

# Lab 3

## Decoders and Multiplexers

### 1. Objectives

- To familiarize students with the structure and the operation of both Multiplexer and Decoder
- To implement 2X4 Decoder using NAND gates
- To implement 4x1 Mux using NAND gates
- To implement Logic Functions using binary Decoder
- To implement Logic Functions using Multiplexer

### 2. Material

- 74HC00 (Quad 2-input NAND)
- 74HC32 (Quad 2-input OR) or 74HC08 (Quad 2-input AND), to achieve minimum number of chips
- 74HC138 (3x8 Decoder)
- 74HC151 (8x1 Multiplexer)
- Digital Logic Trainer
- Wires

### 3. Introduction

#### a. Decoders

A decoder is a logic circuit that detects the precedence of unique input states and generates a unique output for that state. An example is the binary decoder. A binary decoder has **n inputs** and  **$2^n$  unique output lines**. Figure 1 shows the circuit diagram for 2x4 binary decoder. Please note that when the input 'En' is set to '0', all the outputs  $y_0$ - $y_3$  will be to '0'. When  $En=1$  the decoder operates normally. In normal mode, every decoder output ( $y_0$ - $y_3$ ) is set to 0 except for the one output whose number is input on  $w_1$  and  $w_0$ . For example, if  $w_1w_0 = 00$ ,  $y_0$  will be set to 1 and all other outputs are set to 0. If  $w_1w_0 = 01$ ,  $y_1$  will be set to 1 and all other outputs are set to 0. And so on.

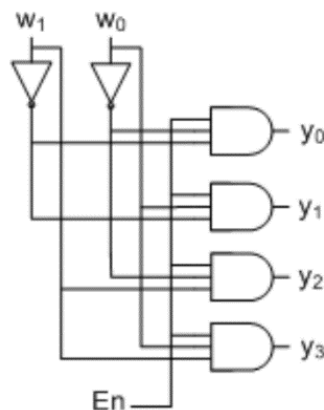


Figure 1. The circuit diagram for 2x4 binary decoder with enable

The circuit can be designed using NAND gates instead of AND gates. In this case every output ( $y_0$ - $y_3$ ) is set to logic '1' except of one output, which is determined by the inputs  $w_0$  and  $w_1$ . A binary decoder is also called a min/maxterm generator. A **minterm generator** is constructed using AND and NOT gates. The appropriate output is indicated by logic 1 (positive logic). A **maxterm generator** is constructed using NAND gates. The appropriate output is indicated by logic 0 (Negative logic).

Any  $n$ -variable logic function, in canonical sum-of-minterms form can be implemented using a single  $n$ -to- $2^n$  decoder to generate the minterms, and an OR gate to form the sum. Figure 2 shows how to implement the function  $(a, b, c) = (4, 6, 7)$  using a 3x8 decoder.

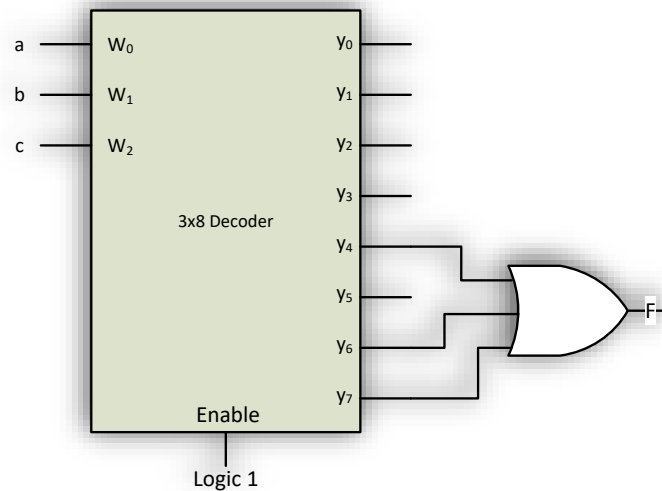


Figure 2. Implementation of function  $F = \sum m(4, 6, 7)$  using a 3x8 decoder

## b. Multiplexers

A multiplexer (MUX) is a digital switch, which connects data from one of  $n$  sources to the output. A number of select inputs determine which data source is connected to the output. The MUX acts like a **digitally controlled multi-position switch** where the binary code applied to the select inputs controls the input source that will be switched on to the output. Figure 3 shows the logic circuit and the block diagram of 4x1 multiplexer.

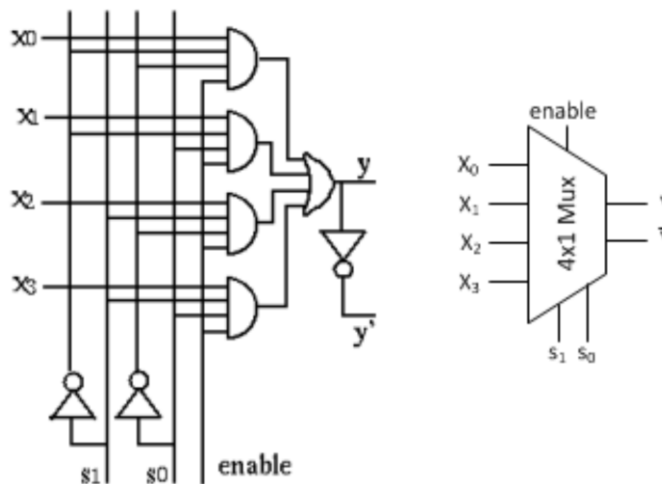


Figure 3. The logic circuit and the block diagram of 4x1 multiplexer

While Multiplexers are primarily thought of as “**data selectors**” because they select one of several inputs to be logically connected to the output, they can also be used to implement Boolean functions. We can **implement any Boolean function of  $x$  variables using a  $2^x$  input MUX**. Multiplexers can be used more effectively by using some forms of functional decomposition; meaning we can implement a 4-variable function using 8-to-1 MUX by using three of the variables as select inputs and feeding an appropriate function of the fourth variable to the data inputs of the MUX. Figure 4 shows how this can be done for the function  $F(a, b, c) = (3, 5, 6, 7)$ .

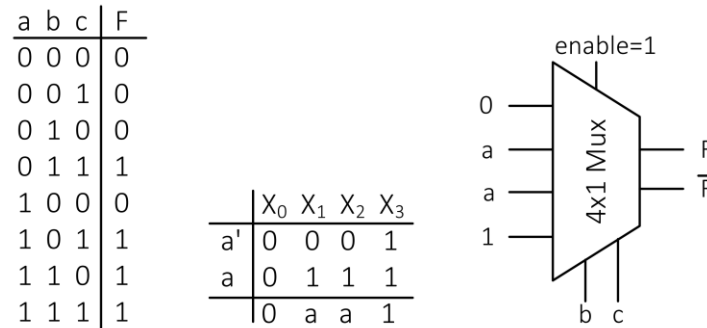


Figure 4. Implementing a 3-variable function using 4x1 multiplexer

## 4. Pre-lab Questions

- Design a logic circuit that has 3 inputs  $x_2$ ,  $x_1$  &  $x_0$  ( $x_2$  is the MSB and  $x_0$  is LSB) and two outputs  $Y_1$  &  $Y_2$ .  $Y_1$  indicates whether the 3-bit input ( $x_2 x_1 x_0$ ) is an odd number, and  $Y_2$  is a majority indicator that outputs 1 if the 3-bit input has more ones in it than zeroes.
  - Write the truth table.
  - Get a simplified Boolean equation for  $Y_1$  and  $Y_2$  using K-maps.
- Draw the logic circuit diagram for a 2x1 multiplexer implemented using NAND gates only. The multiplexer inputs are  $a$  and  $b$ , and the selection line is  $s$ . Do not include the multiplexer enable input.
- Implement  $F(x_3, x_2, x_1, x_0) = \sum m(1, 2, 3, 6, 8, 9, 12, 15)$  using an 8x1 Multiplexer and inverters if needed. Connect  $x_3$ ,  $x_2$ ,  $x_1$  to the multiplexer selection lines.

## 5. Experiments

### 1. Implementing Logic functions using Decoders:

- Download the datasheet of 74HC138 3x8 Decoder chip and carefully read it to connect the chip pins correctly.
- Implement  $Y_1$  and  $Y_2$  (from pre-lab Q1) using 3x8 Decoder chip(s) and AND gates only (Remember: the **active low decoder** can be considered a **maxterm generator**).
- Connect the circuit inputs  $x_2$ ,  $x_1$ ,  $x_0$  to toggle switches and  $Y_1$  and  $Y_2$  outputs to LEDs, then test your circuit.
- Use the minimum possible number of chips. How many chips are needed for the whole circuit and of what type? Include your answer in the lab report.

**2. Building a 2x1 multiplexer using NAND gates:**

- a. Implement a 2x1 multiplexer using NAND gate chips only (from pre-lab Q2). Connect inputs  $a$ ,  $b$ , and  $s$  to toggle switches and connect the output to one of the LEDs. Record the output in Table 1 in the lab report.
- b. How many chips are used and of what type? Include your answer in the lab report.

**3. Implementing Logic functions using Multiplexers:**

- a. Download the datasheet of 74HC151 8x1 Multiplexer chip and carefully read it to connect the chip pins correctly.
  - b. Implement  $F(x_3, x_2, x_1, x_0) = \sum m(1, 2, 3, 6, 8, 9, 12, 15)$  (from pre-lab Q3) using 74HC151 8x1 Multiplexer chip(s) and 74HC04 inverter chip(s) if needed. Connect  $x_3$ ,  $x_2$ ,  $x_1$  to the multiplexer selection lines.
  - c. Connect the circuit inputs  $x_3$ ,  $x_2$ ,  $x_1$ ,  $x_0$  to toggle switches and  $F$  output to LED, then test your circuit.
  - d. Use the minimum possible number of chips. How many chips are needed and of what type? Include your answer in the lab report.
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**Lab Report [10 Pts]**

(Deadline: Tuesday of next week 2:00pm) (Individual submission)

1. [1 Pts] Record the values from experiment 2 in table 1 below and answer the following questions.

**Table 1**

Inputs			Output
a	b	s	
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

- a. How many chips are used in Experiment1(d) and of what type?
  - b. How many chips are used in Experiment2(b) and of what type?
  - c. How many chips are used in Experiment3(d) and of what type?
2. [3 Pts] Show how to build a 4x16 decoder using 2x4 decoders
  - a. Draw the logic diagram.
  - b. Simulate the circuit on Logisim using 7400 chips only. Double click on the chip on Logisim to see the internal design.
  - c. Have a screenshot of the circuit and attach your Logisim .circ file to the report.
3. [6 Pts] Research questions:
  - a. List 2 known applications that use multiplexers in their circuits, describing its role in each.
  - b. List 2 known applications that use decoders in their circuits, describing its role in each.
  - c. Why do some chip designs use active low signals instead of active high?