>
<tr>
<th>Qty</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>74LS00 Quad 2 input NAND</td>
</tr>
<tr>
<td>2</td>
<td>74LSLS02 Quad 2 input NOR</td>
</tr>
<tr>
<td>2</td>
<td>7404 Hex Inverter</td>
</tr>
<tr>
<td>2</td>
<td>74C04 CMOS Hex Inverter</td>
</tr>
<tr>
<td>2</td>
<td>74LS05 Hex Open Coll. Inverter</td>
</tr>
<tr>
<td>1</td>
<td>74LS08 Quad 2 input AND</td>
</tr>
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<td>2</td>
<td>74LS10 Triple 3 input NAND</td>
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<tr>
<td>2</td>
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<tr>
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<td>74LS163 synchronous binary counter</td>
</tr>
<tr>
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<td>74LS194 Shift Register</td>
</tr>
<tr>
<td>1</td>
<td>74LS244 octal tri-state buffer</td>
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<td>1</td>
<td>74LS374 octal D FFs with tri-state outputs</td>
</tr>
<tr>
<td>1</td>
<td>74LS377 octal D FFs with load enable</td>
</tr>
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<td>555 timer</td>
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<td>6116 12K x 8 RAM</td>
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<td>1</td>
<td>toggle switch</td>
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<tr>
<td>4</td>
<td>DIP toggle switch</td>
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CENG 290 Lab 1

Digital Instrumentation

1. **Objective**

This lab is intended to familiarize you with the basic instrumentation used in this course. In particular, you will experiment with

1. power supply
2. multimeter
3. oscilloscope
4. pulse generator
5. logic probe
6. logic analyzer
7. prototype board

Your lab write-up should include a record of all the measurements you took and sketches of relevant waveforms. The write-up should also contain comments and explanations of things you observed and questions you are asked. You are expected to refer to the appropriate equipment manual available in the lab to help you with portions of the lab.

2. **Power supply, multimeter and prototype board.**

Power supplies provide the dc voltages required to power the electronics. Connect the lab power supply to your prototype board. Mount the voltage regulator chip and and a 74LS04 on your board. Connect the voltage regulator and use it to provide power to the 74LS04. You will need to use data sheets for the voltage regulator and the 74LS04 in order to determine the correct pin connections. Provide a good ground reference on your board so that all voltage measurements can be made relative to the board ground.

Vary the supply voltage from 0 to 12 volts and measure the regulator input current and output voltage and current with the multimeter. Tabulate and graph your measurements.
Comment on the power consumed by the regulator and the temperature of the regulator. For what input voltages, does the regulator actually regulate the output voltage?

Try shorting the output of the regulator to ground. If you don’t limit the current supplied by the power supply you will likely burn out your regulator. Make some measurements so you can describe what happens.

3. Oscilloscope

Observe the calibration output signal, one channel at a time, on the two channels of the oscilloscope. Tune the probes and observe underdamped, overdamped and critically tuned probes.

Measure the period of the calibration signal and observe the rise and fall portion of the signal using the X10 magnifier and the delayed sweep feature.

4. Pulse generator

Set up and observe on the oscilloscope a 1 KHz and then a 50 MHZ pulse train.

Set up and observe a 1 MHz pulse train with a 25% duty cycle, a fast rise time and a slow fall time.

5. Logic Probe

Set the logic probe in TTL mode and observe a high and low TTL logic level. Generate a number of TTL pulse trains with the pulse generator and observe the response on the logic probe.

6. Logic Analyzer

Observe the logic analyzer demonstration that is set up in the lab. Comment on the utility of a logic analyzer.
Basic Digital Components and Circuits

1. Objectives

To setup and test some basic digital components and circuits.

2. Prototype Board Power

Install the 5 volt voltage regulator chip on the prototype board and connect the 5 volt output pin to the red bus lines of the board, the ground pin to the blue bus lines and the input pin to the DC power supply. You may now power the board from any DC supply voltage in the range of about 7 volts to 10 volts. A 9 volt battery works well if you wish to use the board outside of the lab. Check to see that the regulator is indeed supplying 5 volts.

3. LED Displays

Connect 6 LEDs through 1K pullup resistors to the 6 open-collector outputs of the inverters of a 74LS05 chip. The inverter inputs are to be used as probe inputs to test circuits you build in this lab and in subsequent labs. Wire this circuit compactly and locate it so that it won’t interfere with other circuits you build in the future. Note the conditions under which a LED is lit. Note also that a 7404 inverter cannot be used in place of a 7405 inverter. Why? You should compare their data sheets.

4. Push Button Debouncer

The switches you have in your kit, and indeed all mechanical switches, do not switch a voltage or current cleanly from one level to another. A switch debounce circuit as shown below is widely used to produce a clean transition when a switch is activated.
Wire the switch debounce circuit compactly in a corner of your board so that it can be used as a source of clean pulses for future experiments. Note that you must use both normally open contacts and normally closed contacts from the push button switches in your kit to realize the SPDT (single pole/double throw) switch that the circuit requires. (Your text explains SPST and SPDT switches) Use an ohm meter to determine suitable contacts to use on the push button switch you choose. In your writeup, give an equivalent NOR based debounce circuit. Display concurrently, the undebounced and debounced signals on an oscilloscope. When is it not necessary to use a debounced signal.

5. Clock Circuit

Build and test the 555 clock circuit given below. The circuit is explained in your text. Select circuit components so that the clock frequency is a few hertz and the duty cycle is about 50%. Observe and record, using a scope, the waveforms of the 555 pins.
6. **Counter Circuit**

Connect the output of your 555 clock circuit through a 7404 inverter to the clock input of a 74163 counter chip. Observe the four 74163 outputs with four LED probes. Note the frequency of the four 74163 outputs relative to the frequency of the clock input to the chip. Note also that the four outputs can be interpreted as the bits of a 4 bit binary number with decimal equivalent values between 0 and 15.

Connect the output of the switch debounce that you wired to the clock input of the 74163 and observe the counter counting the number of times you push the pushbutton. Connect an undebounced switch output to the clock input of the 74163 and observe that the counter does not count correctly.
CENG 290   Lab 3

Gate Characteristics

1. **Objective**

To study the input/output and timing characteristics of some common gates.

2. **Inverter Voltage and Current Characteristics**

   a. Mount a 74LS04 inverter chip on the prototype board and collect data for an output voltage vs input voltage graph. Plot the graph and compare it with the corresponding graph from a 74LS04 data sheet.

   b. Collect data for an input current vs input voltage graph. Plot the graph and compare it with the corresponding graph from a 74LS04 data sheet.

   c. Connect the output of one inverter to the input of another inverter. Measure the current flowing between the two inverters and the voltage between the two inverters when the logic level between the two inverters is high and when it is low. Compare your values with values given in the data sheets.

   d. By looking at the input/output currents of the 74LS04 data sheets, what is the maximum number of inverters that should be driven by a single 74LS04?

3. **Open Collector Circuits**

   The following circuit uses open collector inverters that have their outputs wired together to perform logic functions. Apply all combinations of high and low input voltages to the circuit and record the output voltage as high or low for each input combination. Give truth tables for the circuit a) assuming inputs and outputs are asserted high, b) assuming inputs and outputs are asserted low, and c) assuming inputs are asserted low and the output is asserted high. If canonic forms have been discussed in
class, give SOP and POS equations corresponding to the three truth tables. Describe the role of the pullup resistor. Note that only open collector and tristate output components can have their outputs wired together. Where is it highly desirable to use open collector or tristate outputs?

4. **Feedback Circuits**

   a) Connect an even number of 74C04 inverters in a loop. Show that the circuit can be placed in any one of two possible states by momentarily connecting the output of an inverter to a high or a low voltage. Circuits with two inverters in a loop are the basis of all flip-flop storage components.

   b) Connect an odd number of 74C04 inverters in a loop and observe with an oscilloscope that the circuit oscillates. Sketch the oscillatory waveform and measure the duration of the low and high portions of the waveform. Relate the period of oscillation to the timing data given in the 74C04 data sheet.
CENG 290  Lab 4

Combinational Circuits

1. Objective

To design, simulate, build and test a combinational circuit.

2. 2-bit adder

The combinational circuit you will work with in this lab is a 2-bit adder. The circuit is to have inputs a1,a0 and b1,b0 and outputs s2,s1,s0 where a1,a0 are the 2 bits of one of the numbers to be added, b1,b0 are the 2 bits of the other number to be added and s2,s1,s0 are the 3 bits of the sum. For example, if 11 is added to 10 the sum is 101. Your task is to design, simulate and test circuits corresponding to Boolean equations for s2, s1 and s0. Each equation is a different function of the 4 input variables a1, a0, b1, b0.

Do your design by constructing K-maps for s2, s1 and s0 and then getting minimum sum-of-product expressions for the three outputs.

To implement your equations, assume that all inputs and outputs are asserted high and use only NAND gates and inverters in your circuits. Share product terms among the circuits for the 3 equations to save gates if possible. Note that a 6-input NAND function can be realized with a 4-input NAND, two 2-input NANDs and two inverters. Label your circuits carefully using polarized mnemonics.

Simulate your circuit using LogicWorks, Xilinx Simulator or your favorite simulator for all possible input combinations.

Build your circuit and compare its operation with the simulated circuit.
Elementary Sequential Circuits:
Flip-Flops

1. Introduction

Sequential circuits are logic circuits with feedback used to realize memory of state. Flip-flops are elementary sequential circuits. Sequential circuits are the basis of registers, counters and controllers. In this lab you will experiment with an RS latch flip-flop and an edge-triggered D flip-flop. The difference equation requirements should be done outside the lab.

2. RS Latch

A NAND implementation of an RS latch is shown in below. Build the circuit and test its operation by driving the inputs with logic levels generated by 2 undebounced pushbutton switches and a pair of pullup resistors.

In theory, the flip-flop you have just built is unstable and oscillates when R and S are simultaneously changed from 11 to 00. Connect a scope to the output Q(H) and see if you can demonstrate the unstable oscillatory behavior. If you have trouble observing oscillations (you will), try extending the effective delay time of the NAND gates by adding a pair of rather slow 74C04 inverters to the outputs of the NANDs. Be sure the
input you use is debounced. Observe the frequency of oscillation and correlate the frequency with the delay times of the components in your circuit.

Write difference equations for the circuit under the assumption that each NAND gate has 1 unit of delay. Manually evaluate the difference equations to show the response of an RS=11 to an RS=00 input change. The difference equations could, of course, be implemented in a spread sheet.

3. **Edge triggered D flip-flop**

Build the negative edge-triggered D flip-flop shown below. Apply a variety of inputs to demonstrate that the flip-flop changes state only on negative clock edges. Record the responses to your inputs in a timing diagram.

Explain in words how the flip-flop works.

Why are edge-triggered flip-flops so widely used.
CENG 290  Lab 6
A Shift-Register System

1. Introduction

In this lab you will design, build and test a 4-bit serial adder system using a shift register and other components. This lab should give you a good understanding of the serial method of moving data between registers.

2. Lab

Design, build and test the system illustrated below. Note that the diagram does not include many details. Your final schematic circuit should include all the details.

The 74377 is used to implement a 4-bit shift register that is initially loaded with one of the 4-bit numbers to be added. The other number to be added is initially loaded into the 74194. The 7474 ff is used to save the carry from one cycle for use in the next cycle. The full adder is to be designed and implemented with gates from your kit. After 4 clock pulses are applied the sum is available in the 74377.

Use switches and pushbuttons to set the mode of the 74194, to generate the clock pulses and to load initial values into the two shift registers. Use LEDs to display key variables.

Test and demonstrate your system. In your writeup, explain the operation of your system.
1. Introduction

In this lab you will construct and test a digital system that reads and writes data to a random access memory (RAM). The system is described in detail in Chapter 7 of the text Contemporary Logic Design by Randy H. Katz.

The system is divided into two parts: a datapath that provides for the movement and storage of data and a controller that controls the movement of data in the datapath. A schematic diagram for the datapath, a state diagram for the controller and a circuit for the controller are given below.

A switch in the datapath controls whether data is read from the RAM or written to the RAM. Data is read from, or written to, the RAM address that is present in the 4-bit counter of the datapath. A read or a write is carried out in response to the pushbutton in the controller being pushed. Upon the completion of a read or write the counter is incremented by one so that the next memory access will be to the next memory address.

LEDs are used to display the memory address and the data read from memory. Switches are used to generate new data to be stored in the RAM.
2. **Datapath**

First wire the datapath given Fig. 1 below. The RAM chip in your kit may be slightly different from the one shown in the schematic. Debug and test the datapath by generating the control signals INCADR, WE, CS, LATCH_DATA and ENAB_BUF with switches and the clock signal from a debounced switch. If your RAM is different and uses an output enable signal, OE, be sure to generate this control signal and include it in your diagrams.

![Datapath Diagram](image)

Fig. 1 Datapath
3. **System Controller**

The state diagram for the controller is given in Fig. 2. You will need to add OE if your RAM requires an output enable. A portion of the controller that implements the state diagram for the system is given in Fig. 3. The 74194 is wired as a right shift register that shifts right on the positive edge of a clock pulse whenever the signal S0 is asserted. The bits are ordered Q1,Q2,Q3,Q4 and Q1 gets the value of RS1 when a shift occurs. The signal STATE00 and states are encoded as follows: STATE00 = ZER0 = /Q1./Q2./Q3./Q4

\[
\begin{align*}
\text{ONE} & = Q1./Q2 \\
\text{TWO} & = Q2./Q3 \\
\text{THREE} & = Q3./Q4 \\
\text{FOUR} & = Q1.Q4 \\
\text{FIVE} & = /Q1.Q2 \\
\text{SIX} & = /Q2.Q3 \\
\text{SEVEN} & = /Q3.Q4
\end{align*}
\]

Build the circuit and test it to see that it cycles through the states when the push button is pushed. Draw timing diagrams for Q1, Q2, Q3 and Q4.

Now write the equations for the datapath control signals as they are specified in the state diagram. Implement the equations with gates and connect the control signals to the datapath. Test the system.

The controller could have been implemented many ways. What are the advantages of using a shift register based controller?
Fig. 2 State Diagram

- reset
- go
- zero
- one
- two
  - /CS
  - three
    - read/CS; read/CS,WE
  - four
    - read/CS; read/CS,WE
  - five
    - read/CS,latch_data; read/CS
  - six
  - seven
    - /inc_adr

enable_buf = WE
Demonstrate the operation of your complete system. Include in your report the equations and circuits for the control signal.

State in words how the small circuit at the top of Figure 3 works.