Lab #3

Combinational Logic Circuits and 7-Segment Displays

Lab Format
- This is a Individual Lab so each student must design and test their own circuits.
- Students are free to assist each other in all labs.
- Each student must complete the Preliminary Work Section before lab begins. Preliminary Work will be checked in lab and will be part of the lab report grade.
- Each student must submit his or her own lab report.
- Lab reports will not be accepted until all required circuits have been demonstrated to the instructor.

A. Objective
The objective of this laboratory is to investigate the design procedure for combinational logic circuits discussed in class and to use the design procedure to design and build a custom combinational logic circuit. Some commonly used combinational logic functions are already available commercially and do not have to be designed from scratch. An example is a BCD-to-7-segment decoder. In this lab a 7-segment display will be driven using a commercially available BCD-to-7-segment decoders.

B. Materials
Breadboard
5V Power Supply
Wire, switches, resistors, etc.
Common-anode 7-segment display (GNS-3011, LDS3221, MAN72A, or other)
74LS47 BCD-to-7-segment decoder/driver (common anode)
74LS00, 74LS02, 74LS04, 74LS08, 74LS32, and 74LS86 IC’s

C. Introduction
Combinational logic circuits can be divided into two categories:
1) Custom circuits - Unique circuits where there is no commercially available device. In this case the design procedure for combinational logic circuits can be used.
2) Commercially available devices - Including decoders, encoders, multiplexers, BCD-to-7-segment decoders, magnitude comparators, etc. Note that the general design procedure could be used to design these devices, but it is unnecessary and the commercial devices are often optimized for reduced delay.

Design Procedure (for combinational logic circuits)
1. Specification: Write a specification for the circuit if one is not provided.
2. Formulation: Derive the truth table or initial Boolean equations that define the required relationships between inputs and outputs.
3. Optimization: Apply two-level and multiple-level optimization using Karnaugh Maps or Boolean algebra. Draw a logic diagram or provide a netlist using AND, OR, and NOT gates.
4. Technology Mapping: Implement the circuit using the desired technology, such as using AND/OR/NOT gates, decoders, multiplexers, PLDs, FPGA, etc.
5. Verification: Verify the correctness of the circuit (perhaps by hand analysis or computer simulation).

Example: See examples of the design procedure in the class notes.
**BCD-to-7-segment decoders**

Since BCD-to-7-segment decoders are commercially available, we don’t need to design them using the design procedure. Recall from class notes that there are two types of BCD-to-7-segment decoders:

1. **Common-cathode decoder**
   - Uses active-HIGH outputs (i.e., a HIGH output is used to light a segment)
   - Must be used with a common-cathode 7-segment display
   - Example: 74LS48
   - See Figure 1 below

2. **Common-anode decoder**
   - Uses active-LOW outputs (i.e., a LOW output is used to light a segment)
   - Must be used with a common-anode 7-segment display (such as the GNS-3011 or LDS-3221)
   - Example: 74LS47 (we will use this type in lab)
   - See Figure 2 below

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**Figure 1: 7448 and a common-cathode 7-segment display**

**Figure 2: 7447 and a common-anode 7-segment display**
D. **Preliminary Work** (Include instructions with each step in your report).

1. **7-segment display and decoder circuit.**
   A. Generate a *logic diagram using PSPICE* for Circuit 1 including:
      - 7-segment display (check with the instructor to see which part will be used in lab).
        - If the MAN72A or LDS3221 is to be used in lab, the following part can be used in PSPICE since it has the same pinout: LDS-A30R (in the Discrete Library). Note that the Discrete Library is not part of the evaluation version, so you can’t analyze circuits with this component.
        - If the GNS-3011 is to be used in lab, the following part can be used in PSPICE since it has the same pinout: LDS-A32R (in the Discrete Library).
      - 7447 BCD-to-7-segment decoder (or the 7446 if it is not available, since it has the same pinout)
      - Input switches (DIP switches, resistors, etc). Be sure to label the switches (A,B,C,D).
      - No PSPICE simulation is required (simply draw the schematic)
      - Add text to the schematic (name, course, lab number, title of circuit, etc)

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**Circuit 1: Testing the 7447 and a common-anode 7-segment display**

B. Check the data sheet for the 7447 (see course website) to determine the function of LT, BI / RBO, RBI. Write out a clear description of each (in your own words).

C. Show how to connect four 7447 IC’s (using a simple block diagram) such that leading zeros will not be displayed (for example, the displays will show (blank)607 rather than 0607).

D. Check the data sheet for the 7447 to determine the pattern that is lit on the 7-segment display for each of the 16 possible inputs. Illustrate the results with sketches (or copy them from the data sheet).

(continued on next page)
2. **Student ID Conversion Circuit.** Use the design process to design a combinational logic circuit that will convert the digits 0-6 to the 7 digits in your student ID. It should also convert the digit 7 to a 9. For example, if your student ID is 1302477 then the circuit should make the following conversions:

<table>
<thead>
<tr>
<th>Original Digit</th>
<th>Converted Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

In particular, include the following:

A) List the numbers to be converted using your Student ID (similar to the boxed section above).
B) Draw a truth table. Note that there should be 3 inputs and 4 outputs.
C) Form minimal SOP and POS expression using Kmaps.
D) If the circuit is to be implemented using any of the following types of logic gates, determine the fewest number of gates possible. Consider SOP, POS, gate sharing, XORs, etc.
   - 7400 – 2-input NAND
   - 7404 – NOT
   - 7402 – 2-input NOR
   - 7408 – 2-input AND
   - 7432 – 2-input OR
   - 7486 – 2-input XOR
E) Generate a Logic Diagram using PSpice for Circuit 2A including:
   - Show assigned chip numbers and part numbers (For example: U1 – 7447).
   - Be sure to use all available gates on a given IC before using another IC of the same type (e.g., using U1A, U1B, U1C, etc. instead of U1A, U2A, U3A, etc.
   - Use 3 digital clocks in PSpice for inputs A, B, and C. Do not show DIP switches (even though we will use them in lab).
   - Label all inputs and outputs. Label MSB on the input and the output.
   - Do not include the 7447 and 7-segment display (even though we will connect them to the output in lab).

F) **Extra Credit (10 pts on lab grade):** Simulate your PSpice design and prove that it works correctly. Show the 3 inputs and the 4 outputs. Also add two buses to the output: One showing the decimal value of the input BCD code and one showing the decimal value of the output code (Student ID).
E. **Laboratory Work**

1. **Build and Test Circuit 1**
   - Construct the 7-segment display and decoder circuit according to the PSPICE logic diagram for Circuit 1 from the Preliminary Work. Note any changes.
   - Test the circuit for all 16 possible input switch combinations to verify proper operation and record the results.
   - Demonstrate proper operation of the circuit to the instructor.
   - Record your results.

![Circuit Diagram]

**Circuit 1: Testing the 7447 and common-anode 7-segment display**

2. **Perform additional tests on Circuit 1**
   a) Test the LT input. Verify that it works as expected. Clearly state how you tested it and record the results.
   b) Test the function of \( \overline{\text{RBI}} \) and \( \overline{\text{BI}} / \overline{\text{RBO}} \) as follows: Apply the appropriate inputs (DCBA) and set the value of \( \overline{\text{RBI}} \) as indicated in the table below. In each case, observe what is displayed on the 7-segment display and measure \( \overline{\text{BI}} / \overline{\text{RBO}} \) with a voltmeter.

<table>
<thead>
<tr>
<th>DCBA (set inputs with switches)</th>
<th>RBI (set input with switch)</th>
<th>Digit displayed on 7-segment display</th>
<th>BI / RBO (H or L as measured with a voltmeter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0000</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0011</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0011</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(continued on the next page)
3. **Build and Test Circuit 2**
   - Construct the Student ID Converter according to the PSPICE logic diagram for Circuit 2A from the Preliminary Work with the following exceptions (i.e., you will actually build Circuit 2B):
     a) Use three DIP switches instead of the digital clocks.
     b) Connect the 4 outputs to the inputs of the 7447 so that you can display your student ID.

   ![Circuit 2A](image)

   **Circuit 2A: BCD to Student ID Converter (PSPICE Circuit)**

   ![Circuit 2B](image)

   **Circuit 2B: BCD to Student ID Converter (Circuit to be built and demonstrated in lab)**

   - Note any changes to the circuit.
   - Test the circuit to be sure that it produces the correct output for each input. As you apply the inputs 0 to 7 with the DIP switches, you should see the digits of your Student ID display (followed by the digit 9).
   - Demonstrate proper operation of the circuit to the instructor.
   - Record the results.

4. Leave the 7-segment display and driver (7447) connected on your breadboard for use in later labs.

F. **Report**

Remember that each lab report should have the following four sections. Also see additional notes below.

**Title Page**

**Preliminary Work**
- Include instructions

**Lab Results**
- Include all measured results (truth tables).
- Include step numbers and titles or headings that make it clear what is being shown.

**Discussion/Conclusion**
- Discuss each circuit tested in lab.
- Discuss when the general design procedure for combinational logic circuits should be used.
- What have you proven or demonstrated by completing the experiment?